TECHNOLOGY EVALUATION AND DEVELOPMENT SUB-PROGRAM

STUDIES ON THE CONTROL OF PROBLEM WEED SPECIES IN CONSERVATION TILLAGE SYSTEMS

FINAL REPORT

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Prepared by: SOUTHWESTERN ONTARIO AGRICULTURAL RESEARCH CORPORATION (SWOARC), Harrow, Ontario

Under the Direction of: ECOLOGICAL SERVICES FOR PLANNING LIMITED, Guelph, Ontario - Subprogram Manager For TED

On Behalf of: AGRICULTURE CANADA RESEARCH STATION, HARROW, ONTARIO NOR 1G0

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STUDY TEAM

Dr. B. L. Frick[1], Project Manager and Author

T. Hawkes, Technician, Field and Greenhouse Studies

E. Schuster, Technician, Field Studies

M. Padoin, Technician, Field Studies

S. Woo, Technician, Data Analysis

L. Hutchins, Office Manager

[1] Current address: Crop Development Centre, University of Saskatchewan, Saskatoon, Saskatchewan S7N 0W0

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EXECUTIVE SUMMARY

Conservation tillage systems have been advocated as a means of reducing soil erosion and phosphorous run-off from cropland, and of maintaining long-term soil productivity. Conservation tillage has been defined as any method of tillage which leaves a minimum of 30% residue on the soil surface. Such systems range from strict no-till to chisel plowing, but all involve a reduced frequency of tillage and/or a different type of tillage compared to conventional systems. One of the main obstacles to widespread adoption of conservation tillage is the perception by farmers that new and exacerbated weed problems will occur when tillage is no longer available as a method of weed control. To address this concern a study was undertaken to determine what weed problems resulted from a reduction in tillage, and to examine possible management strategies to handle these problems.

A survey was conducted to examine weed species composition and weed density in 593 farm fields across southwestern Ontario in 1988 and 1989. The crops selected for the survey were corn, soybeans and winter wheat. Tillage systems were categorized as conventional (including some form of soil inversion as by a moldboard plow), conservation (including some soil disturbance other than inversion), and no-till (no tillage between the current and previous crop). Fields were also grouped according to the length of time that a given tillage system had been practised.

In general, the same weed species were found in all tillage systems, but their frequency of occurrence and density varied slightly. All three tillage types were dominated by five weed species that occurred in more than 25% of fields: green foxtail, lamb's-quarters, redroot pigweed, common ragweed, and quack grass. Dandelions also occurred in more than 25% of conservation and no-till fields, as opposed to 21 % of conventional fields. No-till and conservation tillage fields had higher overall weed densities than conventional fields. Weed populations varied greatly within tillage systems.

Only a few trends with length of time in a tillage system were observed. First year conservation tillage fields generally had more green foxtail and dandelions than conventional fields, but these weeds decreased once conservation tillage was established. Quack grass decreased in frequency and density with time in no-till or conservation tillage. Established no-till and conservation fields had markedly less quack grass than conventional fields.

Reduced tillage systems present an altered environment for weed growth and so may affect the rate of development of weed species. Most weed control practices are targeted at particular growth stages. The growth and development of the more common weed species were monitored in a small subset of the surveyed fields in 1989. Lamb's-quarters, redroot pigweed, and velvetleaf showed no difference in the timing of various growth stages among tillage systems. Green foxtail and common ragweed emerged later in no-till than in conventional tillage, and so may have been more likely to escape control. Perennial species emerged at about the same time in all tillages, but grew more slowly in conventional tillage than in no-till. Dandelion was the only weed to show a difference in flowering in relation to tillage. Dandelions flowered most often in no-till fields and least often in conventional fields.

Herbicide use patterns did not vary substantially among tillage systems, other than the increased use of burndown treatments, and decreased use of soil incorporated chemicals in no-till. The literature on herbicide efficacy in reduced tillage systems is not conclusive. The primary concerns of farmers in the study were 1) lack of information on dandelion control, and 2) the limited number of herbicides registered for burndown applications.

Greenhouse experiments were conducted to determine the effects of simulated "tillage" treatments on the survival of seeds, vegetative propagules, and actively growing plants of the more common weed species. Burial of weed seeds in the autumn, as through plowing, favoured annuals over perennials. Overwinter survival of roots and rhizomes of perennial species was decreased if they were brought to the surface. Mechanical damage to the roots of actively-growing annual weeds was an effective control method at all growth stages. Perennial species were susceptible to mechanical damage only over relatively short periods of time.

The results presented here show that problem weed species were not substantially different in different tillage systems. Weed communities were influenced by geographic region, soil type, field history and level of management, in addition to tillage. It is probably not appropriate to design a single strategy for weed management in reduced tillage systems.

The perception that weed management is more difficult in reduced tillage needs to be challenged. Changes in weed communities are small. Some changes offer a greater challenge for weed control; other changes offer opportunities for improved weed control. The transition to conservation tillage or no-till however may initially require more intensive weed management.

INTRODUCTION

Soil erosion is a serious environmental and agricultural concern. In 1984, sheet and rill erosion cost Ontario farmers $68 million in yield reduction, nutrient loss and pesticide loss (Standing committee on Agriculture, Fisheries and Forestry 1984). The nutrients and pesticides contained in cropland run-off make it a significant source of water pollution.

The Soil and Water Environmental Enhancement Program (SWEEP) was designed to reduce soil erosion and run-off from cropland, and to improve agricultural productivity by controlling soil degradation in southwestern Ontario. The Technology Evaluation and Development (TED) subprogram of SWEEP is directed at field level evaluation of technologies which contribute to these goals.

Adoption of conservation tillage systems could significantly reduce erosion, soil degradation and water pollution. Conservation tillage has been defined as any method of tillage which leaves a minimum of 30% plant residue on the soil surface. Such systems range from no-till to chisel plowing, but all involve a reduced frequency of tillage and/or a different type of tillage compared to conventional systems. One of the main obstacles to widespread adoption of conservation tillage is the perception by farmers that new and exacerbated weed problems will occur when tillage is no longer available as a method of weed control (Reichelderfer 1984).

Weed communities reflect farm management practices. As farm management systems change, weed species composition and weed densities may change. Differences in the timing of weed emergence or in the rate of growth of weeds may also occur, which in turn will affect the success of weed control measures. The transitional period during the conversion from conventional to conservation tillage may be particularly problematic, because the weed community is undergoing change and conventional weed control practices must be adapted to new management systems.

This report summarizes a study of weed problems in various tillage systems. The research conducted for this project is presented in four chapters. Two chapters examine weed communities in farm fields that were managed with conventional, conservation and no-till tillage systems. The first chapter considers weed species composition and abundance. These characteristics of the weed community are compared over different environments and management systems. Geographic weed distribution is also considered. The second chapter considers the phenology of important weeds in farm fields in relation to tillage system. Aspects of chemical control in conservation tillage are approached through a literature survey in the third chapter. The fourth chapter reports on greenhouse experiments that simulate the effects of tillage at various stages of growth of the major weed species. Comments on weed management strategies for conservation tillage complete the report.

GENERAL OBJECTIVES

This study was a preliminary examination of weed problems in conservation tillage systems. The objectives of the research are as follows:

1. To determine the weed species likely to be the greatest problem under various conservation tillage systems which have been established for different lengths of time.
2. To determine the timing of phenological stages of problem weed species in different conservation tillage systems.
3. To examine susceptibility of problem weeds to control by herbicide and tillage methods available in conservation tillage systems.
4. To recommend weed management strategies for field testing in conservation tillage systems.

WEED SURVEY

INTRODUCTION

Weed communities generally reflect farm management practices. Changes in tillage patterns are expected to result in changes in the diversity of weeds, and in the densities of various weed species. Some changes in weed communities associated with changes in tillage can be predicted. Changes in tillage result in changes in soil physical properties, and alter the microenvironment for weed germination, growth and development.

Tillage directly and indirectly affects seeds, and alters their germination patterns. Tillage buries weed seeds, often resulting in or enhancing dormancy. Further tillage brings buried weed seeds near the surface where the dormancy is often broken (Froud-Williams 1988). Large seeded species may be encouraged by burial; some are unable to establish on the soil surface. Small seeded species will be especially favoured by cultural practices which accumulate seeds at or near the soil surface, as they are unable to emerge from the deep soil layers (Froud-Williams *et al.* 1984). Tillage can stimulate germination due to improved soil aeration, enhanced seed-soil contact and reduced soil density (Swanton *et al.* 1990). As tillage is reduced, total weed germination often decreases (Witt 1984; Kells and Meggitt 1985). Seeds are lost from the soil seed bank primarily through germination. Depletion of the seed bank occurs more rapidly in cultivated than uncultivated soils (Roberts and Feast 1973; Roberts and Dawkins 1967; Froud-Williams 1988).

Tillage also influences the environment for established plants. Reductions in tillage generally result in increased crop residues on the soil surface. Crop residues physically restrict weed emergence and may have an allelopathic effect on weeds (Frisbie 1984). Standing crop residues can act to catch the seeds of wind-dispersed species, making them more prevalent in uncultivated plots (Froud-Williams *et al.* 1983). The insulating effect of snow trapped by standing stubble may afford greater survival to perennial weed species

(Schimming and Messersmith 1988). Perennials are often favoured in continuous no-till (Kells and Meggitt 1985; Froud-Williams *et al.* 1983), although Derksen (1990) found that this was not always true. Perennial weeds that spread underground may increase in the absence of tillage. Woody species may become a problem (Frisbie 1984). Perennial weeds may invade fields from ditch-banks and field margins. Soil cultivation selects for perennial weeds that rely on fragmentation and dispersal of root fragments for successful regeneration. These are expected to decrease in reduced tillage (Froud-Williams 1988). The distribution of perennial weeds may become more patchy when root fragments and rhizomes are not spread by tillage.

Reductions in tillage may lead to increased reliance on herbicides for weed control. Continuous use of the same or similar herbicide results in weed floras poor in species diversity, as species susceptible to the herbicides are eliminated. As species numbers are reduced, the remaining species occupy the newly available spaces; these species occur at very high density(Froud-Williams 1988).

Research results are not uniform. Reduced tillage may favour annual grasses over annual broadleaves (Kells and Meggitt 1985; Frisbie 1984; Witt 1984; Froud-Williams 1988; Froud-Williams *et al.* 1983; Johnson *et al.* 1989), partly as a result of the more effective broad-leaved herbicides (Froud-Williams 1988). Broadleaf weed densities may not be affected by tillage (Wrucke and Arnold 1985) or may show variable results (Johnson *et al.* 1989). Some annual grasses may become easier to control, because their seeds remain exposed (Witt 1984). There may be a shift within the annual grasses, to the more difficult to control (Frisbie 1984). Reduced tillage has led to problems with green foxtail in some fields (Froud-Williams 1988; Wrucke and Arnold 1985; Johnson *et al.* 1989), and to less green foxtail in others (Derksen 1990; Holm 1990).

Fall panicum and crab grasses have increased in some reduced tillage corn (Froud-Williams 1988). Velvetleaf may be favoured by conventional tillage compared to no-till, because of its need for seeds to be buried in order to germinate (Buhler and Daniel 1988; Buhler and Oplinger 1990). Particularly problematic in reduced tillage systems are common milkweed (Kells and Meggit 1985; Frisbie 1984; Holm 1990), yellow nut sedge (Kells and Meggitt 1985), quack grass (Kells and Meggitt 1985, Witt 1984; Froud-Williams *et al.* 1983; Holm 1990); dandelion (Frisbie 1984; Froud-Williams et al. 1983; Holm 1990), Canada thistle (Frisbie 1984; Froud-Williams *et al.* 1983; Holm 1990), foxtail barley (Thomas and Derksen 1990) and field bindweed (Holm 1990).

Some studies indicate that the intensity of weed problems is not affected by the tillage system. Thomas and Derksen (1990) report on weed communities at 4 Saskatchewan sites. They conclude that there were no significant changes in weed spectrum after 4 years of conservation tillage. There were also no significant differences in total weed density in each of the tillage systems for each of 3 research sites. In a fourth, foxtail barley was more abundant in the absence of tillage than when fields were tilled. They concluded that conservation tillage did not result in weed problems that could not be controlled and that weed problems were not necessarily more difficult to control in conservation tillage than in conventional tillage.

Pollard and Cussans (1981) suggested that although some species responded strongly to tillage, there was no cumulative effect. Species that increased with the introduction of reduced tillage did not continue to increase.

In general, research indicates that reduced tillage requires better management skills on the part of the farmer, but offers the potential for effective weed management. Fields that were dominated by grassy weeds tend to have greater densities of these weeds if left uncultivated; fields with few grassy weeds had lower densities of weeds if uncultivated. The gradual elimination of broadleaved weeds was possible, using herbicides on uncultivated plots Froud-Williams *et al.* 1983). Good weed control gets easier while fields that had poor weed control become worse with reduced tillage (Kells and Meggitt 1985).

OBJECTIVES

Weed communities may change as tillage practices change. Surveys can be used to examine these changes. The objectives of the survey were twofold:

1. To develop a species list for weeds found in various tillage systems.
2. To examine correlations among weed species abundance and tillage system, numbers of years in a tillage system, crop and rotational system, soil type and region.

METHODS

Sampling procedure

The survey was conducted over seven counties in 1988: Essex, Kent, Lambton, Elgin, Middlesex, Huron and Perth. In 1989, these counties were surveyed again, and an additional four counties were added: Waterloo, Wellington, Oxford and Brant. Surveys were conducted from mid-July to mid-September in 1988, and during July and August of 1989. This allowed us to consider weeds that had escaped the various control measures used, and that were potentially competing with the crops.

Names of potential farm co-operators were obtained from a variety of sources: OMAF soil conservation advisors, Conservation Authority agronomists, soil conservation clubs, other farmers. Fields were selected on the basis of farmer co-operation, location, tillage history, and current crop. Farm operators were asked questions on the management history of each field. Soil series was determined from the Ontario Soil Survey Map (Report #30, Soil Association of Southern Ontario). The series represented 6 soil textures and three great groups.

In each field, the number of individuals of each weed species was determined within 20 x 0.25 m^2 quadrats, using the sampling design of Thomas (1985). For some perennial species (quack grass, field bindweed, yellow nut sedge, field horsetail and Canada thistle) shoots or tillers rather than individuals were counted.

Data Analysis

A total of 593 fields were surveyed: 228 in 1988 and 365 in 1989. Summaries for the two years were remarkably similar, despite the differences in growing conditions in those years. The data were combined for analysis and were summarized over a number of variables that were suspected of being important determinants of weed distribution (Appendix 1).

For the purposes of the survey, tillage practices were grouped into three types: conventional (including some form of soil inversion, such as moldboard plow), conservation (including some soil disturbance other than inversion) and no-till (no tillage in the current crop or between the current and previous crop). Fields were also grouped according to the length of time that they had been managed with a given tillage type. First year fields were considered separately. Fields in the second or third year of a tillage type were considered transitional; those in the fourth or later year, established. These groupings were determined in part by available sample size.

Three crops were selected for the survey: corn, soybeans and winter wheat. Fields in other crops were not surveyed. An even distribution of tillage types was sought among crops. This was not possible in winter wheat. Few farmers used inversion tillage techniques prior to planting of winter wheat.

A great diversity of rotational sequences was identified. These were grouped into three distinct crop rotation types: continuous corn, rotations including perennial forages, and rotations of annual crops without perennial forages. Corn was the single species used in continuous rotation in a sufficiently large number of fields to warrant consideration. The inclusion of perennial species in the crop rotation may have consequences for the weed community. The type of perennial crop was considered less important. Most other rotations included two to several species of annual or winter-annual crops. No other single rotation type was sufficiently unique, or occurred in sufficient number to be treated as a distinct group.

Summary **tables**

Weed data are presented in this chapter, and in a self-contained weed survey report presented as Volume 2 of this report. The survey report presents several series of summary tables. Common names given in the summaries are those listed in Alex et al. (1980). All summary tables present weed frequency, uniformity, density, and relative abundance. Frequency is expressed as the percentage of fields in a category. Uniformity is expressed as a percentage of all the quadrats surveyed in a category (uniformity - all fields) or as a percentage of the quadrats in occurrence fields only in that category (uniformity - occurrence fields). Density is expressed per square meter, averaged over all fields, or averaged over occurrence fields only. Relative abundance is the sum of relative frequency, relative uniformity (all fields), and relative density (all fields). See Thomas (1985) for further description of terms.

Summary tables for all species are presented separately for each of a number of environmental and management variables (Volume 2). Weed frequency data are presented in this chapter for major species in each of three weed groups: annual broad-leaved, annual grass, perennial plants. Major species are considered to be those that occurred in at least

6% of fields overall. Other species are considered as minor. Weed density data are presented in this chapter for weed groups.

RESULTS AND DISCUSSION

We recorded 82 weed types in the 593 fields surveyed (Volume 2). Most of these were single species, but some such as annual smartweeds and crab grasses represent congeneric groupings that were difficult to distinguish in the field. Many weeds were relatively rare: 30 weeds occurred in less than 1 % of fields and a total of 59 weeds occurred in less than 5% of fields. Only six species were found in more than 25 % of the fields: green foxtail, lamb's-quarters, quack grass, redroot pigweed, common ragweed, and dandelion. These same 6 species were the only ones found in more than 5 % of the quadrats sampled. A weed flora dominated by few species is common for communities sampled after control measures have been used (Thomas and Wise 1987)

A survey of weed species in Essex and Kent in the late 1970's (Hamill and Thomas 1985) found a greater number of species at frequencies of 25 % or more. These included foxtails, lamb's-quarters, pigweeds and common ragweed but not quack grass or dandelion. In addition, the Essex/Kent survey also included barnyard grass, velvetleaf, lady's-thumb, 'field bindweed, canada thistle, milkweed spp., sow-thistle spp., and eastern black nightshade.

The average combined density of all weeds over all fields was 25 per m^2. This compares to 21 weeds per m^2 in corn fields and 10 per m^2 in soybean fields in the Essex/Kent surveys (Hamill and Thomas 1985). In the current study, several species equalled or exceeded the average occurrence densities of the six most frequent species. Many of the species with high densities were grasses. Four weeds had average occurrence densities greater than 10 plants per m^2: yellow foxtail, common chickweed, green foxtail, and crab grasses. Twelve weeds had average occurrence densities greater than 5 plants per m^2: the 4 listed above, plus quack grass, yellow nut sedge, volunteer winter wheat, lamb's-quarters, fall panicum, redroot pigweed, giant foxtail, and unidentified grasses.

Weed populations varied tremendously from field to field. A few fields had no weeds that occurred in the sample quadrats. Most fields had a few individuals of each of 5 to 10 species. Occasionally a single species reached high density (eg. more than 200 green foxtail or lamb's-quarters plants per m^2). Fields of each classification (tillage type, crop, etc.) showed this type of variability.

Tillage

Weed communities were not qualitatively different among tillage types (Table 1 and Volume 2). Conventional fields had a total of 61 species; conservation, 69; no-till, 68. The species not common to all three tillages were very minor species in the tillages in which they did occur. All three tillage types were dominated by five species that occurred in greater than 25 % of fields: green foxtail, lamb's-quarters, redroot pigweed, common ragweed, and quack grass. Dandelion also occurred in greater than 25 % of conservation and no-till fields. It occurred in 22 % of conventional fields. The relative frequency of weed groups did not differ markedly among tillage systems.

Weed communities differed somewhat in density among the tillage types (Table 2). Average combined densities of all weeds were 17 per m^2 for conventional tillage, 25 per m^2 for conservation tillage and 32 per m^2 for no-till. In other words, no-till fields had the same kinds of weeds as conventionally tilled fields, but had approximately twice as many of them.

Table 1. Frequencies (%) of species and weed groups managed with various tillage systems.

Weed group and species	Tillage system		
	Conventional	Conservation	No-till
<u>Annual broadleaf</u>			
lamb's-quarters	53	55	47
redroot pigweed	33	40	49
common ragweed	37	30	38
annual smartweeds	20	22	23
velvetleaf	12	20	18
wild buckwheat	14	20	21
common yellow wood-sorrel	10	9	15
black nightshade	4	13	7
prostrate knotweed	3	8	12
Relative frequency of group	38	42	40
<u>Annual grass</u>			
green foxtail	44	51	47
crab grasses	7	12	12
barnyard grass	18	16	14
witch grass	11	11	14
Relative frequency of group	16	17	15
<u>Perennial</u>			
quack grass	51	36	41
dandelion	22	26	39
field bindweed	22	13	21
common milkweed	23	18	24
yellow nut sedge	6	9	11
broad-leaved plantain	4	11	12
Relative frequency of group	26	22	26
Minor species			
Relative frequency of group	20	19	19

Table 2. The total density (no./m^2) of weed groups in fields managed with various tillage systems.

Weed group	Tillage system		
	Conventional	Conservation	No-till
Annual broad-leaved	4.7	9.4	9.9
Annual grass	4.5	8.2	8.3
Perennial	5.1	3.9	7.4
Minor species	2.7	3.1	6.1
TOTAL	17.0	24.7	31.7

<u>Time in a tillage system</u>

Trends in the weed communities over time were generally weak. The trends were not the same for conservation tillage and no-till (Tables 3 and 4). In conservation tillage there was a trend to decreasing frequency of perennials and decreasing weed density over time.

The most common annual broad-leaved weeds were generally found at greater density in conservation tillage fields than in conventional fields. First year conservation fields generally had greater densities of annual grasses and of perennials than conventional fields.

Table 3. Frequencies (%) of species and weed groups in fields managed for 1, 2 or 3, and 4 or more years with a conservation tillage or no-till system compared to fields managed for 4 or more years with a conventional tillage system.

Weed group and species	Conventional tillage system (4 or more years)	Years with a conservation system			Years with a no-till system		
		1	2 or 3	4 or more	1	2 or 3	4 or more
Annual broad-leaved							
lamb's-quarters	53	52	52	59	54	37	45
redroot pigweed	27	41	28	46	49	52	45
common ragweed	43	37	22	30	47	24	36
annual smartweeds	22	22	18	23	30	6	29
velvetleaf	15	14	13	30	18	7	33
wild buckwheat	16	17	20	23	27	20	7
common yellow wood-sorrel	10	8	10	10	17	15	12
black nightshade	5	11	8	19	4	7	14
prostrate knotweed	6	11	5	8	18	2	12
Relative frequency of group	40	36	39	49	42	35	38
Annual grass							
green foxtail	45	58	45	48	55	35	45
crab grasses	6	17	13	8	12	7	19
barnyard grass	21	20	17	11	10	9	31
witch grass	9	12	10	10	17	11	14
Relative frequency of group	17	18	19	15	15	13	18
Perennial							
quack grass	49	47	33	28	45	41	31
dandelion	16	40	17	19	41	37	38
field bindweed	26	13	8	17	19	17	31
common milkweed	30	17	17	20	18	30	31
yellow nut sedge	6	17	7	4	7	15	12
broad-leaved plantain	4	17	5	10	11	7	19
Relative frequency of group	27	26	19	19	23	30	27
Minor species							
Relative frequency of group	16	20	23	17	20	22	17

Table 4. Densities of weed groups and selected species in fields managed for various lengths of time under various tillage systems, (cs = conservation, cv = conventional, nt = no-till; 1 = first year, 2 = second or third year, 4 = fourth year or longer).

	Tillage History						
	cv4	cs1	cs2	cs4	nt1	nt2	nt4
Annual broad-leaved	4.1	10.1	13.4	6.2	11.2	8.4	9.3
Annual grass	4.3	15.9	5.9	2.4	7.2	9.9	9.2
green foxtail	3.3	12.3	4.0	1.4	4.7	4.7	8.0
Perennial	5.5	6.7	3.2	1.9	9.6	5.6	4.9
quack grass	4.3	2.9	1.4	1.1	7.0	2.6	1.7
dandelion	0.2	1.0	0.3	0.3	1.5	0.7	0.4
Minor species	2.1	3.7	3.5	2.4	3.9	3.8	14.4
TOTAL	16.0	36.4	25.9	12.9	31.9	27.8	37.8

The levels of these weeds decreased once conservation tillage was established. These trends are especially evident for green foxtail, quack grass and dandelion.

Frequencies and densities of annual weeds were generally higher in no-till than in conventional or established conservational tillage. This may in part result from summer weed control (eg. inter-row scuffling) that was more often a part of conventional and conservation tillage systems..

Dandelion was much more frequent in no-till than in conventional fields regardless of the length of time in no-till. Dandelion occurred in high densities in early no-till fields, but had lower density in established no-till.

Quack grass decreased in frequency and density with time in no-till. Established no-till had markedly less quack grass than conventional fields.

Cropping **practices**

Weed communities were not qualitatively different for fields that differed in the current crop, the previous crop, or the crop rotation (Volume 2). Most species were common to all cropping systems.

Current crop

Weed frequencies differed among crops (Table 5). Winter wheat fields had greater frequencies of annual smartweeds, wild buckwheat, common yellow wood-sorrel, and broad-leaved plantain. This difference relative to corn and soybeans may reflect the lack of summer tillage in wheat, and the reduced rate of herbicide application. Redroot pigweed and velvetleaf were less frequent in winter wheat fields.

Table 5a . Frequencies (%) of species and weed groups in corn managed with various tillage systems.

	Tillage system		
Weed group and species	Conventional	Conservation	No-till
Annual broad-leaved			
lamb's-quarters	55	58	43
redroot pigweed	36	49	55
common ragweed	17	17	24
annual smartweeds	15	12	15
velvetleaf	12	28	21
wild buckwheat	7	9	15
common yellow wood-sorrel	13	6	12
black nightshade	3	16	4
prostrate knotweed	3	2	8
Relative frequency of group	33	39	36
Annual grass			
green foxtail	51	54	51
crab grasses	9	21	11
barnyard grass	20	17	15
witch grass	17	10	20
Relative frequency of group	20	20	18
Perennial			
quack grass	55	37	44
dandelion	24	27	43
field bindweed	24	8	24
common milkweed	25	20	25
yellow nut sedge	5	13	12
broad-leaved plantain	1	9	9
Relative frequency of group	28	23	29
Minor species			
Relative frequency of group	19	18	17

The effect of tillage system on the frequencies of weeds differed in different crops. Redroot pigweed and prostrate knotweed occurred less frequently in conventional winter wheat than in conservation or no-till wheat. Common ragweed occurred in approximately equal frequencies in conservation and conventional fields of corn or winter wheat, but was twice as common in conventional soybeans as in conservation soybeans. Dandelion occurred

Table 5b. Frequencies (%) of species and weed groups in soybeans managed with various tillage systems.

Weed group and species	Tillage system: Conventional	Conservation	No-till
Annual broad-leaved			
lamb's-quarters	53	54	45
redroot pigweed	34	40	49
common ragweed	53	28	40
annual smartweeds	17	14	21
velvetleaf	14	21	22
wild buckwheat	17	15	11
common yellow wood-sorrel	4	4	11
black nightshade	7	15	10
prostrate knotweed	3	4	15
Relative frequency of group	43	43	41
Annual grass			
green foxtail	41	43	47
crab grasses	4	5	15
barnyard grass	16	20	18
witch grass	4	10	10
Relative frequency of group	14	17	16
Perennial			
quack grass	44	31	22
dandelion	17	19	34
field bindweed	20	10	21
common milkweed	19	19	19
yellow nut sedge	7	6	8
broad-leaved plantain	6	0	10
Relative frequency of group	24	19	21
Minor species			
Relative frequency of group	19	21	22

in greater frequency in no-till fields in all crops. Quack grass occurred in greater frequency in conventional fields, but this was especially true for soybeans.

Table 5c. Frequencies (%) of species and weed groups in winter wheat managed with various tillage systems.

Weed group and species	Tillage system: Conventional	Conservation	No-till
Annual broad-leaved			
lamb's-quarters	50	50	57
redroot pigweed	11	24	38
common ragweed	56	57	57
annual smartweeds	50	48	38
velvetleaf	6	5	6
wild buckwheat	33	45	45
common yellow wood-sorrel	17	22	26
black nightshade	0	7	9
prostrate knotweed	11	24	13
Relative frequency of group	41	43	43
Annual grass			
green foxtail	28	57	43
crab grasses	11	9	11
barnyard grass	17	9	9
witch grass	11	12	13
Relative frequency of group	12	13	11
Perennial			
quack grass	61	41	64
dandelion	22	35	40
field bindweed	22	26	15
common milkweed	22	14	30
yellow nut sedge	0	7	13
broad-leaved plantain	11	29	19
Relative frequency of group	24	23	27
Minor species	23	21	19
Relative frequency of group			

Weed communities differed somewhat in density among the crops (Table 6). Average combined densities of all weeds were 25 per m^2 for corn, 16 per m^2 for soybeans and 40 per m^2 for winter wheat. Winter wheat had markedly higher densities of weeds irrespective of tillage system (Table 7). This was true for all weed types, and for a majority of weed species. The grasses were especially dense in the wheat fields: green foxtail in conservation fields, and quack grass in conventional fields.

Table 6 . The total density (no./m^2) of weed groups in the three surveyed crops.

	Crop		
Weed group	Corn	Soybean	Winter wheat
Annual broad-leaved	7.5	6.2	13.5
Annual grass	7.5	3.7	13.0
Perennial	4.8	4.0	9.1
Minor species	5.6	2.1	4.2
TOTAL	25.4	16.0	39.9

Table 7. The total density (no./m^2) of weed groups and selected species in the surveyed crop fields managed with various tillage systems

	Tillage system		
Crop and weed group	Conventional	Conservation	No-till
Corn			
Annual broad-leaved	4.4	10.7	6.6
Annual grass	5.7	9.3	7.0
Perennial-	5.3	4.3	5.3
Minor species	2.3	4.8	9.7
TOTAL	17.4	29.1	28.6
Soybeans			
Annual broad-leaved	4.7	3.5	10.5
Annual grass	2.6	2.9	5.5
Perennial	3.0	2.5	6.6
Minor species	2.4	1.0	3.0
TOTAL	12.7	10.0	25.6
Winter wheat			
Annual broad-leaved	5.6	15.5	14.2
Annual grass	7.2	13.5	14.7
Green foxtail	5.7	10.7	6.4
Perennial	13.2	5.4	12.1
Quack grass	11.2	1.8	6.9
Minor species	5.7	3.1	5.1
TOTAL	31.7	37.5	46.1

Cropping history

Weed frequencies show few consistent trends relative to cropping history (Table 8). Alfalfa was common as a weed only in fields where it previously grew as a crop. Dandelion and quack grass occurred especially often in rotations that included perennial species. Field horsetail occurred particularly often in continuous corn. Fields with mixed crops, excluding perennials, generally had lower frequencies of annual grasses.

Table 8a. Frequencies (%) of species and weed groups in a continuous corn rotation managed with various tillage systems.

	Tillage system		
Weed group and species	Conventional	Conservation	No-till
Annual broad-leaved			
lamb's-quarters	56	54	50
redroot pigweed	33	39	40
common ragweed	11	15	30
annual smartweeds	11	23	0
velvetleaf	0	15	30
wild buckwheat	22	23	10
common yellow wood-sorrel	22	0	20
black nightshade	0	0	0
prostrate knotweed	11	7	10
Relative frequency of group	28	37	26
Annual grass			
green foxtail	67	39	70
crab grasses	11	31	30
barnyard grass	33	39	20
witch grass	22	7	30
Relative frequency of group	22	25	21
Perennial			
quack grass	44	39	40
dandelion	33	31	70
field bindweed	44	0	30
common milkweed	0	7	30
yellow nut sedge	11	7	20
broad-leaved plantain	11	0	10
Relative frequency of group	24	18	27
Minor species			
Relative frequency of group	26	20	26

Table 8b. **Frequencies (%) of species and weed groups in a mixed annual crop rotation managed with various tillage systems.**

Weed group and species	Tillage system: Conventional	Conservation	No-till
Annual broad-leaved			
lamb's-quarters	52	54	47
redroot pigweed	31	36	49
common ragweed	42	32	42
annual smartweeds	22	22	25
velvetleaf	15	22	20
wild buckwheat	14	20	21
common yellow wood-sorrel	7	11	13
black nightshade	5	13	7
prostrate knotweed	4	7	12
Relative frequency of group	42	43	42
Annual grass			
green foxtail	38	47	45
crab grasses	6	9	11
barnyard grass	17	12	16
witch grass	8	10	10
Relative frequency of group	15	15	15
Perennial			
quack grass	48	35	38
dandelion	16	25	33
field bindweed	21	13	20
common milkweed	25	19	25
yellow nut sedge	7	10	8
broad-leaved plantain	4	11	12
Relative frequency of group	26	22	24
Minor species			
Relative frequency of group	17	20	19

Table 8c. Frequencies (%) of species and weed groups in a mixed annual and perennial crop rotation managed with various tillage systems.

Weed group and species	Tillage system: Conventional	Conservation	No-till
Annual broad-leaved			
lamb's-quarters	57	67	35
redroot pigweed	33	40	40
common ragweed	23	20	0
annual smartweeds	13	13	15
velvetleaf	7	7	0
wild buckwheat	13	20	25
common yellow wood-sorrel	20	0	25
black nightshade	3	7	10
prostrate knotweed	0	13	10
Relative frequency of group	33	31	26
Annual grass			
green foxtail	63	67	50
crab grasses	13	27	10
barnyard grass ,	13	27	0
witch grass	20	20	35
Relative frequency of group	19	23	16
Perennial			
quack grass	57	60	60
dandelion	37	47	70
field bindweed	13	0	15
common milkweed	17	20	10
yellow nut sedge	0	13	25
broad-leaved plantain	3	0	10
Relative frequency of group	24	23	31
Minor species			
Relative frequency of group	24	23	27

Fields in continuous corn production had higher grass weed densities than other rotations, regardless of tillage type (Table 9). Forcella and Lindtrom (1988) also reported increased weed problems in continuous corn. They found at least twice as many buried weed seeds in soil subjected to continuous corn production as there were in soils under corn/soybean rotations. In the current study, no-till fields were at a special disadvantage under continuous corn, in terms of total weed densities. Dandelion was especially dense in no-till fields in a rotation that included perennials. It is likely that the dandelions become established in the perennial crop, and simply persist in the absence of tillage.

Table 9. The total density (no./m^2) of weed groups in fields managed with various crop rotations and tillage systems.

	Tillage system		
Crop rotation and weed group	Conventional	Conservation	No-till
Continuous corn			
Annual broad-leaved	2.5	6.0	9.7
Annual grass	14.2	15.0	26.7
Perennial	4.9	9.3	14
Dandelion	0.2	0.1	1.5
Minor species	5.8	2.7	7.5
TOTAL	27.4	33.0	57.8
Mixed annual crops			
Annual broad-leaved	5.1	9.9	10.5
Annual grass	3.7	5.4	7.5
Perennial	5.3	3.5	6.1
Dandelion	0.2	0.6	0.5
Minor species	2.7	2.9	6.5
TOTAL	16.8	21.6	30.6
Mixed annual and perennial crops			
Annual broad-leaved	3.0	4.9	3.6
Annual grass	4.8	12.1	2.8
Perennial	3.2	5.8	12.7
Dandelion	0.3	0.8	4.2
Minor species	2.0	2.4	3.6
TOTAL	13.0	25.3	22.6

Geographic distribution

Farmers in different areas were faced with different weed populations. In many instances, the geographic differences had a greater effect on weed populations than the management factors. Volume 2 contains distribution maps for 25 common weed species. Some species, such as redroot pigweed, green foxtail and lamb's-quarters were found frequently throughout the surveyed area. Others, such as wild carrot, Canada thistle, broad-leaved plantain, prostrate knotweed, yellow foxtail, barnyard grass, crab grasses, witch grass, field horsetail and fall panicum were found in relatively low frequency throughout. Only a very few species have distribution patterns that suggest the factors limiting their success. Velvetleaf and eastern black nightshade have frequency distributions that suggest relatively recent introduction in the extreme southwest, and subsequent limited expansion. Wild buckwheat shows a distinct gradient from more frequent in the north to less frequent in the south of the surveyed area. Common yellow wood-sorrel shows a similar gradient from northeast to southwest. Dandelion was especially abundant in the east of the surveyed area. This may reflect the greater incidence of dairy farms in this area, and the corresponding increase in rotations with perennial crops. Field bindweed and common milkweed have similar patterns, with highest frequencies in Perth, Huron and Middlesex. Annual smartweeds, yellow nut sedge, common chickweed, common ragweed and quack grass have distinct patterns that are not easily explained.

Tables summarizing the weed data by county for other species, and giving additional data on the mapped species are found in Volume 2.

Soil

Soil type had an effect on the distribution of only a few species (Tables 10, 11). For these species (velvetleaf and most of the major perennials) the trends were not consistent over texture groups.

Table 10. The total density (no/m^2) of weed groups and selected species in fields with various soils.

	Clay		Clay loam					Loam		Sandy loam		
	Ha[1]	Li	Pe	Hu	Bro	Tu	Ho	Lo	Gu	Bra	Fox	Be
Annual broad-leaved	9.4	8.6	9.1	8.8	11.6	7.5	2.8	8.9	5.8	4.6	5.4	9.0
Annual grass	8.8	3.4	6.8	11.2	8.4	2.2	1.4	3.7	5	0.8	13.1	23.4
Perennial	11.2	2.3	6.8	5.9	1.8	1.8	2.0	3.5	5.8	0.3	9.2	11.4
Minor species	6.5	7.3	2.3	3.8	8.8	2.2	0.6	2.8	2.0	0.2	2.1	2.1
Total	35.8	21.6	25.1	29.6	30.6	13.8	6.8	19.0	18.5	6.0	29.7	45.9

[1]Ha = haldimand; Li = Lincoln; Pe = Perth, Hu = Huron; Bro = Brookston; Tu = Tuscola silt loam; Ho = Honeywood very find sandy loam; Lo = London; Gu = Guelph; Bra = Brady; Be = Berrien.

Table 11. Frequencies (%) of species and weed groups in fields with various soils.

	Clay		Clay loam					Loam		Sandy loam		
Weed group and species	Ha[1]	Li	Pe	Hu	Bro	Tu	Ho	Lo	Gu	Bra	Fox	Be
Annual broad-leaved												
lamb's-quarters	55	47	62	65	51	24	33	62	36	52	43	69
redroot pigweed	47	59	49	47	32	21	22	50	25	33	45	23
common ragweed	55	37	37	23	40	24	50	31	15	10	38	69
annual smartweeds	19	10	22	23	29	10	17	19	23	14	23	62
velvetleaf	11	35	16	4	51	0	17	0	0	29	0	15
wild buckwheat	6	4	26	25	12	14	17	27	30	0	21	31
common yellow wood-sorrel	6	8	9	16	5	3	17	19	15	0	26	31
black nightshade	4	28	5	0	13	0	0	8	3	24	13	8
prostrate knotweed	8	2	8	14	13	10	0	8	2	0	15	8
Relative frequency of group	40	46	42	34	46	31	40	38	33	55	34	49
Annual grass												
green foxtail	38	53	59	49	56	28	33	39	33	48	47	54
crab grasses	15	12	5	11	16	10	0	8	12	5	23	15
barnyard grass	21	26	16	14	23	3	11	19	10	5	11	8
witch grass	4	8	11	25	12	0	6	12	21	5	17	8
Relative frequency of group	15	20	16	16	20	12	12	13	17	21	15	13
Perennial												
quack grass	62	24	53	49	17	38	61	35	44	5	49	69
dandelion	25	22	31	40	23	48	17	39	26	5	40	15
field bindweed	0	8	28	28	20	3	11	46	18	5	4	31
common milkweed	25	10	19	33	7	21	33	46	38	5	15	15
yellow nut sedge	9	4	8	0	7	10	22	0	2	0	38	23
broad-leaved plantain	4	12	8	16	18	3	6	4	7	5	11	0
Relative frequency of group	24	16	26	26	17	36	35	29	30	8	24	24
Minor species	21	18	16	24	17	21	13	20	20	16	27	14

[1]Ha = Haldimand; Li = Lincoln; Pe = Perth, Hu = Huron; Bro = Brookston; Tu = Tuscola silt loam; Ho = Honeywood very fine sandy loam; Lo = London; Gu = Guelph; Bra = Brady; Be = Berrien.

SUMMARY

There is an overwhelming perception that reducing tillage will be impractical in terms of weed control. This is not the overall conclusion of the current study. Weed populations were highly variable. The range of variation was great both within a tillage system and among them. Some conservation and no-till fields were very weedy; some were very clean. The same was true of conventional fields. The weed community reflects a combination of factors including the region, soil, cropping history, tillage history, and skill of the farm manager. The change from conventional tillage to conservation tillage or no-till did not lead to markedly different weed communities, at least not in terms of the weed community that remained after all control practices had been utilized. The residual weed community was largely unchanged, though final overall weed densities were somewhat larger with less tillage.

A few trends exist in the data. A farmer moving from conventional tillage to conservation tillage should be alert for a possible initial increase in the frequency of redroot pigweed, green foxtail and dandelion. Weeds such as field bindweed and common milkweed may be less problem than usual. Annual species are likely to occur in greater densities in first year conservation fields. Once conservation tillage is established, redroot pigweed and velvetleaf may be more frequent, while common ragweed, barnyard grass, field bindweed, common milkweed and quack grass may be less frequent. Many annual broad-leaved weeds may occur at higher density; dandelion and quack grass may occur at lower density. Again, most weeds will not change markedly.

A farmer moving from conventional tillage to no-till should be alert for the possibility of a small initial increase in the frequency of some annual weeds and of dandelion. Dandelion and quack grass are likely to occur in greater densities in first year no-till fields. Once no-till

is established, the density of these may decline below conventional levels. Many weeds may
occur at higher density; quack grass may occur at lower density. Again, weeds will not change markedly.

RECOMMENDATIONS FOR FURTHER RESEARCH

Further characterization of changes in weed community with changes in tillage would best involve experiments in which the wide range of management practices and environmental variables were under some degree of control. However, such studies would be of limited applicability. Perhaps the most appropriate scale for such studies would be that of individual farmers determining what is appropriate for them.

This study suggests changes in weed densities associated with conservation tillage and no-till. It does not indicate if these changes are important. It may be worthwhile to determine if yield loss due to weeds differs with tillage.

WEED PHENOLOGY IN RELATION TO TILLAGE PRACTICES

INTRODUCTION

Reduced tillage systems present an altered environment for weed growth and so may affect the rate of development of weed species. This in turn has implications for weed management practices which are geared to particular growth stages.

Changes in soil temperature, light penetration and water content will affect germination patterns. Soil disturbance stimulates germination of several species (Roberts and Potter 1980; Kells and Meggitt 1985). Germination is often more sporadic, and occurs over a longer period in the absence of tillage. Germination patterns may follow environmental factors such as rainfall, in the absence of larger cues such as tillage (Kells and Meggitt 1985). Buried seeds may show both extended and delayed periodicity of emergence (Froud-Williams *et al.* 1984).

Reduced mechanical damage will affect the rate of development of established plants. Perennials may mature more uniformly under no-till (Kells and Meggitt 1985). Perennials are likely to achieve maximum size, and to reproduce earlier in the season without the set-back of tillage. Tillage in the fall may increase the injury of perennials by freezing temperatures, and thus reduce the vigour of perennial weeds in conventional tillage systems (Schimming and Messersmith 1988).

Factors that affect the germination and early growth of annual weeds in reduced tillage systems may also affect crop plants. The cooler, moister seed bed may delay emergence of crop plants. Crop plants may be affected by previous crop and weed residues.

OBJECTIVES

The ability to control weeds by chemical, cultural or mechanical means is greatly dependent on the growth stage of both the crop and the weed. It is important therefore to examine the phenology, or development, of weeds and crops under reduced tillage systems. The objectives of the phenological study were as follows:

1. To determine the relative timing of important growth stages of major weeds in various tillage systems.
2. To determine the relative abundance of various growth stages of the major weeds in the various tillage systems.
3. To correlate the timing of growth stages with management practices.
4. To estimate the reproductive potential of important weeds in various tillage systems.

METHODS

Phenological monitoring was done in 7 counties (Huron, Perth, Lambton, Middlesex, Kent, Elgin and Essex), for weeds in 3 crops (corn, soybeans and winter wheat). The monitoring in corn and soybeans was conducted at 4 different times: May, prior to planting; June, prior to the application of post-emergent herbicides; July, after most control measures were complete; August, to examine weeds at maturity. Monitoring in winter wheat fields was conducted at the same times, though at different crop stages. A target of 9 fields per county was set. This was to include a no-till, a conservation till and a conventional till field for each crop. We attempted to locate fields that had been in each tillage type for several years. For the purposes here, we defined no-till as involving no tillage between the current and previous crops; conventional tillage to include an operation that caused soil inversion (eg. moldboard plow); and conservation tillage to include tillage other than inversion techniques. When several fields were available for sampling, fields were selected for uniformity.

Field sampling intensities were near to the targeted levels for soybeans and corn (Table 12). It was difficult to find conventional and conservation winter wheat fields. Presumably, this indicates that farmers have found the traditional levels of tillage unnecessary for this crop.

Table 12. The number of fields monitored for phenology in each county, crop and tillage system (nt = no-till, cs = conservation till, cv = conventional till).

	Corn			Soybeans			Winter Wheat		
County	cv	cs	nt	cv	cs	nt	cv	cs	nt
Essex	1	1	1	1	1	1	0	3	1
Kent	1	1	1	1	1	1	0	1	1
Lambton	2	1	1	1	1	1	1	0	1
Elgin	1	2	1	2	0	2	1	0	2
Middlesex	1	0	2	1	1	2	1	0	1
Huron	1	1	1	1	1	1	1	1	3
Perth	1	1	2	2	0	2	2	1	1

A total of 10 quadrats were considered in each field at each monitoring. These quadrats were systematically placed within the field, but no attempt was made to return to the same quadrat locations in subsequent monitorings. We determined the density of all weeds in the quadrats. For most species density is the number of individuals per square meter. For spreading perennials, density refers to the number of shoots. The height of one individual of each species in each quadrat was measured, and its reproductive state was recorded. Heights were considered important because herbicide recommendations are often based on height. Height is also an indication of competitive ability. The stage of the crop was recorded in five locations and averaged over each field.

Weed species lists for the different tillages were compared to each other and to the survey data. For the more common species, height and density measurements were examined using analysis of variance with tillage and time considered as the independent variables.

The targeted sampling intensity would have given 10 measurements per species per combination of county, crop and tillage, if each species occurred in each quadrat of each field. Realized sampling intensities were much lower. Even major weeds were absent from some fields, and from some quadrats in occurrence fields. Densities of species varied with county and from field to field within counties. This made it difficult to make direct comparisons over all of the variables. In an uncontrolled study, a great number of management practices differ among fields. There were many different factors that may have influenced weed behavior. It was not practical to consider them all as separate factors. Grand means for weed densities and heights over county and over crop suggest that these factors may be responsible for part of the variation, but it was felt that time and tillage were the more important variables.

Observations were taken of the reproductive state and reproductive output of each species. These varied tremendously among individuals of each species. It was felt therefore, that the behaviours of species were not well summarized by the means. These data were not subjected to statistical analyses.

RESULTS AND DISCUSSION

Crop stage

Crop stages were uniform across the different tillage systems (Table 13). Crop stage is determined not only by tillage, but by management practices other than tillage, such as date of seeding, and by other environmental differences. Samples within a county were selected to minimize environmental and management differences other than tillage type, but such differences did exist. Differences in the rate of development of the crops among tillage types may be discovered in more controlled environments.

Table 13. **Average growth stages of the crops in different tillage systems at the time of monitoring**

	Monitoring Period			
	1	2	3	4
Corn				
Conventional	pre-emergent	3 leaf	6 leaf	flowering
Conservation	pre-emergent	4 leaf	6 leaf	flowering
No-till	pre-emergent	4 leaf	7 leaf	flowering
Soybeans				
Conventional	pre-emergent	2 leaf	5 leaf	fruiting
Conservation	pre-emergent	2 leaf	5 leaf	fruiting
No-till	pre-emergent	2 leaf	6 leaf	fruiting
Winter Wheat				
Conventional	5 leaf	flowering	fruiting	harvested
Conservation	4 leaf	flowering	fruiting	harvested
No-till	4 leaf	flowering	fruiting	harvested

Weed Communities

The phenological study indicated that the same weed species were found in each tillage system (Table 14). Weed communities sampled for phenological study in July were quite similar to those sampled in the overall survey. The 10 most common species in the phenological study were all included among the 13 most common of the survey. Quack grass, dandelion, and crab grasses were somewhat less common in the phenological study; field bindweed and common milkweed were less common in the survey.

Weed communities differed more substantially among monitoring times. These differences are primarily the result of differences in the times of emergence of different species. There was no indication of a major reduction in the frequency of occurrence of weed species in the later monitoring periods, following the application of post-emergent chemicals.

Table 14. **Percentage frequency of occurrence of weed species in quadrats examined for phenological studies, compared by tillage. Only those species which occurred in greater than 1% of quadrats in any tillage are listed.**

Species	Conventional	Conservation	No-till
common ragweed	16	24	14
lamb's-quarters	20	13	15
annual smartweeds	5	9	7
redroot pigweed	8	8	11
velvetleaf	4	6	2
green foxtail	9	5	6
quack grass	9	4	5
clover species	1	4	2
wild buckwheat	3	4	5
barnyard grass	3	3	0
cocklebur	0	3	0
yellow nut sedge	1	2	0
common milkweed	1	2	4
yellow wood-sorrel	0	2	1
dandelion	1	1	7
field bindweed	8	1	5
wild mustard	2	1	1
crab grasses	2	1	0
common chickweed	1	1	3

Phenology of Selected Species

Only 11 species were encountered frequently enough at the various monitoring times and in each tillage to merit further investigation. These species were common ragweed, lamb's-quarters, redroot pigweed, annual smartweeds, green foxtail, quack grass, field bindweed, wild buckwheat, dandelion, velvetleaf and common milkweed. The densities, heights and timings of reproduction did not vary with tillage for lamb's-quarters, redroot pigweed or velvetleaf. The other 8 species are considered below, by crop and monitoring period.

Corn fields

Common ragweed, dandelion and quack grass were the only species encountered in any number at the May monitoring (Table 15). Annual smartweeds generally established in May and June; green foxtail in May to July. Field bindweed generally became established in June.

In May, common ragweed was most abundant in conventional tillage. This probably resulted from earlier emergence in conventional till. By June, the differences in density among tillages were reduced. The earlier establishment of ragweed in conventional field did not result in greater size by the June monitoring period. Although ragweed populations were similar in July, the ragweed growing in conservation fields were smaller, and less mature by the August monitoring. Ragweed had similar heights in conventional tillage and no-till, but they flowered somewhat earlier in no-till.

Annual smartweeds were slower to establish and to flower in no-till. They reached larger sizes and flowered earlier in conventional tillage. In conservation tillage they were intermediate in size, but did not flower in the samples.

Green foxtail emerged much earlier in conventional tillage than in conservation or no-till. Conventional fields had greater numbers of foxtail at each monitoring time, and generally had larger plants. In August, the green foxtail in conservation till fields were larger. In no-till, plants emerged later, but flowered somewhat earlier, at a smaller size. This would probably result in smaller seed production.

Common milkweed emerged after planting in all tillages. Plants were of similar densities in the different tillages. Plants in conventional tillage were shorter, and flowered earlier.

Table 15. Summary of data collected in corn fields for major weed species in each tillage type.

	Density (#/10 m^2)			Height (cm)			Flowering (%)		
	cv	cs	nt	cv	cs	nt	cv	cs	nt
May									
common ragweed	15	2	9	1	1	2	0	0	0
wild buckwheat	0	0	6	-	-	1	-	-	0
annual smartweeds	1	4	0	1	3	-	0	0	-
green foxtail	3	0	0	2	-	-	0	-	-
common milkweed	0	0	0	-	-	-	-	-	-
dandelion	0	1	1	-	9	7	-	0	25
field bindweed	0	0	1	-	-	2	-	-	0
quack grass	1	1	8	10	20	15	0	0	0
June									
common ragweed	14	11	7	4	6	5	0	0	0
wild buckwheat	1	0	1	32	-	0	0	-	0
annual smartweeds	3	3	8	9	11	5	0	0	0
green foxtail	1	0	0	9	-	-	0	-	-
common milkweed	2	1	3	6	26	21	0	0	0
dandelion	2	2	3	11	12	9	0	100	100
field bindweed	6	2	8	6	6	5	0	0	0
quack grass	5	3	2	20	24	16	0	0	20
July									
common ragweed	5	2	3	10	9	9	0	0	0
wild buckwheat	0	0	3	-	-	8	-	-	0
annual smartweeds	2	2	1	48	9	21	67	0	0
green foxtail	12	0	1	15	-	6	4	-	0
common milkweed	1	2	7	16	46	24	50	25	13
dandelion	1	2	3	11	23	12	2	33	17
field bindweed	7	2	1	31	17	6	7	0	0
quack grass	3	2	3	51	18	28	33	25	8
August									
common ragweed	5	5	4	24	11	23	33	0	80
wild buckwheat	0	0	0	-	-	-	-	-	-
annual smartweeds	1	2	1	51	27	15	0	0	100
green foxtail	10	4	8	28	42	19	57	57	82
common milkweed	1	2	1	20	35	43	0	0	100
dandelion	0	1	1	-	10	29	-	0	0
field bindweed	5	0	1	24	-	22	44	-	0
quack grass	2	2	2	60	36	38	100	100	100

In the May monitoring, dandelion was most abundant in no-till. By June the dandelion densities were approximately equal in each tillage. Although the dandelions established earlier in the no-till, the plants were of similar size in all tillages by the June monitoring. In conventional fields, dandelions generally did not grow substantially after June, did not flower, and did not survive the season. In conservation and no-till fields, plants did flower, and some survived the season.

Field bindweed plants were similar in all tillages in June. By July plants were larger in conventional than in no-till fields. Only plants in conventional fields flowered in the samples. Plants persisted longer in conventional fields.

Quack grass established earlier in no-till, but by June the plants in no-till fields were smaller than those in the other tillages. Plants were of similar densities in all tillages after May. They reached their largest sizes in conventional fields.

Soybean fields

Soybean fields had more weed growth than corn fields (Table 16). Weeds generally emerged earlier, attained a greater density, and a greater proportion flowered within the sampling period.

Common ragweed, wild buckwheat, annual smartweeds, dandelion and quack grass were common at the May monitoring. Green foxtail was beginning to establish at that time. Common milkweed and field bindweed were somewhat later.

In May, annual weeds were at similar densities and sizes in all tillages. Common ragweed was most abundant in conservation tillage and least abundant in no-till in May and June. By August, densities were equal in all tillage types, and all plants were flowering. Plants were somewhat larger in conservation tillage, and smaller in no-till. This parallels the early densities in the species, and may be associated with similar trends in seed production.

Table 16. Summary of data collected in soybean fields for major weed species in each tillage type.

	Density (#/10 m²)			Height (cm)			Flowering (%)		
	cv	cs	nt	cv	cs	nt	cv	cs	nt
<u>May</u>									
common ragweed	13	16	9	2	2	2	0	0	0
wild buckwheat	4	3	7	2	3	2	0	0	0
annual smartweeds	2	5	2	2	2	3	0	0	0
green foxtail	1	2	0	1	3	-	0	0	-
common milkweed	0	0	0	-	-	-	-	-	-
dandelion	0	2	8	-	7	6	-	67	14
field bindweed	0	0	0	-	-	-	-	-	-
quack grass	10	11	7	16	16	23	0	0	0
<u>June</u>									
common ragweed	9	12	4	6	9	4	0	0	0
wild buckwheat	2	2	6	8	2	4	0	0	0
annual smartweeds	4	0	2	10	-	6	0	-	0
green foxtail	3	4	2	5	16	4	0	0	0
common milkweed	1	0	3	6	-	23	0	-	12
dandelion	1	1	5	11	1	10	0	0	100
field bindweed	4	2	2	5	14	4	0	0	0
quack grass	5	2	2	24	22	22	0	0	25
<u>July</u>									
common ragweed	7	4	2	10	9	6	6	0	25
wild buckwheat	1	4	1	3	9	8	0	0	0
annual smartweeds	2	2	1	11	21	9	0	0	0
green foxtail	3	8	5	14	16	10	0	0	0
common milkweed	3	2	4	38	6	23	17	50	22
dandelion	0	0	6	-	-	13	-	-	36
field bindweed	4	0	4	5	-	8	0	-	11
quack grass	5	4	1	29	19	25	54	0	0
<u>August</u>									
common ragweed	5	5	5	33	37	29	100	100	100
wild buckwheat	0	1	0	-	5	-	0	-	-
annual smartweeds	1	1	1	24	6	14	0	100	100
green foxtail	8	10	1	45	41	60	100	100	100
common milkweed	1	1	2	40	102	40	100	100	100
dandelion	1	0	2	31	-	14	100	-	0
field bindweed	1	0	1	24	-	9	33	-	75
quack grass	2	2	1	48	71	40	100	100	100

Wild buckwheat plants were more abundant in no-till than in the other tillages early in the year. The plants did not become large or flower in any of the samples.

Green foxtail emerged later and grew more slowly early in the year in no-till fields than in other tillages. In all tillage types, plants grew substantially between the July and August monitorings. Plants grew most quickly, and achieved the greatest final size in no-till fields.

Common milkweed and field bindweed were not common enough in soybean fields for us to determine trends in their phenology.

Dandelions were consistently more abundant and flowered more often in no-till fields. Quack grass plants were larger in May in no-till, but by June plants in all tillage types were similar. Plants reached their largest sizes in August in the conservation fields.

Winter wheat fields

Winter wheat fields had greater numbers of annual weed species than did corn or soybean fields (Table 17).

Conventional fields were very clean in May, and had consistently fewer annual weeds than fields of the other tillage types throughout the season. Conventional fields had greater numbers of field bindweed at all monitorings, and these plants were larger in June and July, than in fields of other tillage types.

Conservation fields had consistently more annual weeds than did no-till fields. No-till had consistently more perennial weeds than did conservation fields.

Trends in size and timing are not consistent for annual species across tillage. Common milkweed and dandelion were not found in conventional fields. Field bindweed was more abundant and larger in conventional fields in June and July, than in other tillage types. This trend was not continued in August. Peak aboveground growth of quack grass was later in conservation tillage than in either conventional or no-till.

Table 17. Summary of data collected in winter wheat fields for major weed species in each tillage type.

	Density (#/10 m^2)			Height (cm)			Flowering (%)		
	cv	cs	nt	cv	cs	nt	cv	cs	nt
<u>May</u>									
common ragweed	0	24	12	-	2	2	-	0	0
wild buckwheat	1	8	3	3	10	6	0	0	0
annual smartweeds	0	5	1	-	9	3	-	0	0
green foxtail	0	2	0	-	2	-	-	0	-
common milkweed	0	0	0	-	-	-	-	-	-
dandelion	0	1	1	-	18	4	-	0	100
field bindweed	0	0	0	-	-	-	-	-	-
quack grass	0	0	0	-	-	-	-	-	-
<u>June</u>									
common ragweed	1	44	12	15	6	9	0	0	0
wild buckwheat	1	9	3	4	18	25	0	0	0
annual smartweeds	6	22	12	14	8	10	0	6	0
green foxtail	0	6	0	-	5	-	-	0	-
common milkweed	0	1	2	-	37	31	-	0	20
dandelion	0	1	2	-	15	21	-	0	100
field bindweed	9	0	7	23	-	19	0	9	0
quack grass	0	0	2	-	-	50	-	0	100
<u>July</u>									
common ragweed	1	31	12	4	12	16	0	0	0
wild buckwheat	1	5	2	55	53	56	0	0	33
annual smartweeds	2	11	10	15	16	18	0	6	8
green foxtail	1	1	7	6	4	23	0	0	0
common milkweed	0	2	2	-	43	50	-	33	100
dandelion	0	0	2	-	-	12	-	-	75
field bindweed	5	4	4	61	43	36	0	0	27
quack grass	1	1	3	80	32	91	0	100	100
<u>August</u>									
common ragweed	0	34	10	-	18	16	-	8	42
wild buckwheat	5	2	2	11	28	13	71	0	100
annual smartweeds	5	13	5	13	24	14	54	5	100
green foxtail	6	9	14	15	21	11	33	38	46
common milkweed	0	1	11	-	-	50	-	-	-
dandelion	0	1	2	-	25	13	-	0	33
field bindweed	3	1	2	17	25	19	0	0	0
quack grass	7	1	6	13	76	18	0	0	0

Herbicide use

Of the 11 species examined, only redroot pigweed showed a significant reduction in density following post-emergent herbicide application in June. For all species, there was a general increase in height from May to July. This suggests that the plants measured after post-emergent herbicide application survived the treatment, rather than emerged after it. This is surprising, and would indicate a lack of effect of the herbicide.

SUMMARY

Some species such as redroot pigweed, lamb's-quarters, and velvetleaf showed no differences among tillage systems. Trends in the other species were weak, but in general, the annuals (especially common ragweed and green foxtail) grew more quickly and the perennials (especially common milkweed and dandelion) grew more slowly in conventional tillage. For most species, little emergence of new individuals occurred after June, regardless of tillage.

Dandelion was the only species that showed strong trends in flowering over tillage. Dandelions flowered most often in no-till fields. Dandelions did not flower in conventional corn fields; they were not found in conventional winter wheat fields.

In corn, annual weeds reproduced somewhat earlier in no-till than either conservation or conventional tillage. In all tillages, it is likely that viable seed would be produced before harvest. Quack grass and common milkweed flowered in all tillages prior to harvest. Dandelion did not flower in conventional tillage; dandelion flowered early in the season in other tillages.

In soybeans, many of the weeds flowered. Most would continue to flower and produce seed until harvest, or beyond. For these plants, reproductive output was sufficiently variable to obscure trends among tillages.

Our samples did not include any flowering weeds in conventional winter wheat prior to harvest. Only perennial weeds flowered in any number in the other tillages in winter wheat prior to harvest. Perennials generally did not flower after harvest by the time of the August sampling period.

RECOMMENDATIONS FOR FURTHER RESEARCH

The variation in weed occurrence, and in farm management practices, made it difficult to determine if important differences in phenology existed in the weed communities examined, and impossible to separate causal factors. It was very difficult, and perhaps impractical, to try to get sufficient sample sizes to make these determinations. These questions might be more appropriately addressed with experiments at the research station level. If farm management practices other than tillage could be standardized, if plots were small enough to allow for similar environmental conditions among plots, and if starting weed communities were standardized, then the data may indicate meaningful trends.

An appropriate design for such an experiment should include intensive monitoring early and late in the season. Differences in the phenology are most important if they occur at times when control measures are applied, both early in the development of the crop, and between crops.

CHEMICAL CONTROL OF WEEDS IN RELATION TO TILLAGE PRACTICES

INTRODUCTION

Reduced tillage systems present an altered environment for herbicide-weed interactions. The trash that characterizes reduced tillage can have an effect on the efficacy of applied herbicides and on their persistence. Trash may intercept herbicides which would otherwise be applied to the soil surface. Rainfall soon after herbicide application may be necessary to move the chemical to the germinating seedlings (Witt 1984). The trash may prevent an even spread of chemical over the soil surface (Kells and Meggitt 1985). Koppatschek *et al.* (1989) found that the amount of metribuzin reaching the soil was less when applied to high levels of corn residue compared to low residue levels. However, they found corn residue level had no effect on weed control. There may be a weed suppressing effect of the trash itself, either allelopathic (Frisbie 1984), or as a result of its effect on the physical environment of weed seeds and seedlings. Johnson *et al.* (1989) found that surface corn residue helped control weeds, more than making up for any reduced soil reception of herbicide. Webber *et al.* (1987) found weed control least effective in conventional tillage.

Reduced tillage systems may also be characterized by a reduced soil pH, relative to conventional systems. This may be the result of the decomposition of the trash layer, or it may result from surface application of nitrogen fertilizer. Reduced pH can reduce herbicide efficacy (Kells and Meggitt 1985; Witt 1984), as can the increased organic matter content of the soil itself (Triplett 1985).

Herbicide efficacy is also determined by the nature of the weed community. Herbicides are less effective at high weed densities. Increased weed density in a given volume of soil can decrease the level of herbicide uptake (Triplett 1985). An increased herbicide use in reduced tillage is often reported. This may result in stronger selection pressures for weed biotypes resistant to particular herbicides, and thus reduce herbicide efficacy (Frisbie 1984). Increased herbicide use may also select for weed species or weed types such as perennials or annual grasses that are difficult to control (Witt 1984).

The growth stage that weeds are at can also affect chemical control. Perennial weeds may be more readily controlled under no-till, as they may mature more uniformly (Kells and Meggitt 1985). The germination of annual weeds may be more sporadic, reducing the proportion that are at an appropriate stage at the time of herbicide application (Kells and Meggitt 1985).

Although many factors can alter herbicide performance somewhat, there is not an overwhelming and consistent effect of tillage on chemical weed control. Johnson *et al.* (1989) reviewed several studies and found that some reported poor herbicidal weed control in reduced-tillage and no-tillage systems, some that found comparable weed control with preemergence herbicides in both reduced-tillage and moldboard plow tillage systems, and others indicated that increasing control was achieved by increasing trash. In most trials, tillage system did not influence weed control efficacy with preemergence herbicides. Similar conclusions were made by Witt (1984), Mills and Witt (1989) and Derksen (1990).

OBJECTIVES

Farmers are concerned that herbicide use may increase, or become less effective in reduced tillage systems. The objectives of the chemical study are as follows:

1. To examine herbicide use patterns in various tillage systems.
2. To determine the chemical control systems available for important weed species found in conservation tillage systems.
3. To determine the optimal weed and crop growth stages and environmental conditions for their application.

METHODS

Co-operators were questioned about herbicide use as part of the farm management questionnaire. Herbicide data are summarized in the current chapter and separately in Volume 2, by crop, tillage system, and the number of years that a tillage system had been used. Chemical control data were obtained from a review of the literature.

RESULTS AND DISCUSSION

A great diversity of herbicide use patterns was found (Tables 18 - 20, Volume 2). The chemicals used did not vary greatly with tillage or with time in a tillage. Two obvious exceptions to this are the decreased use of soil incorporated herbicides (such as ethalfluralin, trifluralin and EPTC) and the increased use of burndown treatments (such as glyphosate or 2,4-D) in no-till. Alternate formulations of soil incorporated herbicides may expand the range of options in no-till systems. Schreiber *et al.* (1987) claim that controlled release formulations of trifluralin may be used in no-till soybean production.

Table 18. Herbicide use in surveyed corn fields expressed as a percentage of all fields.

Type of application	Herbicide	Conventional	Conservation	No-till
Prior to planting[1]	Atrazine	27	27	23
	Glyphosate	11	16	33
	Metolachlor	9	11	7
	2,4-D or 2,4-DB	0	3	17
	EPTC	5	8	0
	All others	9	4	5
Preemergence	Metolachlor	37	36	47
	Dicamba	33	24	31
	Atrazine	12	19	15
	Cyanazine	8	7	13
	All others	4	5	15
Postemergence	Dicamba	12	27	25
	Atrazine	13	19	15
	2,4-D or 2,4-DB	3	13	16
	Bromoxynil	8	8	5
	MCPA or MCPB	5	5	4
	Cyanazine	1	5	5
	All others	4	10	4
Spot[2]	Glyphosate	4	6	35
	2,4-D or 2,4-DB	0	7	7
	Mecoprop	0	6	4
	Dicamba	0	6	4
	All others	5	6	8

[1] This category included previous fall, burndown, and preplant applications.

[2] Spot treatments included applications at all times of the year.

Table 19. Herbicide use in surveyed soybean fields expressed as a percentage of all fields.

Type of application	Herbicide	Conventional	Conservation	No-till
Prior to planting[1]	Glyphosate	6	11	36
	Metolachlor	18	22	10
	Metribuzin	20	17	14
	2,4-D or 2,4-DB	0	2	25
	Ethalfluralin	10	7	0
	Trifluralin	6	7	0
	All others	7	4	6
Preemergence	Metolachlor	46	36	42
	Linuron	31	31	31
	Metribuzin	38	25	25
	All others	4	4	10
Postemergence	Bentazon	18	19	18
	Sethoxydim	7	7	17
	Fenoxaprop-ethyl	4	5	4
	All others	8	7	10
Spot[2]	Glyphosate	15	14	32
	Bentazon	4	9	15
	All others	1	6	11

[1] This category included fall, burndown, and preplant applications.

[2] Spot treatments included applications at all times of the year.

Table 20. Herbicide use in surveyed winter wheat fields expressed as a percentage of all fields.

Type of application	Herbicide	Conventional	Conservation	No-till
Postemergence	MCPA or MCPB	33	36	24
	2,4-D or 2,4-DB	6	15	20
	Dicamba	0	8	2
	Mecoprop	0	8	0

More chemicals were applied per corn or soybean field in no-till than in either conventional or conservation tillage. This increase was very slight (Table 21). There was an increase in the percentage of herbicides in both conservation tillage and no-till that were applied as spot treatments.

Table 21. Herbicide use on fields of corn, soybean or winter wheat under conventional, conservation or no-till management.

	Corn			Soybean			Winter wheat		
	cv	cs	nt	cv	cs	nt	cv	cs	nt
Number of fields surveyed	75	96	75	70	80	73	18	59	46
Number of fields not treated	2	0	0	1	2	1	9	29	20
Mean number of herbicides used per treated field, excluding spot treatments	2.1	2.4	2.7	2.3	2.2	2.7	1.0	1.5	1.2
Mean number of spot treatments used per treated field	0.1	0.3	0.5	0.2	0.3	0.6	0	0.1	0.1
Percentage of the herbicides applied prior to planting [1]	29	23	26	27	31	30	22	6	23
applied preemergence	44	33	35	49	41	35	0	0	0
applied postemergence	23	32	22	16	16	16	78	87	70
applied as spot treatment	4	12	17	9	12	19	0	7	7

[1] This category included previous fall (corn and soybean only), burndown, and preplant applications.

Herbicide use patterns found here were similar to those found by Thomas *et al.* (1983) and Hamill and Thomas (1985) for Essex and Kent counties in the late 1970's. The earlier studies included very few no-till or conservation tillage fields. In corn crops, our data indicate greater use of dicamba and metolachlor and generally less use of 2,4-D. In soybeans, our data show less use of trifluralin (or ethalfluralin), and chloramben, and greater use of metribuzin, metolachlor, linuron and bentazon. Herbicide use in winter wheat was low in both studies.

The phenology study indicated that weed densities did not drop in the same season following postemergent herbicide application. This probably reflects a strong reliance on preemergent herbicides. The chemicals most commonly used in corn can be applied as either preemergent or postemergent treatments (atrazine, dicamba, metolachlor); while the chemicals most commonly used in soybeans are generally used as preemergent treatments (linuron, metribuzin, metolachlor).

Herbicide requirements

The weed species commonly encountered were the same in each tillage system (see Survey chapter). Crop stages were similar in each tillage system; weed stages were generally similar in each tillage system (see Phenology chapter). This suggests that herbicide requirements would be similar as well within a crop. Rates of preemergence herbicides may have to be increased slightly if they are tied up by high levels of residues. No-till systems have a requirement for burn-down herbicides before planting. At present only a very few herbicides are registered for such treatments.

The most abundant species were green foxtail, lamb's-quarters, quack grass, redroot pigweed, common ragweed, and dandelion. Yellow foxtail, common chickweed, crab grasses, quack grass, yellow nut sedge, volunteer winter wheat, fall panicum, giant foxtail and other grasses also occurred at high densities. Of these species, dandelion, field bindweed and annual grasses were especially problematic in reduced tillage fields, occurring in slightly greater percentages or at slightly higher densities.

Herbicide recommendations for major species

Herbicides are available for the control *of* most *of* the major weeds encountered in the survey (Anonymous 1990). The most commonly used corn herbicides (dicamba, metolachlor and atrazine) should give excellent control of most of the annual weeds (foxtails, lamb's-quarters, pigweeds, ragweeds, crab grasses and barnyard grass). In soybeans, metribuzin, metolachlor, linuron and bentazon should give excellent control of the same group of annual weeds. The recent registration of imazethapyr in soybeans gives further options for both pre and post emergence weed control. Glyphosate offers the opportunity of controlling perennials such as quack grass and field bindweed between crops, especially after winter wheat, although control of quack grass may be less effective if post-application tillage is eliminated. Bentazon can be used in either corn or soybeans to give some control *of* nut sedge, field bindweed and Canada thistle if applied at early growth stages. Treatments to control dandelion are not listed specifically.

Alterations of timing of herbicide application in reduced tillage

Herbicide use is limited to the time when both crop and weed are at specific growth stages. The phenological study indicated that growth stages of crops do not differ substantially among tillage systems, and thus would be unlikely to require alterations in herbicide use.

Some differences in weed emergence and growth rate may effect herbicide use. In corn, warm season annuals such as common ragweed, annual smartweeds and green foxtail emerged earlier in conventional tillage. The preferred chemical applications recommend treatment when the corn is very young (preemergence for metolachlor, preemergence to 1 leaf stage for atrazine, prior to 15 cm in height for dicamba, Anonymous 1990). Although all three chemicals have residual activity, the likelihood of weeds escaping control are greater with later emerging seedlings.

Differences in weed emergence with tillage were less pronounced in soybeans, but some reduction in herbicide efficacy is possible.

A majority of winter wheat fields received no chemical. Differential herbicide efficacy in this crop is therefore difficult to assess.

SUMMARY

There appear to be viable chemical options for weed control in reduced tillage systems. The only major exception is dandelion. Farmers would like to see a greater variety of herbicides registered for burn-down treatments.

RECOMMENDATIONS FOR FURTHER RESEARCH

Research results indicate that there may or may not be differences in herbicide efficacy with differences in tillage. Local testing would be needed to determine if a given herbicide offered adequate weed control under specific field conditions.

Dandelion is a concern for farmers who reduce tillage. There is a slight increase in dandelion in reduced tillage. Control recommendations are not in place. The perceived problem may be more important. Many of the farmers we talked to were concerned about dandelions in their fields.

SUSCEPTIBILITY OF WEEDS TO CONTROL BY TILLAGE

INTRODUCTION

Most conservation tillage systems other than strict no-till involve limited tillage. These tillage events may occur at different times and to different soil depths. Tillage operations, whether or not they are intended primarily for weed control, cause mechanical damage to weeds. Such damage may be sufficient to kill the weeds or may simply alter their phenology. The effectiveness of these tillage operations for weed control will depend on the growth stage of the weed species at the time of damage.

OBJECTIVES

1. To determine the effect of burial on the survival and germination or sprouting of propagules.
2. To determine the effect of mechanical damage at different developmental stages on the survival and phenology of the important weed species.
3. To determine the effects of damage resulting from various types or depths of tillage on weed survival and phenology.

METHODS

Tillage offers two types of soil disturbance that may be important to the performance of weed species: seeds and vegetative propagules are buried by inversion of the soil layer during plowing, generally in the autumn. Actively growing plants may be physically damaged or buried during secondary tillage operations in the spring and summer. Experiments were initiated to examine each type of disturbance.

Burial of propagules

We examined the effect of overwintering at different depths in the soil, on the dormancy and viability of plant propagules. We used all of the species that we were able to collect in sufficient numbers at the end of the survey in 1988 (late September to early October). Seeds of the following species were used: barnyard grass, broad-leaved plantain, Canada thistle, dandelion, fall panicum, giant foxtail, green foxtail, yellow foxtail, lamb's-quarters, large crab grass, common milkweed, black nightshade, common ragweed, redroot pigweed, lady's thumb, stinkweed, velvetleaf, wild buckwheat, and wild carrot. Dandelion roots, yellow nut sedge tubers and rhizomes of field bindweed and quack grass were also used.

Seeds and vegetative materials were stored at 4ºC until they were used. Samples were placed in fine mesh bags in 25 cm clay pots of soil and buried at the Ridge farm of the Harrow Agriculture Research Station on December 8. The bags were placed at the soil surface, or buried at a depth of 7.5 cm or 15 cm below the soil surface. The buried material was retrieved April 13, separated by burial depth and processed. Fresh samples of seeds and vegetative material were processed at the time of burial. Each sample contained 100 seeds, or approximately equal amounts vegetative material per sample (20 field bindweed or quack grass rhizomes, each 5 cm; 6 dandelion roots; 7 common milkweed roots; 20 yellow nut sedge tubers). Three replicates were assigned randomly to each treatment.

The seeds were set to germinate in a growth chamber with a 30/20ºC temperature regime and a 14 hour photoperiod. Germinated seedlings were tallied and removed 3 times per week. At the end of 10 weeks, viability of the remaining seeds was determined by squeezing the seeds with forceps. The viable number of seeds was the sum of those that germinated and those that were firm at the end of the experiment. The data were examined by analysis of variance of the arc-sine square-root of the percentage of germinated or viable seeds, separated by treatment and species.

Vegetative materials were planted in flats of soil and allowed to sprout in a greenhouse. These flats were maintained at a 30/20ºC temperature regime and a 14 h photoperiod. At the end of 4 weeks, the number of shoots were counted. These data were also examined by analysis of variance. In this and the following experiments, the probability level used to detect significant differences among treatments was 0.05.

Mechanical damage

We examined the responses of weeds of different ages to different types of mechanical damage. We selected 12 species, including the species that occurred in the greatest number of surveyed fields, and those whose life history or means of vegetative reproduction suggested that they may become important in reduced tillage systems. The following species were selected: green foxtail, lamb's-quarters, quack grass, field bindweed, redroot pigweed, common ragweed, dandelion, barnyard grass, common milkweed, yellow nut sedge, velvetleaf and wild carrot. Tumble pigweed was accidentally substituted for redroot pigweed. It is likely that the behavior of tumble pigweed is an accurate reflection of what would have been the response of redroot pigweed.

Annual species were grown from seeds. Quack grass and field bindweed were grown from rhizome cuttings; yellow nut sedge from tubers; dandelion, from root cuttings. Seedlings and transplanted cuttings were grown in large flats (approximately 60 cm x 90 cm x 50 cm deep) to allow underground development to proceed as "naturally" as possible. This is critical in an experiment that includes disturbance of plants below the soil surface. Each flat contained 3 to 4 replicates of each weed species, and a border row of Maple Arrow soybeans. Each flat received a single damage treatment.

Individual plants of the 12 different weed species received one of 4 treatments: roots were severed at approximately 2 cm below the surface; roots were severed at approximately

15 cm below the surface; roots were severed at approximately 15 cm below the surface, and the 15 cm soil plug was inverted approximately 135º; a control treatment was left undisturbed. These will be referred to as shallow, deep, inversion and control treatments. The treatments (other than the control) were applied at one of 5 times (2, 3, 4, 8 or 12 weeks) after planting.

Two types of data and analyses are presented. 1) The effect of the mechanical damage on plant survival was determined 10 weeks after each treatment, or for controls, at the end of the experiment. 2) Surviving plants were harvested at that time and separated into the following component parts: flowers and fruits; other aboveground tissues; roots; tubers or rhizomes. Plant parts were dried and weighed.

Analyses of variance were used to determine if differences existed among treatments in the percentage of plants that survived and biomass. Both factorial analyses ("tillage" x time) and one-way analyses were performed. Multiple contrasts and Tukey's multiple range tests were performed to characterize differences.

RESULTS AND DISCUSSION

Viability of buried propagules

Viability of seeds of most weed species did not decrease overwinter regardless of depth of burial. However, few seeds of large crabgrass survived the winter, and seeds of the perennial broadleaves Canada thistle, dandelion and common milkweed had decreased survival overwinter (Table 22). The increased viability of overwintered seed of common ragweed, lady's thumb and giant foxtail, relative to fresh seed, suggests that overwintered seed may be less likely to rot during imbibition than fresh seed in these species. Seeds of giant foxtail survived better when buried than when left on the soil surface overwinter. Seeds of the perennial broadleaves, and to a lesser extent large crab grass, showed the opposite trend.

Table 22 Percentage viability of seeds of weed species following various burial treatments (mean ± standard error; only species with significant differences among treatments are shown).

Species	Fresh	Overwintered Depth of Burial		
		0 cm	7.5 cm	15 cm
Annual broadleaves				
Common ragweed	77 ± 8	97 ± 2	95 ± 3	92 ± 3
Lady's thumb	82 ± 1	90 ± 3	94 ± 3	92 ± 1
Annual grasses	87 ± 3	55 ± 13	98 ± 1	95 ± 2
Giant foxtail				
Large crab grass	61 ± 2	4 ± 1	6 ± 4	0 ± 0
Perennial broadleaves	82 ± 7	62 ± 3	46 ± 10	49 ± 9
Canada thistle				
Dandelion	74 ± 2	32 ± 6	38 ± 4	14 ± 7
Common milkweed	96 ± 1	65 ± 1	61 ±1	45 ± 10

Germination of buried propagules

The ability to germinate increased over the winter for most annual species, suggesting that fresh seeds were dormant or required an after ripening period (Table 23). Exceptions to this were large crab grass and stinkweed. Percentage germination also increased for common milkweed and broad-leaved plantain after the winter treatment but decreased for Canada thistle and dandelion.

Giant foxtail and wild buckwheat had greater germination after burial than after the surface treatment. The opposite trend was seen for yellow foxtail, barnyard grass, and redroot pigweed. Burial reduced germination for most perennial broadleaved species.

Table 23. Percentage germination of seeds of weed species following various burial treatments (mean ± standard error; only species with significant differences among treatments are shown).

Species	Fresh	Overwintered Depth of Burial		
		0 cm	7.5 cm	15 cm
Annual grasses				
Giant foxtail	0 ± 0	24 ± 8	74 ± 6	77 ± 11
Yellow foxtail	0 ± 0	19 ± 6	10 ± 4	5 ± 3
Large crab grass	9 ± 0.3	4 ± 1	5 ± 4	0 ± 0
Barnyard grass	2 ± 1	65 ± 8	49 ± 11	26 ± 10
Annual broadleaves				
Common ragweed	37 ± 3	93 ± 4	95 ± 3	92 ± 3
Lamb's-quarters	24 ± 3	45 ± 1	53 ± 8	30 ± 4
Redroot pigweed	64 ± 12	87 ± 5	39 ± 13	8 ± 4
Wild buckwheat	2 ± 1	15 ± 8	14 ± 3	27 ± 2
Stinkweed	89 ± 3	46 ± 2	50 ± 12	49 ± 14
Perennial broadleaves				
Canada thistle	72 ± 5	61 ± 4	42 ± 6	49 ± 9
Dandelion	70 ± 4	32 ± 6	33 ± 6	13 ± 8
Common milkweed	4 ± 1	63 ± 1	60 ± 0.3	40 ± 12
Broad-leaved plantain	44 ± 6	83 ± 3	74 ± 6	83 ± 5

Sprouting of buried propagules

Quack grass rhizomes produced the same number of shoots regardless of the depth of burial, and survival was not reduced over the winter (data not shown). Field bindweed rhizomes, did not survive the winter well, regardless of depth of burial (Table 24), although there was a trend toward increased survival with greater depth of burial. Dandelion and milkweed roots and yellow nut sedge tubers also showed greater overwinter survival with greater depths of burial. Most species had very poor survival when left to overwinter on the soil surface. This may point to a control method for these perennial species.

Table 24. **Number of sprouts from vegetative material (roots, rhizomes or tubers) of perennial weed species following burial treatments (mean ± standard error; only species with significant differences among treatments have been indicated).**

Species	Fresh	Overwintered Depth of Burial		
		0 cm	7.5 cm	15 cm
Dandelion	13 ± 3	0 ± 0	7 ± 0.6	10 ± 0.7
Field bindweed	20 ± 3	0 ± 0	1 ± 0.3	2 ± 0.9
Common milkweed	0 ± 0	0 ± 0	4 ± 0.3	4 ± 0.6
Yellow nut sedge	63 ± 1	1 ±0.7	33 ± 16	67 ± 4

Survival after mechanical damage

A few species (field bindweed, dandelion, tumble pigweed) were difficult to grow in the greenhouse and had relatively low survival even under undisturbed conditions. The overall survival of field bindweed was so low it could not be included in the analyses.

Survival of annuals after damage was generally less than perennials (Tables 25 and 26). The timing of tillage treatments did not have an effect on the survival of annuals. Annual

Table 25. **Percentage survival of annual species 10 weeks after various "tillage" treatments (Treatments that were not significantly different have been combined).**

Species	Control	Deep	Shallow \ Inversion
Annual grasses			
Barnyard grass	100	51	25
Green foxtail	90	30	22
Annual broadleaves			
Common ragweed	100	63	23
Red-root pigweed	60	19	10
Lamb's quarters	100	70	42
Velvetleaf	100	37	15

plants were vulnerable to damage at all stages. All of the mechanical damage treatments reduced the survival of annuals compared to undisturbed plants, but more so with shallow cutting or inversion than with deep cutting.

Table 26. Percentage survival of perennial species 10 weeks after various "tillage" treatments (Treatments that were not significantly different have been combined.

Species	Control	Deep	Shallow / Inversion Weeks after planting				
			2	3	4	8	12
Perennial grasses							
Quack grass	95	60	60	30	25	75	74
Yellow nut sedge	100	97	95	45	60	80	95
Perennial broadleaves							
Wild carrot	85	53	40	10	20	55	30
Common milkweed	100	57	45	15	5	70	60
Dandelion	67	62	60	20	9	47	47

The deep cutting treatment involved severing roots at 15 cm. This would have little effect on plants that had not reached that depth. The reduction in survival associated with this treatment for all annual species suggests that they either were deeply rooted in the flats, or that the disturbance had other effects. The treatment loosened the soil, and may have physically damaged root hairs, or it may have caused the soil to dry sufficiently to cause damage. The lack of effect of timing may suggest that root development was rapid, and did not change from 4 to 12 weeks. More likely, it suggests that the damage to plants was from factors other than root severing.

The shallow and inversion treatments were equally damaging to annual species. The shallow treatment involved severing roots at 2 cm below the soil surface. It is surprising that any annuals survived this treatment. The inversion treatment may have damaged plants by loosening the soil, as was suggested for the deep treatment. The greater severity of the inversion treatment relative to the deep treatment reflects the difficulty associated with burial.

Percentage survival of perennials was highest in undisturbed controls, and lowest after shallow cutting or inversion (Table 26). For yellow nut sedge and dandelion, the deep treatment caused very little mortality. The survival of yellow nut sedge did not always indicate survival of the parent shoot. Apparently, the vulnerability of the parent shoot was balanced by the production of daughter tubers. Dandelion may have been primarily exploiting initial reserves, rather than establishing (vulnerable) new root material.

The timing of shallow cutting and inversion treatments did affect survival of perennials. Percentage survival was least for these treatments if the treatment occurred 3 or 4 weeks after planting. The importance of timing of these treatments probably reflects the fact that cuttings or tubers were used instead of seeds. For very early treatments (i.e., at 2 weeks), plants survived burial or root pruning by utilizing reserves in the initial planting material. Percentage survival was less after 3 or 4 weeks, probably because reserves had been used up, and not yet replenished. Presumably after 8 or 12 weeks, reserves had again built up.

Biomass was determined for plants that survived for 10 weeks after treatment. For untreated controls, biomass was determined for survivors at the termination of the experiment (22 wks after planting). Greenhouse space was not sufficient to allow a destructive sample of control plants at the harvest of each treatment.

In general, for annual plants, biomass was reduced only after shallow cutting at 2 wk after planting. Other treatments did not significantly reduce the biomass of surviving plants. For perennials, the undisturbed control plants were generally intermediate in biomass. Shallow cutting at an early stage reduced the biomass the most. Treatments at later times stimulated biomass production, especially for dandelion, quack grass and yellow nut sedge (Table 27).

Table 27. Total biomass (g) of dandelion, quack grass, and yellow nut sedge plants at harvest (mean ± standard error).

Species	Dandelion	Quack grass	Yellow nut sedge
Time of treatment			
Control	2 ± 2	4 ± 3	8 ± 6
2 weeks	0.6 ± 0.6	1 ± 1	4 ± 2
3 weeks	1 ± 1	2 ± 2	1 ± 1
4 weeks	1 ± 0.3	1 ± 0.3	5 ± 1
8 weeks	8 ± 7	6 ± 4	15 ± 15
12 weeks	4 ± 4	8 ± 4	35 ± 48

SUMMARY

The effects of the simulated "tillage" treatments varied with weed species and developmental stage. Autumn burial generally decreased the survival of seeds of perennial species but not of seeds of annual species, with the exception of large crab grass. Vegetative propagules from perennial roots or rhizomes generally survived better when buried than when left on the soil surface where they were exposed to drying and freezing temperatures. Inversion of the soil would bring some vegetative propagules to the surface. This reduced the viability of all perennial propagules tested under experimental conditions. Inversion would bury newly produced seeds, and move buried seeds to the surface. Experimental results suggest that this would delay rather than prevent the germination of most annual species.

Actively growing annual weeds were vulnerable to damage from cultivation at all growth stages. There was some indication that early damage treatments reduced growth rate and biomass of survivors more than later treatments, but this trend was weak.

The developmental stage of the plant at the time of tillage was more important in the control of perennial weeds. Actively growing perennials (especially quack grass, dandelion and yellow nut sedge) were only vulnerable to damage for a short period of time. Treatments at other times were less effective at reducing survival, and stimulated growth rate and final biomass of the survivors. Under these experimental conditions, plants were most sensitive to damage at 3 or 4 weeks after the roots or rhizome had resumed growth. This period probably corresponds to the time when parental reserves are depleted, and vegetative propagules are not yet sufficiently mature to survive independently.

The deep cutting treatments (cut at 15 cm below the soil surface) were intended to simulate the effect of tillage with a device similar to a Noble blade cultivator. These treatments were least effective at reducing survival of the weeds. Although the treatment involved root pruning, the effectiveness of the treatment on some young annual plants with short roots suggests that this may not have been the most destructive aspect of the" treatment. Perhaps the deep treatments would have been more effective if the soil had been allowed to dry out even longer. (Plants were watered daily, except on the day following treatments.) It is likely that the effectiveness of non-inversion tillage in the field is largely dependent on weather.

Shallow cutting treatments simulated shallow tillage with harrow, cultivator, disk, etc. Inversion treatments simulated moldboard plowing. Both were equally effective in reducing survival of actively growing weeds. Shallow cutting treatments caused greater reduction of biomass of surviving annual plants than either deep cutting or inversion.

RECOMMENDATIONS FOR FURTHER RESEARCH

The results presented here are limited mainly by questions of applicability of greenhouse studies to field situations. The question is one of whether, and how well, the treatments simulate tillage in terms of the damage caused to plants. The answer to the question probably depends on environmental variables -- temperature and soil moisture conditions at the time of tillage.

The major conclusions of the study are clear: perennials are most vulnerable at certain developmental stages when the root reserves are lowest; some forms of mechanical damage are more damaging than others. Further examination of these conclusions might be best approached with different sorts of experiments.

Comparisons of the vulnerability of perennials to mechanical damage would be appropriate. This might best be approached in a field setting, or using established plants, and considering single versus repeated treatments.

Further comparisons of tillage methods should consider the effect of environmental conditions. For instance, the timing of precipitation relative to tillage may be of major significance.

CONCLUSIONS

IDENTIFICATION OF PROBLEM WEEDS

Weed communities were a reflection of many variables, both in terms of farm management (crop, rotation, tillage) and in terms of extrinsic environment (geographic region, soil). The survey results presented here indicate that conservation tillage and no-till systems have weed communities that are qualitatively similar to those in conventional tillage systems. The reduction of tillage did not necessarily lead to more difficult weed problems. Overall, weeds that were a problem in one tillage system were a problem in them all.

CHANGES IN WEED PHENOLOGY

The timing of weed emergence was not different in different tillage systems, for most species. Some annual weeds, especially the warm season species like green foxtail and common ragweed, were slower to emerge in no-till than in conventional tillage. Growth rates and timing of reproduction were not markedly different in the different tillage systems. There was some evidence of more uniform development of perennials in no-till fields as compared to conventional fields, which may lead to better control of these weeds with herbicides.

CHEMICAL CONTROL

No-till management systems used slightly more herbicide overall, were more likely to include a chemical burndown treatment, more likely to include spot treatments, and less likely to use soil incorporated herbicides. There were no other marked differences among tillage systems in herbicide use. The literature on herbicide efficacy in reduced tillage systems is not conclusive. As similar stages of the same weeds exist in each tillage system, similar levels of chemical weed control can be expected, at least as a first approximation.

EFFECTS OF TILLAGE ON WEEDS

Burial of weed seeds may favour annual over perennial species. Vegetative propagules of perennial species are less likely to survive if brought to the surface. Actively growing perennial species were susceptible to tillage as a control mechanism only over relatively short periods. They may be most susceptible when parental reserves are depleted but before propagules are mature.

EXACERBATED WEED PROBLEMS

This study does not indicate that reduced tillage systems necessarily result in exacerbated weed problems. Weed communities were highly variable in all tillage systems. The tillage system was not a single over-riding factor in determining the intensity of weed problems; many management factors are involved in determining weed communities. As in all farming systems, weed problems in conservation tillage or no-till require management. Successful weed management is possible in reduced tillage systems.

WEED MANAGEMENT STRATEGY FOR CONSERVATION TILLAGE

The results presented here show that weed communities were not substantially different in different tillage systems. Weed communities differed from field to field. They were influenced by region, soil type and by a variety of management practices. Weed management strategies need to consider this diversity. A strategy designed for conservation tillage in general is inappropriate if weed communities are not primarily a reflection of tillage practices.

The optimal weed management strategy would be individualized to field conditions. It is important to consider the distribution pattern of weeds to determine what the likely weed species will be. The weed history of a field is especially important. Ideally, a field going into reduced tillage should be relatively clean to start. It is then important to scout the field regularly to determine which species are becoming a problem, and to determine the intensity of each problem. Weed control tactics should be determined on the basis of this information.

The perception that weed management is more difficult in reduced tillage needs to be challenged. Reduced tillage, and especially no-till offer opportunities for improved weed management as well as challenges to established techniques. In no-till, weed seeds that enter a field remain on or near the soil surface. They do not contribute to a dormant seed bank to nearly the extent that they would if buried. In no-till, buried weed seeds are not returned to the surface to renew the weed plant populations. With fewer inputs to the seed bank, and fewer returns from the seed bank, weed problems become more of a reflection of current practices and less an accumulation of previous problems. Initial increases in the soil seed bank. If the seed set of these weeds can be minimized, this can be viewed as an opportunity to finally get these species under control.

Reduced tillage also offers advantages in dealing with perennial species that spread by fragmentation. Quack grass is a classic example. Cultivation can spread quack grass throughout a field. In the absence of cultivation, quack grass forms localized patches that are more amenable to spot treatment.

The cooler, moister soils of reduced tillage may offer an advantage in dealing with warm-season weeds. The phenology study indicated that some weed species may have later emergence in no-till, while crop stages were not substantially affected. If the crop can establish, and especially if it can close the leaf canopy earlier relative to the weed, weed emergence and growth may be reduced. This suppression of the weed by the crop may give a competitive advantage to the crop, and reduce the need for other means of weed control.

Standing stubble may present some difficulties in reduced tillage because of its ability to trap wind-dispersed seeds. This effect could be minimized by assuring that such weeds in headlands and roadsides were not allowed to go to seed. There may be advantage in situating shelterbelts in the path of prevailing winds, or in leaving higher stubble in those areas to trap seeds and prevent their dispersal into the field.

The increase in wind-dispersed species is often perceived as greater than it is. Because seeds are trapped by stubble as they blow into a field, the headlands often have far higher densities of dandelion, for instance, than the field overall. Individuals who scout the field from the roadways, or who do not venture too far into the field may find exaggerated infestation levels.

The generalized use, in all tillage systems, of pre-plant and preemergent herbicides with long-term residual activity (eg. several weeks) suggests that weed management is often in
anticipation of weed problems rather than in response to them. It would probably be a useful exercise to leave a check strip in a crop untreated. This would allow the farm manager to

determine if the chemical control was effective, and if the herbicide program should be altered to achieve the desired goals.

Weed management is necessary in all tillage systems. Reduced tillage systems in southwestern Ontario include a wide range of weed management practices. As in conventional tillage systems, some are very good and some are not. Reducing tillage, like other changes in farm practice, requires a period of learning and adjustment. Optimal weed control during this period may require a greater intensity of management, or greater management skill. There may be additional challenges; there may be greater opportunities. Successful weed management is possible.

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