OPTIMAL HERBICIDE USE IN CONSERVATION TILLAGE SYSTEMS

A Research Report

Presented to

The Technology and Development Sub Program

of

The Soil and Water Environment Enhancement Program

by

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In fulfilment of requirements

for ted contract 01686-7-0286

March, 1991

ATTENTION

THE HERBICIDE RECOMMENDATIONS MADE IN THIS REPORT DO NOT NECESSARILY REPRESENT REGISTERED TREATMENTS FOR USE IN **ONTARIO**. THESE RECOMMENDATIONS ARE ONLY FOR RESEARCH PURPOSES AT THIS TIME.

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ACKNOWLEDGEMENTS

The authors express their gratitude to the Technology Evaluation and Development (TED) sub-program of the Soil and Water Environmental Enhancement Programme (SWEEP) for their financial support. The financial management of Mr. D.W. Taylor, Director, Ridgetown College of Agricultural Technology is also gratefully acknowledged.

The authors express their appreciation to Mr. R.H. Brown for his numerous contributions to this project.

The Authors also wishes to thank Mr. Dave Bilyae, Kevin Chandler, Bob Stone and all summer students who helped in conducting field experiments. The valuable research by graduate students Mr. Godwin Aflakpui, Allen Eadie and Mike Walker towards various objectives in this project is also highly appreciated. The authors also thank Mr. Don Lobb, Art Wardle, Jack Rigby, Al and Paul Jones who provided land and helpful comments in order to ensure the applicability of the experiments to the on-farm situations.

The authors also sincerely acknowledge Dr. A. Weersink for his supervision of Mr. Mike Walker's research and thesis writing.

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EXECUTIVE SUMMARY

The goal of this study was to develop weed control recommendations for farmers utilizing conservation tillage systems. Efforts were directed towards optimizing herbicide selection, dosage and timing of application in order to achieve effective weed control. Moreover, research was also conducted to optimize herbicide inputs by developing an integrated weed management system for no-till corn. An economic and risk management study of weed control measures was also completed.

The results of this study will provide weed control and specific crop recommendations for farmers using conservation tillage. This information will facilitate the acceptance of conservation tillage practices within the Ontario farming community.

Field experiments were conducted from 1987 to 1990 to address the specific objective outlined in this report. Our findings included:

1. Currently recommended herbicides and herbicide combinations provided excellent broad-spectrum weed control in all tillage systems tested.
2. Control of weeds in conservation tillage systems did not require higher dosages of herbicides despite the presence of crop residue on the soil surface.
3. Perennial weeds can be effectively controlled and should not pose a significant threat to successful crop production in conservation tillage systems.
4. The integration of banded herbicide applications, inter-row cultivation and reduced herbicide dosage can be integrated as a weed control alternative for no-till corn . Adoption

of these practices can reduce the total amount of herbicide applied into the environment by 60%.

5. An economic comparison of alternative tillage systems and weed control practices among various tillage systems was completed. Optimum preemergence herbicide applications were identified for both corn and soybeans grown under four different tillage systems. The reductions in labour associated with the reduced tillage systems indicated that labour cost were reduced by up to 61% annually when compared with an conventional tillage systems. This saving in labour was illustrated as an opportunity cost associated with reduced tillage systems on sandy soils. A sensitivity analysis between moldboard plough and no-till indicated that no-till will dominate in risk preferring intervals, and an increase in no-till net farm returns of \$ 40 ha^{-1} would change dominance in favour of no-till among risk averse individuals. It is possible for conservation tillage systems to dominate conventional tillage systems, if proper weed control and crop production techniques are undertaken.

1.0 INTRODUCTION

Tillage has been used for centuries to prepare fields for cropping. Perhaps the most important reason for tillage is for the preparation of a vegetation-free seedbed at planting. However, this seedbed preparation exposes the soil to wind and water erosion.

A recent study in the Thames River basin in Ontario, Canada, indicated that up to 95% of total nitrogen and 74% of the phosphorus found in the Thames river came from various diffuse source inputs, especially agricultural farmland (Anonymous 1975). Most of these nutrients are strongly attached to the soil particles. Their movement beyond farm boundaries was mainly attributed to the eroded soil particles. In Ontario, total annual losses due to soil erosion were estimated to be $74 million (Wall and Driver 1982). These costs do not include the off-site effects on society. Measurement of off-site erosion effects is very difficult to accomplish because it involves a number of commodities for which price is not available. However, Fox and Dickson (1990) attempted to provide a dollar value to some of these off-site losses in southern Ontario. In their conservative estimation, the cost for sediments removal from public water supplies alone was around $10.2 million. They also estimated that total benefits to sport fishing of $35 million if all of the excess sedimentation of lakes and rivers in southern Ontario is removed. Such issues are of major concern to the agriculturalists, to the government and public in Canada. These issues have led research workers to try alternative crop production systems.

It is now well established that extensive tillage practices are not a pre-requisite for crop establishment. Recent advances in crop seeding with minimum soil disturbances and maintaining a vegetation-free seedbed using herbicides opened a new avenue for successful crop production with reduced erosions from farmers' fields. In this ongoing review, an attempt has been made to define various conservation tillage systems employed in Ontario and their respective weed management strategies.

Conservation tillage in Ontario has taken three main directions, minimum-till, ridge-till and no-till. Minimum-tillage systems encompass several variations in tillage practices. Tillage, prior to planting occurs even though the seedbed is left rough and covered to some degree by previous crop residue. In this system weed control methods are very similar to those of conventional tillage. Early weed suppression and crop establishment is enhanced by tillage prior to planting. Since tillage is still an important component of the weed control system, the weed spectrum is usually not changed drastically from what exists in the conventional system. The major difference between minimum-till and conventional-till is the presence of previous crop residue. In minimum-tillage systems large amounts of crop residue may interfere with good incorporation of herbicides. Soil type, amount and type of crop residue, and incorporation equipment available determines the feasibility of the preplant incorporation method of chemical weed control. If good herbicide incorporation cannot be achieved, the grower is limited to preemergence and postemergence herbicide treatments. Crop residue, if plentiful may also intercept large percentages of soil surface applied herbicides and prevent them from being activated in the soil where they perform the function of destroying weed seedlings. Research in this area indicates that normal rainfall washed herbicides off crop residues and into the soil where they work. There is evidence in the literature that allelopathic chemicals produced in decaying crop residue interfere with seedling growth and may contribute significantly to weed control. Our research does not address these concepts. Basically, weed control in minimum-tillage is very similar to that of conventional-tillage.

In ridge-till systems, when the basic ridge-till concepts are adhered to, early weed suppression and crop establishment is enhanced by tillage during planting. The aggressive cultivation and ridging procedure that follow provide a great deal of mechanical weed control. This system is well suited to broadcast or band applications of preemergent or postemergent herbicides. Weed control in this system requires the least amount of herbicide of any system provided seeding, cultivation and re-ridging are timely and equipment is properly adjusted. If weed problems develop, they usually begin in the side of the ridges where perennial weeds like dandelion gain a foothold. Moreover, if seeding is delayed in the spring, winter annual and perennial weeds that grow rapidly early in the spring, may be a problem. Fall application of herbicides, while these weeds are still actively growing, may be a practical approach to their control.

If a grower chooses to go the no-till route, he faces the toughest challenge in weed control. In this system, the farmer is depending entirely on herbicides to provide early weed control as well as control of those weeds that emerge later after initial burndown. Because there is very little soil disturbance, weeds that are characteristic to conventional tillage do not thrive and other weeds, particularly perennials, may become the problem weeds. Weed emergence patterns are also very different under no-till conditions. The herbicides available are fairly well understood in conventional conditions, but they may perform quite differently when imposed into a no-till condition with large amounts of crop residue and a very different and diverse weed spectrum.

Much of what is learned about individual herbicide performance, tank mixes, and sequential herbicide applications in no-till, will also apply to the other forms of conservation tillage. Thus, our approach to weed control in conservation tillage has been to work primarily with no-till hoping that knowledge gained can have direct application to ridge-till and minimum-till systems.

Our main efforts have been directed at evaluating herbicides, herbicide tank-mixtures and sequential treatments, currently being used in conventional-till systems for their suitability in no-till system. Many of the herbicides being evaluated are currently registered for use in conventional production systems and may require slight label modifications for use in conservation-tillage systems. Growers prefer to make as few trips across their fields as possible and are anxious to combine burndown and residual herbicide treatments into one applications. Our aim has been to evaluate this concept from the point-of-view of cost, efficacy, and crop safety. Therefore, the objectives of this study were to determine:

1. the effectiveness of various herbicides for burndown of cover crops tank-mixed with residual preemergence herbicides for annual weed control in corn and soybeans.
2. the interaction (antagonism) of various burndown herbicides tank-mixed with residual preemergence herbicides for annual weed control in corn and soybeans grown in various conservation tillage systems.
3. the effect of various additives on the burndown effects of tank-mixes of herbicides in conservation tillage in a corn and soybeans crop.
4. the benefits of fall application of herbicides for control of weeds in a corn and soybeans crop grown in a minimum tillage system[†].
5. the various aspects of an integrated weed management in no-till cropping system.
6. the cost/benefit ratio and associated risk of weed control strategies under various tillage systems.

[†] Two experiments were conducted under objective 4 and are being summarized as experiment 3.6 on page 24 and experiment 5.7 on page 98.

2.0 WEATHER DATA

Table 1. Average monthly rainfall accumulation in 1987, 1988, 1989 and 1990 at Dealtown Research Station.

		Precipitation			
	1987	1988	1989	1990	10 year average
	mm				
April	59.0	45.5	45.6	44.1	81.2
May	4.8	45.3	132.6	71.0	73.3
June	53.0	15.0	89.0	47.0	81.4
July	72.7	65.8	35.0	93.0	85.1
August	234.6	78.5	90.1	145.2	98.9
September	126.8	74.5	49.2	123.4	84.6
October	68.4	108.0	63.2	64.0	57.0

Table 2. Average daily temperature in 1987, 1988, 1989 and 1990 at Dealtown Research Station.

	Temperature			
	1987	1988	1989	1990
	EC			
April	10.0	8.0	6.5	9.6
May	16.3	16.0	13.0	12.7
June	21.5	20.0	18.5	19.4
July	22.8	24.0	22.2	21.4
August	20.5	23.0	20.7	20.5
September	19.3	17.0	16.5	16.3
October	8.5	8.0	11.5	10.8

Table 3. Average monthly rainfall accumulation in 1986, 1987 and 1988 at Elora Research Station, and in 1988 and 1989 at Woodstock Research Station.

	Precipitation					
	Elora		Woodstock			10 year
	1986	1987	1988	1988	1989	average
	mm					
April	62.3	44.6	68.2	54.4	56.8	70.2
May	78.6	44.2	41.8	60.4	65.4	77.6
June	135.0	78.2	22.8	5.8	60.6	86.9
July	84.6	130.4	101.3	149.8	-	73.0
August 158.6	81.6	52.1	71.5	67.2	72.1	
September	133.8	71.2	93.1	60.6	40.0	71.3
October	77.6	79.4	66.3	127.0	79.1	66.3

Table 4. Average daily temperature in 1986, 1987 and 1988 at Elora Research Station, and in 1988 and 1989 at Woodstock Research Station.

	Temperature					
	Elora		Woodstock	10 year		
	1986	1987	1988	1988	1989	average
	EC					
April	7.3	7.9	5.0	6.1	4.7	10.2
May	13.6	13.8	13.2	14.2	13.1	11.3
June	15.6	18.4	17.0	17.7	18.6	17.1
July	19.4	20.3	21.3	22.1	-	19.1
August 17.0	18.0	19.6	21.2	19.4	18.1	
September	13.7	14.3	13.7	15.3	15.5	14.4
October	8.2	6.0	5.6	6.4	9.3	8.5

OBJECTIVE # 1

3.0 BURNDOWN AND RESIDUAL HERBICIDES FOR LEGUME AND CEREAL COVER CROP PLANTED TO CORN AND SOYBEANS

Over the past 20 years in Ontario, there has been an increase in the land area devoted to monoculture, particularly under row crops such as corn and soybeans (Anonymous, 1989). The high cost of land during the mid 70's to early mid 80's and good commodity prices contributed to the increased production of row crops. This monoculture cropping system increased the soil water erosion losses (Dickinson et al. 1975), lowered soil organic matter content and impaired soil physical properties such as porosity and stable aggregation (Ketcheson and Webber, 1978). Therefore, to control soil degradation and thereby improve the productivity of agricultural land in Ontario, there is a need to re-emphasize cropping management options. Some of these cropping management options are adopting reduced or conservation tillage systems and/or covering the soil during critical erosion periods with cover crops.

Cover crops offer scope for crop rotation and at the same time provides an organic mulch cover during the time of year when crops cannot be grown. The cover crop under a no-till cropping system may be of further advantage. They may accelerate water losses from no-till fields by means of evapo-transpiration and thereby increase soil temperature to facilitate timely crop sowing. However, cover crops may also have a negative impact; they may be difficult to control and thus compete with the primary crop for available resources such as nutrients, water and space.

It was hypothesized that cover crops under a no-till cropping system may facilitate weed control and provide additional organic matter to the soil. With proper herbicide selection and timing of application, cover crops could be controlled thereby reducing any negative impact on final crop yield. Therefore, a series of field experiments were initiated to study the effectiveness of various herbicides for burndown of cover crops.

3.1 METHODS AND MATERIALS

Field experiments were conducted in 1988 and 1989 to evaluate the efficacy of various burndown and residual herbicides to control cover crops in corn and soybeans. The details of experimental procedures followed and material used are described briefly.

3.1.1 Experimental Locations

Details of experimental locations and soil types are described in Table 5.

Table 5. Details of experimental locations and soil types for experiments conducted in 1988 and 1989.

Crop	Cover	Experiment	Soil						
	Crop	Site	Location	Type	Sand	Silt	Clay	O.M.	pH
					%				
Soybeans	Alfalfa	Dealtown Research Station	42E 15'N 82E 5' W	Fox Gravelly loam	54	31	15	5.6	6.0
Soybeans	Wheat	Woodstock Research Station	43E 8' N 80E 45'W	Guelph loam	42	45	13	3.5	6.6
Fallow	Wheat	Dealtown Research Station	42E 15'N 82E 5' W	Fox Gravelly loam	54	31	15	5.6	6.0
Corn	Red clover	Woodstock Research Station	43E 8' N 80E 45'W	Guelph loam	41	46	13	3.3	6.7

3.1.2 Agronomy

Experiments were conducted using standard agronomic practices (OMAF publication 296, Field Crop Recommendations) in no-till plots. Soil samples were taken from each field at the beginning of the crop season and were analyzed for soil available nutrient status. Fertilization was done according to soil tests and requirements of individual crop. Fertilizer was placed at the time of sowing of the crop with minimum soil surface disturbances.

Corn cv. Pioneer® 3925 was planted at a seeding density of 73,000 plants ha^{-2} in rows spaced 76 cm from each other. Individual plot size was 2 x 6 m.

Soybeans cv. Pioneer® 0877 at Woodstock and Elgin at Dealtown were planted at a seeding rate of 80-100 kg.ha^{-1} with row-spacing of 40 cm. Individual plot size at Woodstock was 3 x 7 m and Dealtown 1.5 x 6 m.

Corn and soybeans were harvested from the centre of plots leaving side border rows at woodstock site and from whole plot at dealtown site. Final yield was later converted and expressed at 14% and 15.5% moisture content for soybeans and corn, respectively.

The details of dates of planting, spraying and crop harvesting are presented in Table 6.

Table 6. Planting, spraying and crop harvesting dates for experiments conducted in 1988 and 1989.

Crop	Cover Crop	Date(s)					
		Planting		Spraying		Harvest	
		1988	1989	1988	1989	1988	1989

Soybeans	Alfalfa	May 18	May 10	May 20	May 18	-	Oct 28
Soybeans	Wheat	May 31	May 29	May 2 June 2	May 2 June 1	Oct 27	Oct 12
Fallow	Wheat	Sept 30	Sept 27	May 2† May 8 May 17	Apr 26‡ May 3 May 12	-	-
Corn	Red Clover	May 5	May 17	Apr 25	Apr 28	Oct 27	Oct 27

† in 1989, ‡ in 1990

3.1.3 Spraying Equipment and Procedures

Individual plots were sprayed using a 'bicycle sprayer' at Woodstock site and by an 'Oxford Precision Sprayer' at Dealtown site. The quantity of spray solution used for the bicycle sprayer was 225 $l.ha^{-1}$ at 180 kPa. The 'Oxford Precision Sprayer' used 200 $l.ha^{-1}$ of spray solution at 240 kPa.

3.1.4 Experiment Design and Analysis

All experiments were conducted in randomized complete block design (RCBD) with 4 replications. Results were analyzed using analysis of variance (ANOVA) procedures and means were then separated using least significant difference (LSD) at 5% level of significance.

3.2 ESTABLISHED ALFALFA BURNDOWN IN NO-TILL SOYBEANS

RESEARCH SUMMARY:

Amitrole plus ammonium thiocyanate (amitrole-t) with linuron or metribuzin consistently provided excellent control of alfalfa, dandelion and quackgrass. Results were similar whether these herbicides were tank-mixed or applied alone as separate applications. Glyphosate, tank-mixed with linuron provided significantly better alfalfa and quackgrass burndown than when tank-mixed with metribuzin in 1988. Tank-mixed glyphosate at both doses (0.9 and 1.8 $kg.ha^{-1}$) with linuron provided similar control of alfalfa and other weeds. Tank-mixed, glyphosate + linuron had significantly higher control of alfalfa and quackgrass than when these herbicides were applied separately in 1989.

Glyphosate + dicamba or 2,4-D when tank-mixed were equally effective in controlling alfalfa and other weeds in 1988. However, in 1989, glyphosate + dicamba treated plots had significantly lower control of alfalfa and quackgrass than glyphosate + 2,4-D treated plots. The three-way tank-mixes of glyphosate + metolachlor + metribuzin or linuron provided significantly less alfalfa burndown than two-way mixture of glyphosate + metribuzin or linuron.

The annual weed control by various herbicide combinations was marginal in both years. Amitrole-t + linuron and tank-mixed amitrole-t + metribuzin were the only herbicides which provided satisfactory annual weed control in both years. Split applications of glyphosate + dicamba and metribuzin + Kornoil concentrate® also provided satisfactory broad leaved weed control in both years. No significant differences in soybeans yields were recorded in 1989.

Table 7. Soybeans yield as affected by various treatments in 1989.

#	Treatment[†]	Dose[‡]	Yield
		kg a.i./ha	1989
			– kg/ha –
1	Weedy check (cover crop and weeds)		400
2	Glyphosate (annual weeds only)	1.8	1220
3	Glyphosate + metolachlor + metribuzin	0.9 + 2.4 + .56	1180
4	Glyphosate + metolachlor + linuron	0.9 + 2.4 + 1.5	1150
5	Glyphosate + metribuzin	0.9 + .75	1260
6	Glyphosate + linuron	0.9 + 2	1370
7	Glyphosate + metribuzin	1.8 + .75	1210
8	Glyphosate + linuron	1.8 + 2	1590
9	Glyphosate ; metolachlor + metribuzin	0.9; 2.4 + .56	1170
10	Glyphosate ; metolachlor + linuron	0.9; 2.4 + 1.15	960
11	Glyphosate ; linuron	0.9; 2.0	1030
12	Glyphosate ; metribuzin	0.9; 0.75	1030
13	Glyphosate + 2,4-D LV ester; metribuzin	0.9 + 1; .75	950
14	Glyphosate + 2,4-D amine; metribuzin	0.9 + 1; .75	1160
15	Glyphosate + dicamba; metribuzin	0.9 + 0.3; .75	1200
16	Amitrole-t + linuron	4.0 + 2.0	1310
17	Amitrole-t + metribuzin	4.0 + 0.75	1200
18	Amitrole-t; linuron	4.0 ; 2.25	1290
19	Amitrole-t; metribuzin	4.0 ; 0.75	1030
20	Glyphosate + amitrole-t; metribuzin	0.45 + 3.0;	1280
	LSD 5%		580

[†] in treatments 3 to 8, 16 and 17 burndown and residual herbicides were tank-mixed at the time of spray.

[‡] herbicides were sprayed with Kornoil concentrate® at 1% (v/v). Glyphosate in treatment 9 to 12 and 20 was applied with ammonium sulphate at 2 $kg.ha^{-1}$ + Agral® 90 at 0.1% (v/v).

Table 8. Alfalfa and initial weed burndown expressed as percent of weedy check as affected by tank-mixing various burndown and residual herbicides.

#	Treatment†	Visual control ratings				Alfalfa	
	Dandelion Quackgrass	1988	1989	1988	1989	1988	1989
		%					
1	Weedy check (cover crop and weeds)	0	0	0	0	0	0
2	Glyphosate (annual weeds only)	100	98	88	89	100	71
3	Glyphosate + metolachlor + metri.‡	64	80	28	23	66	81
4	Glyphosate + metolachlor + linuron	68	88	16	35	71	84
5	Glyphosate + metri.	80	93	64	36	73	59
6	Glyphosate + linuron	90	95	69	54	86	85
7	Glyphosate + metri.	80	99	53	61	68	76
8	Glyphosate + linuron	95	99	85	59	94	89
9	Glyphosate; metolachlor + metri.	99	66	97	0	100	76
10	Glyphosate; metolachlor + linuron	96	65	99	0	100	74
11	Glyphosate; linuron	100	73	99	16	100	69
12	Glyphosate; metri.	94	71	97	10	98	81
13	Glyphosate + 2,4-D ester; metri.	100	100	100	55	100	84
14	Glyphosate + 2,4-D amine; metri.	100	100	98	25	97	79
15	Glyphosate + dicamba; metri.	100	80	100	0	100	80
16	Amitrole-t + linuron	100	100	100	99	100	99
17	Amitrole-t + metri.	100	100	99	84	100	94
18	Amitrole-t; linuron	100	100	100	100	100	81
19	Amitrole-t; metri.	100	99	100	100	100	74
20	Glyphosate + amitrole-t; metri.	100	100	100	100	100	97
	LSD 5%	10	8	23	22	10	32

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† herbicides were sprayed with Kornoil concentrate®. Glyphosate in treatment 9-12 and 20 was sprayed with ammonium sulphate + Agral® 90.

‡ metribuzin

Table 9. Annual weed control expressed as percent of weedy check as affected by tank-mixing various burndown and residual herbicides.

#	Treatment†	Annual weed control ratings			
		Broadleaf		grasses	
		1988	1989	1988	1989
		%			
1	Weedy check (cover crop and weeds)	0	0	0	0
2	Glyphosate (annual weeds only)	25	0	69	0
3	Glyphosate + metolachlor + metribuzin	74	41	74	55
4	Glyphosate + metolachlor + linuron	78	50	80	74
5	Glyphosate + metribuzin	83	59	80	53
6	Glyphosate + linuron	75	54	80	58
7	Glyphosate + metribuzin	73	50	76	38
8	Glyphosate + linuron	69	76	75	59
9	Glyphosate ; metolachlor + metribuzin	10	40	51	58
10	Glyphosate ; metolachlor + linuron	60	43	70	45
11	Glyphosate ; linuron	58	43	39	45
12	Glyphosate ; metribuzin	40	55	50	43
13	Glyphosate + 2,4-D LV ester; metribuzin	19	46	34	33
14	Glyphosate + 2,4-D amine; metribuzin	20	70	20	28
15	Glyphosate + dicamba; metribuzin	70	84	53	39
16	Amitrole-t + linuron	83	83	81	68
17	Amitrole-t + metribuzin	73	78	79	75
18	Amitrole-t; linuron	76	68	80	66
19	Amitrole-t; metribuzin	28	55	8	65
20	Glyphosate + amitrole-t; metribuzin	34	66	40	76
	LSD 5%	33	33	35	23

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† herbicides were sprayed with Kornoil concentrate®. Glyphosate in treatment 9-12 and 20 was sprayed with ammonium sulphate + Agral® 90.

3.3 WINTER WHEAT COVER CROP CONTROL IN SOYBEANS

RESEARCH SUMMARY:

Four burndown herbicides, DPX Y6202-31, glufosinate, glyphosate and paraquat were evaluated for control of winter wheat prior to seeding of soybeans. Glyphosate and paraquat provided excellent season-long control of winter wheat seedlings. However the control of winter wheat by DPX Y6202-31 and glufosinate was highly variable. DPX Y6202-31 failed to control winter wheat in 1988 and glufosinate in 1989.

Excellent annual weed control within the crop of soybeans was obtained with a standard residual herbicide treatment of linuron + metolachlor with every burndown herbicide treatment.

Soybean yields were significantly higher in treatments where glyphosate or paraquat were applied at higher doses as compared to DPX Y6202-31 or glufosinate. This may be due to poor winter wheat control by the latter two herbicides.

Table 10. Soybeans yield as affected by various treatments in 1988 and 1989.

#	Treatment[†]	Dose[‡] kg a.i./ha	Yield 1988	 1989
			—— kg.ha^{-1}	——
1	Weedy (cover crop + Ann. weeds)		160	390
2	Glyphosate (annual weeds only)	1.8	1850	1300
3	Linuron + metola.[§]	0.850 + 1.68	2630	3660
4	DPX Y6202-31; linuron + metola.	0.048; 0.85 + 1.68	460	3100
5	DPX Y6202-31; linuron + metola.	0.060; 0.85 + 1.68	970	2610
6	DPX Y6202-31; linuron + metola.	0.072; 0.85 + 1.68	1020	2650
7	Glufosinate; linuron + metola.	0.500; 0.85 + 1.68	350	1580
8	Glufosinate; linuron + metola.	1.000; 0.85 + 1.68	2040	1460
9	Glufosinate; linuron + metola.	1.500; 0.85 + 1.68	2400	2030
10	Glyphosate; linuron + metola.	0.450; 0.85 + 1.68	2530	2380
11	Glyphosate; linuron + metola.	0.900; 0.85 + 1.68	2550	3170
12	Glyphosate; linuron + metola.	1.800; 0.85 + 1.68	2250	3550
13	Paraquat; linuron + metola.	0.500; 0.85 + 1.68	2490	2970
14	Paraquat; linuron + metola.	1.000; 0.85 + 1.68	2420	3510
15	Paraquat; linuron + metola.	1.500; 0.85 + 1.68	2540	3500
	LSD 5%		470	610

† burndown herbicides were applied before soybean planting and residual herbicides as preemergence to soybeans.

‡ residual herbicides were applied with Kornoil concentrate® at 1% (v/v) in both years and herbicide DPX Y6202-31 with Canplus® 411 at 1.1% (v/v) in 1989.

§ metolachlor

Table 11. Wheat burndowm ratings expressed as percent of weedy check as affected by various herbicides in 1988 and 1989.

#	Treatment[†]	Wheat burndown ratings			
		1988[‡]		1989	
		%			
1	Weedy check (cover crop + Ann. weeds)	0	0	0	0
2	Glufosinate (annual weeds only)	84	100	100	100
3	Linuron + metolachlor + COC[§]	80	100	100	100
4	DPX Y6202-31; linuron + metolachlor + COC	0	28	65	100
5	DPX Y6202-31; linuron + metolachlor + COC	0	44	68	100
6	DPX Y6202-31; linuron + metolachlor + COC	10	43	73	100
7	Glufosinate; linuron + metolachlor + COC	63	46	0	0
8	Glufosinate; linuron + metolachlor + COC	79	80	18	3
9	Glufosinate; linuron + metolachlor + COC	84	96	46	5
10	Glyphosate; linuron + metolachlor + COC	75	94	54	8
11	Glyphosate; linuron + metolachlor + COC	84	98	89	100
12	Glyphosate; linuron + metolachlor + COC	90	100	100	100
13	Paraquat; linuron + metolachlor + COC	89	83	94	95
14	Paraquat; linuron + metolachlor + COC	93	98	100	100
15	Paraquat; linuron + metolachlor + COC	95	99	100	100
	LSD 5%	6	9	8	6

[†] herbicide DPX Y6202-31 with Canplus® 411 at 1.1% (v/v) in 1989.

[‡] wheat burndown ratings were recorded on May 11 and June 8 or 11.

[§] Kornoil concentrate®

3.4 WINTER WHEAT BURNDOWN WITH GLYPHOSATE

RESEARCH SUMMARY:

Field experiments were conducted in 1988 and 1989 to investigate the control of established winter wheat with glyphosate. Glyphosate was applied at four dosages: 0.30, 0.45, 0.60 and 0.90 kg.ha^{-1} alone or tank-mixed with the additives of ammonium sulphate at 2 l.ha^{-1} and Agral® 90 at 0.1% (v/v). Herbicide treatments were applied at three different stages of winter wheat growth.

Control of established winter wheat varied with stage of the wheat growth at the time of herbicide application. At early stages when winter wheat had only 2 to 3 leaves (12-14 cm tall) glyphosate at 0.30 kg.ha^{-1} with additives provided excellent winter wheat burndown. However, at 3 to 4 leaf stage when winter wheat was 16-18 cm tall, a higher dose of glyphosate (0.45 kg.ha^{-1}) with additives was required to burndown winter wheat. Similarly at subsequent growth stages when winter wheat plants had 4 to 5 leaves (22-24 cm tall), a minimum of 0.60 kg.ha^{-1} glyphosate with additives or 0.90 Kg.ha^{-1} without additives were required for winter wheat burndown.

Overall, winter wheat burndown was better in 1988 than 1989. Differences in overall control between years may have influenced by higher fertility levels applied to the wheat in 1989.

Table 12. Winter wheat burndown ratings expressed as percent of weedy check as affected by glyphosate dose, time of application and additives in 1988 and 1989.

#	Treatment[†]	Dose	Wheat burndown ratings		
		kg a.i./ha	1989[‡]	1989	1990
			%		
1	Check		0	0	0
2	Glyphosate	0.30	92	87	23
3	Glyphosate + A.S.[§] + Agral 90	0.30 + 2 + 0.1%	99	99	70
4	Glyphosate	0.45	97	97	43
5	Glyphosate + A.S. + Agral 90	0.45 + 2 + 0.1%	99	100	90
6	Glyphosate	0.60	100	100	65
7	Glyphosate + A.S. + Agral 90	0.60 + 2 + 0.1%	100	100	99
8	**Glyphosate**	**0.90**	**100**	**100**	**100**
9	Glyphosate	0.30	84	87	16
10	Glyphosate + A.S. + Agral 90	0.30 + 2 + 0.1%	96	96	44
11	Glyphosate	0.45	98	96	44
12	Glyphosate + A.S. + Agral 90	0.45 + 2 + 0.1%	100	100	79
13	Glyphosate	0.60	99	99	61
14	Glyphosate + A.S. + Agral 90	0.60 + 2 + 0.1%	100	100	86
15	Glyphosate	0.90	100	100	99
16	**Glyphosate**	**0.30**	**36**	**43**	**25**
17	Glyphosate + A.S. + Agral 90	0.30 + 2 + 0.1%	76	86	38
18	Glyphosate	0.45	34	46	58
19	Glyphosate + A.S. + Agral 90	0.45 + 2 + 0.1%	93	93	69
20	Glyphosate	0.60	96	96	71
21	Glyphosate + A.S. + Agral 90	0.60 + 2 + 0.1%	98	98	90
22	Glyphosate	0.90	98	98	95
	LSD		5	7	19

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† treatments 2 to 8 were applied when winter wheat had 2-3 leaves, treatments 9 to 15 when winter wheat had 3-4 leaves and treatments 15 to 22 when winter wheat had 4-5 leaves.

‡ assessment were made 2 and 3 weeks after spraying in 1988 and on May 22 in 1990.

§ ammonium sulphate

3.5 RED CLOVER BURNDOWN IN CORN

RESEARCH SUMMARY:

Glufosinate + metolachlor + atrazine or dicamba provided excellent season-long red clover control. Red clover burndown with other residual herbicides such as glyphosate, paraquat or 2,4-D was average in the beginning of season, however, excellent red clover burndown was achieved with these herbicides by late season. Application of atrazine or metolachlor without burndown herbicides was not sufficient to control established red clover. However, the addition of dicamba with atrazine or metolachlor provided excellent red clover control. Dicamba had a poor residual activity and thus poor mid-season annual weed suppression was achieved.

Corn yields were not affected in treatments where herbicides were applied to control established red clover and annual weeds in 1989. However, in 1988, dicamba when applied with herbicides glyphosate, paraquat or 2,4-D (1 kg.ha^{-1}) resulted in significantly less corn yields as compared to atrazine with these burndown herbicides. This may be due to corn injury caused by dicamba. Corn yields were also significantly higher in treatments where atrazine was applied in combination with the higher dosage of 2,4-D as compared to the lower 2,4-D dose.

Table 13. Corn yield as affected by various treatments in 1988 and 1989.

#	Treatment[†]	Dose kg a.i./ha	Yield 1988	 1989
			—— kg.ha^{-1}	——
1	Weedy (cover crop + annual weeds)		10	10
2	Glyphosate (with annual weeds)	1.8	4440	7220
3	Dicamba + meto.[‡]	0.60 + 1.92	4680	8930
4	Dicamba + atrazine + meto.	0.60 + 1.50 +1.92	6560	8550
5	2,4-D ester + atrazine + meto.	0.50 + 1.50 +1.92	7420	8740
6	2,4-D ester + atrazine + meto.	1.00 + 1.50 +1.92	8310	8960
7	2,4-D amine + atrazine + meto.	0.50 + 1.50 +1.92	6210	8230
8	2,4-D amine + atrazine + meto.	1.00 + 1.50 +1.92	8280	8440
9	Atrazine + meto.	1.50 +1.92	5630	8830
10	Glufosinate + atrazine + meto.	1.00 + 1.50 + 1.68	4970	8310
11	Glufosinate + dicamba + meto.	1.00 + 0.60 + 1.68	6670	7940
12	Glyphosate; atrazine + meto.	0.90; 1.50 + 1.68	8950	7990
13	Glyphosate; dicamba + meto.	0.90; 0.60 + 1.68	6220	7520
14	Paraquat + atrazine + meto.	1.00 + 1.50 + 1.68	8360	8310
15	Paraquat + dicamba + meto.	1.00 + 0.60 + 1.68	6500	8230
	LSD 5%		1630	1260

[†] herbicides were applied prior to corn planting and with Kornoil concentrate® at 1% (v/v). Treatment 12 and 13 were applied as split application.

[‡] metolachlor

Table 14. Red clover burndown ratings expressed as percent of weedy check as affected by various treatments in 1988 and 1989.

#	Treatment	Clover control ratings†			
		1988		1989	
		%			
1	Weedy (cover crop + annual weeds)	0	0	0	0
2	Glyphosate (annual weeds only)	-	-	68	100
3	Dicamba + metolachlor	-	-	88	100
4	Dicamba + atrazine + metolachlor	78	100	85	100
5	2,4-D ester + atrazine + metolachlor	73	91	75	93
6	2,4-D ester + atrazine + metolachlor	74	98	76	90
7	2,4-D amine + atrazine + metolachlor	71	86	74	90
8	2,4-D amine + atrazine + metolachlor	74	95	79	95
9	Atrazine + metolachlor	35	75	71	80
10	Glufosinate + atrazine + metolachlor	93	100	94	98
11	Glufosinate + dicamba + metolachlor	98	98	96	100
12	Glyphosate; atrazine + metolachlor	61	98	71	98
13	Glyphosate; dicamba + metolachlor	70	100	85	100
14	Paraquat + atrazine + metolachlor	71	96	76	90
15	Paraquat + dicamba + metolachlor	79	100	74	98
	LSD 5%	6	6	6	7

† red clover ratings were recorded on May 11 and September 13 in 1988 and on May 23 and July 12 in 1989.

3.6 ESTABLISHED ALFALFA CONTROL IN NO-TILL CORN

ABSTRACT

The successful production of no-till corn (Zea mays L.) after an established alfalfa (Medicago sativa L.) sod depends on successful control of the alfalfa. Field experiments were conducted in 1988 and 1989 to determine the optimum application time of selected herbicides for control of established alfalfa in no-till corn. Herbicide treatments included fall and spring applied treatments of atrazine applied alone or tank mixed with glyphosate, glufosinate, 2,4-D amine, 2,4-D ester, dicamba, and 2,4-D + dicamba + mecoprop. Based on plant dry weight in both years, the most consistent treatment for alfalfa control was glufosinate applied in the fall, followed by atrazine in the spring or as a tank mix with atrazine in the spring. No significant differences occurred with this treatment between fall or spring applications. Alfalfa control varied with time of herbicide application for all remaining treatments. Corn grain yield and ear moisture were not significantly affected by the time of herbicide application. Results of this research indicated that herbicide selection was more critical than timing of herbicide application, in controlling alfalfa in no-till corn.

Key Words : herbicides, legume control, corn yield

The impact of soil erosion on agricultural land in Ontario has been well documented. Dickinson et al. (1975) estimated average soil erosion losses of 0.07 to 1.9 tonnes ha^{-1} yr^{-1}. The Ontario Institute of Agrologists (1983) estimated cropland erosion losses to be approximately $74 million per year. As well, Ketcheson and Webber (1978) reported that erosion lowered the organic

C and N equilibrium levels of soils and impaired soil structure and tilth in terms of total porosity and aggregate stability.

To control soil degradation and hence sustain the productivity of agricultural land, cropping management options which keep the soil surface covered for a greater part of the year are receiving increased attention. Soil degradation can be moderated by adopting reduced or conservation tillage practices. The use of conservation tillage systems can either retard the rate of soil deterioration, relative to conventional tillage or, in some cases, actually improve soil structure (Lindstrom and Onstad, 1984). Horner (1960) reported that sod-based rotations provided more effective erosion control and soil organic matter maintenance than cropping systems without the meadow. Growing forage legumes is an effective system which can keep the soil surface well protected but there are problems with eliminating the legume prior to planting the main crop.

Killing the forage legume too far in advance of planting the following annual crop will limit nitrogen production by the legume. The biomass of the remaining mulch may be insufficient to provide adequate soil moisture conservation later in the growing season. Delayed chemical kill of a high producing forage legume will decrease soil moisture (Worsham and White 1987, Utomo et al. 1987). Some researchers have found it difficult to control legumes adequately in no-till systems and therefore, have suggested that inadequate control of the legume cover may result in a reduced crop stand and delayed early season crop growth (Breman and Wright 1984, Griffin and Taylor 1986). Conversely, reports of adequate control exist in the literature.

Glufosinate effectively controlled subterranean clover, crimson clover and vetch (Griffin and Taylor, 1986). Gallaher (1986) cited by Worsham and White (1987) found that a minimum of 0.41 kg ha^{-1} paraquat was necessary to completely desiccate a crimson clover cover crop. Moreover, glyphosate or glyphosate + 2,4-D was effective in giving complete kill of crimson clover. Swanton and Chandler (1988) observed that red clover control with atrazine plus metolachlor was significantly less than that achieved with the addition of 2,4-D or dicamba. Furthermore, burndown herbicides including glufosinate, glyphosate or paraquat gave excellent full season control while 2,4-D amine or 2,4-D ester both gave greater control at 1.0 kg ha^{-1} than at 0.5 kg ha^{-1}.

The time of herbicide application has also been found to affect the extent of control of the forage legume. Moomaw and Martin (1976) noted that spring rather than fall application of 2,4-D amine plus dicamba provided the most consistent control of alfalfa. Hartwig (1980) reported that fall applications of atrazine plus pendimethalin at 2.2 + 2.2 kg ha^{-1} alone or with 2,4-D + dicamba did not effectively control alfalfa. Atrazine + simazine applied at 2.2 + 2.2 kg ha^{-1} alone or with 2,4-D + dicamba increased alfalfa control not but annual grasses. If 2,4-D + dicamba were applied in the spring, alfalfa and dandelion (<u>Taraxacum</u> <u>officinale</u> Weber) control was 96 and 98% respectively. Oliveira et al. (1985) reported excellent control of alfalfa with 2.3 kg a.i ha^{-1} glyphosate applied prior to planting followed by 3.3 kg a.i ha^{-1} atrazine at crop seeding. Atrazine alone at 4.5 kg ha^{-1} provided 50% control of the established alfalfa. Buhler and Mercurio (1988) reported that all treatments containing fall-applied glyphosate usually gave 85% or greater control of all sod species. Dicamba + 2,4-D was effective for alfalfa and dandelion control, but did not control perennial grasses.

There are no current recommendations for controlling established alfalfa in no-till corn in Ontario. The objectives of this research were to evaluate herbicides for effective control of alfalfa in a subsequent no-till corn crop and to investigate the efficacy of fall versus spring herbicide applications.

3.6.2 MATERIALS AND METHODS

Field experiments were conducted in 1988 and 1989 at the Woodstock Research Station, Ontario (43^{o} 8'N, 80^{o} 45'W) on a Guelph Loam series (Typic Hapludalf) containing approximately 43% sand, 45% silt, 13% clay with 3.5% organic matter and pH of 6.6. The previous crop was a five year sod containing 75% alfalfa by weight in both years (Aflakpui, 1989). The alfalfa was cut twice in the final year prior to the establishment of the experiment. Potash was applied at 150 kg ha^{-1}, according to soil tests, in the fall prior to ploughing. A randomized complete block design with 20 treatments (Table 15) and 4 replications was used. Plots not receiving tillage were 8 m in length by 3 m wide. Plots that were fall ploughed were 6 m in width, to facilitate the use of machinery for tillage operations. Herbicide treatments were applied using bicycle-wheel plot sprayer equipped with SS 8002LP spray nozzles and calibrated to deliver 225 l ha^{-1} at a pressure of 180 kPa. Herbicides treatments were applied on October 14, 1987, and October 13, 1988; spring preplant and postemergence on April 26 and June 7, 1988; April 25 and June 5, 1989, respectively. Conventional tillage plots were moldboard ploughed to a depth of 20 cm in the fall followed by two passes of a field cultivator with mounted harrows and drawn crow-foot packer in spring. Corn variety Pioneer® 3925 was planted in 76 cm rows at 70,000 seeds ha^{-1} with a 4-row John Deere® 7000 conservation planter on May 6, 1988 and May 17, 1989, respectively. Phosphorus was banded at 50 kg ha^{-1} at planting. Nitrogen was knifed into the plots, between the corn rows, as liquid urea ammonium nitrate (UAN) at 120 kg N ha^{-1} on June 8, 1988 and June 15, 1989.

The efficacy of fall and spring applied herbicides was evaluated 30 and 90 days after spring preemergence herbicide applications (DAT). Visual ratings on a linear scale of 0-100 were used to evaluate the effectiveness of the herbicide treatments where 0 = no control and 100 = complete control. At the same dates as the visual evaluation, a 0.25 m^2 quadrat was randomly placed between the two central rows of corn and the above ground vegetation clipped at ground level and removed. The vegetation was separated into alfalfa and quackgrass, oven dried at 80^0C for 4 days and the dry weight calculated in g m^{-2} per plot. Ears were harvested by hand from a 3 m length of each of the two central rows, weighed and dried for 5 days at 80^0C to calculate ear percent moisture and then shelled. Data was checked for homogeneity of variance and weed biomass was transformed prior to analysis. Visual rating scores were analyzed by the Statistical Analysis System (SAS) NPAR1WAY procedure, a non-parametric analysis procedure. The no-till, no herbicide treatment was not included in the analysis because weed pressure was so high that no crop data was obtained. Single degree of freedom contrasts were then used to determine significant treatment effects.

3.6.3 RESULTS AND DISCUSSION

Alfalfa Control

In general, there was no consistent trend in the timing of herbicide application on the degree of alfalfa control over the two years of this research. In 1988, fall applied herbicides on average gave poorer alfalfa control than spring application at both sampling dates (Table 16). In 1989, however, spring applied herbicides on average gave poorer alfalfa control (Table 17).

Applying glufosinate alone in the fall followed by atrazine in the spring, or glufosinate + atrazine in the spring did not lead to significant differences in the level of alfalfa control 30 and 90 DAT in both years. The level of alfalfa control achieved with fall or spring applied glyphosate was not significantly different 30 DAT in 1988, but by 90 DAT, the spring applied glyphosate resulted in better alfalfa control. In 1989, fall applied glyphosate gave better alfalfa control 30 DAT than the spring application, however, the differences were not significant at 90 DAT. In 1988, plots treated with 2,4-D low volatile ester, 2,4-D amine, dicamba or 2,4-D + dicamba + mecoprop, all as tank mixtures with atrazine in the spring gave better alfalfa control than fall applications followed by atrazine in spring 30 DAT. By 90 DAT, only spring applied 2,4-D + dicamba + mecoprop plus atrazine maintained superior alfalfa control compared to the fall 2,4-D + dicamba + mecoprop application plus spring atrazine in spring. There were no significant differences in the degree of alfalfa control achieved with either fall applied 2,4-D low volatile ester, 2,4-D amine or dicamba all followed by atrazine in spring or a tank mix with atrazine in spring at both sampling dates in 1989. Plots treated with 2,4-D + dicamba + mecoprop in the fall followed by atrazine applied in the spring or as a single tank mix with atrazine in the spring did not give significantly different alfalfa control levels 30 DAT. By 90 DAT, fall applied 2,4-D + dicamba + mecoprop followed by atrazine applied in the spring atrazine resulted in better alfalfa control.

The general result of spring applied herbicides achieving greater alfalfa control in 1988 is in agreement with other research. Moomaw and Martin (1976) noted that spring rather than fall application of 2,4-D amine with dicamba provided the most consistent control of alfalfa, while Hartwig (1980) observed 96-98% control of alfalfa for spring applied tank mix of 2,4-D with dicamba. Buhler and Mercurio (1988) also observed that alfalfa control was greatest (84-89%) with spring preplant application of dicamba, dicamba plus 2,4-D, or glyphosate applied in the fall.

Also consistent with results of Moomaw and Martin (1976); Hartwig (1980); Buhler and Mercurio (1988) were the individual treatment effects obtained 30 DAT with 2,4-D low volatile ester, 2,4-D amine, dicamba, or 2,4-D + dicamba + mecoprop and with glyphosate or 2,4-D + dicamba + mecoprop 90 DAT in 1988. Results with glufosinate in both years and the 1989 results of superior alfalfa control with fall applied herbicides, however, were at variance with the above. Glufosinate was the only herbicide in which alfalfa control was not influenced by time of application in both years.

The superior level of alfalfa control attained with spring herbicide applications in 1988 and the general non significant differences amongst individual treatments in 1989 has important implications for sustainable agriculture. Spring applications may minimize erosion losses compared to fall ploughed fields, since more crop cover would be left on the soil surface over the winter.

Quackgrass Control

Quackgrass [Agropyron repens (L.) Beauv.] control in general was significantly higher in plots treated with herbicides in fall than the spring applications at both sampling dates in 1988 (Table 16). In 1989, timing of herbicide application was not different in quackgrass control at both sampling dates (Table 17). Individual treatment comparisons revealed a non-significant difference in the level of quackgrass control between fall applied 2,4-D low volatile ester, 2,4-D amine (1.1 $kg.ha^{-1}$), dicamba, 2,4-D + dicamba + mecoprop or glufosinate, all followed by atrazine in spring or as tank mixes with atrazine in spring 30 DAT in 1988. By 90 DAT, no significant differences were observed between fall applied 2,4-D low volatile ester, 2,4-D amine (1.1, 1.5 $kg.ha^{-1}$), dicamba, glufosinate or 2,4-D + dicamba + mecoprop all followed by atrazine in spring or the tank mixes with atrazine in spring. Fall applied glyphosate, however, consistently gave higher quackgrass control than spring applications at both sampling dates in 1988. Buhler and Mercurio (1988) observed 85% or more control of all sod species for fall applied glyphosate.

Grain Yield and Ear Moisture

Corn grain yield on average was not significantly influenced by the time of herbicide application in both years (Table 18). Individual treatment comparisons also revealed a non-significant difference in grain yield between fall and spring applied herbicides. Thus the higher level of alfalfa control from the spring applied herbicides in 1988 was not reflected in a significant increase in grain yield. Moomaw and Martin (1976) observed that spring applications of the alfalfa control herbicide usually resulted in higher corn yield than fall applications. Oliveira et al. (1985), however, observed that maize dry matter accumulation and yield were the same for plots with 100 or 50% alfalfa suppression. They reported 32% lower yields with band applications of herbicides which also achieved 50% alfalfa suppression. Grain yield was however significantly higher with conventional tillage plus fall and spring postemergence atrazine relative to no-till with atrazine applied at the same time. This result indicates that the application of atrazine alone may not be appropriate for alfalfa and quackgrass control in no-till. Fall ploughing without any herbicide application (control) resulted in the lowest grain yield of 3860 and 5890 $kg.ha^{-1}$ in 1988 and 1989, respectively. The non-significant difference in grain yield between the best no-till and ploughed plots is consistent with results obtained in rotation studies in Ontario. Vyn (1987) observed that corn grain yields were lower (but usually non significant) with no-till than with conventional tillage when corn was grown in rotation with crops other than corn. The results are also in consonance with reports of Mock and Erbach (1977) and Levin et al. (1987) who observed that grain yields with zero tillage have generally equalled or exceeded those obtained with conventional tillage.

Ear moisture content at harvest was not significantly influenced by the time of herbicide application for the individual treatment comparisons (Table 18). There was also no significant effect of the levels of alfalfa and quackgrass control on the ear moisture at harvest. There was, however, lower ear moisture for no-till corn compared to conventionally tilled corn where atrazine was applied in fall and postemergence in spring (Table 18). This may be due poorer alfalfa control, hence competition between corn and alfalfa within a no-till system.

CONCLUSIONS

Glufosinate applied in fall, plus atrazine in spring or as a tank mix with atrazine was most consistent in controlling alfalfa and quackgrass with no difference between fall or spring applications. Alfalfa and quackgrass control with glyphosate, 2,4-D amine or low volatile ester, dicamba or 2,4-D + dicamba + mecoprop varied with time of application over the two years of the research. Grain yield and corn growth parameters were not influenced by time of herbicide application. Grain yields from the best no-till plots were not significantly different from those obtained with conventional tillage.

Table 15. List of herbicide treatments applied for control of established alfalfa in no-till corn in 1988 and 1989

Treatment #	**Herbicide**	**Dose** kg a.i. ha^{-1}	**Time of Application**
Fall ploughed treatments			
1.	atrazine[†]	2.0; 2.0	S ppi; post
2.	atrazine	2.0; 2.0	F; post
3.	control, no herbicide		
No-till treatments			
4.	control, no herbicide		
5.	atrazine;	2.0; 2.0	S pre; post
6.	atrazine;	2.0; 2.0	F; post
7.	2,4-D lve; atrazine	1.1; 2.0; 2.0	F; S pre; post
8.	2,4-D amine; atrazine	1.1; 2.0; 2.0	F; S pre; post
9.	2,4-D amine; atrazine	1.5; 2.0; 2.0	F; S pre; post
10.	dicamba; atrazine	0.6; 2.0; 2.0	F; S pre; post
11.	2,4-D/m/d[‡]; atrazine	1.1; 2.0; 2.0	F; S pre; post
12.	glyphosate; atrazine	1.5; 2.0; 2.0	F; S pre; post
13.	glufosinate; atrazine	1.5; 2.0; 2.0	F; S pre; post
14.	2,4-D lve + atrazine	1.1+ 2.0; 2.0	S pre; post
15.	2,4-D amine+ atrazine	1.1+ 2.0; 2.0	S pre; post
16.	2,4-D amine+ atrazine	1.5+ 2.0; 2.0	S pre; post
17.	dicamba + atrazine	0.6+ 2.0; 2.0	S pre; post
18.	2,4-D/m/d + atrazine	1.1+ 2.0; 2.0	S pre; post
19.	glyphosate; atrazine	1.5; 2.0; 2.0	S pre; post
20.	glufosinate+ atrazine	1.5+ 2.0; 2.0	S pre; post

† atrazine was always applied with 1% Kornoil concentrate® and applied twice in a season;

‡ 2,4-D/mecoprop/dicamba;

F= fall applied prior to ploughing; S pre, S post = spring pre and postemergence respectively; lve= low volatile ester.

Table 16. Mean biomass values for alfalfa and quackgrass control in no-till corn in 1988.

#	**Treatment**	**ALF**	**QGS**	**ALF**	**QGS**
		--- 30 DAT[†] --		**---- 90 DAT ---**	
		g m^{-2}			
Fall ploughed treatments					
1.	atrazine[‡]	2.3	8.1	3.1	84.5
2.	atrazine	5.8	2.2	18.9	6.5
3.	control, no herbicide	1.6	22.9	35.6	181.1
No-till treatments					
5.	atrazine	40.3	41.6	28.9	64.1
6.	atrazine	46.0	5.9	19.7	0.7
7.	2,4-D lve; atrazine	46.1	34.5	36.6	10.9
8.	2,4-D amine; atrazine	28.6	41.4	20.5	16.3
9.	2,4-D amine; atrazine	59.4	14.9	60.4	10.9
10.	dicamba; atrazine	22.8	29.6	18.5	27.1
11.	2,4-D/m/d[§]; atrazine	39.1	35.6	49.9	21.6
12.	glyphosate; atrazine	43.5	0.0	48.2	0.0
13.	glufosinate; atrazine	61.5	2.1	39.9	3.0
14.	2,4-D lve + atrazine	2.4	40.7	11.8	11.3
15.	2,4-D amine+ atrazine	0.2	38.6	11.2	22.1
16.	2,4-D amine+ atrazine	3.4	50.4	16.9	20.1
17.	dicamba + atrazine	0.1	45.6	2.8	36.9
18.	2,4-D/m/d + atrazine	0.0	60.3	5.9	18.8
19.	glyphosate; atrazine	24.3	2.5	13.9	9.1
20.	glufosinate+ atrazine	34.1	4.5	24.3	8.4
Contrasts					
Treatments 7-13 vs 14-20		**	**	**	**
Fall vs spring 2,4-D lve		**	NS	NS	NS
Fall vs spring 2,4-D amine		**	NS	NS	NS
Fall vs spring 2,4-D amine		**	**	NS	NS
Fall vs spring dicamba		**	NS	NS	NS
Fall vs spring 2,4-D/m/d		**	NS	*	NS
Fall vs spring glyphosate		NS	**	*	*
Fall vs spring glufosinate		NS	NS	NS	NS
	CV. %	65.6	58.5	106	133
	SD	15.9	14.8	26.3	42.2

[†] days after spring preemergence herbicide application, 7.5, 9.5 months after fall herbicide application;

[‡] atrazine was always applied with 1% Kornoil concentrate® and applied twice in a season;

[§] 2,4-D/mecoprop/dicamba;

ALF= alfalfa, QGS= quackgrass, lve= low volatile ester;

*,** means differ at $p<0.05$ and 0.01 respectively, NS not significant

Table 17. Mean biomass values for alfalfa and quackgrass control in no-till corn in 1989.

Treatment		30 DAT[†]		90 DAT	
		ALF	QGS	ALF	QGS
Fall ploughed treatments		g m^{-2}			
1.	atrazine[‡]	1.0	3.7	0.0	6.2
2.	atrazine	1.0	2.8	0.0	4.1
3.	control, no herbicide	0.7	3.4	0.0	169.7
No-till treatments					
5.	atrazine	64.7	27.6	1.9	7.9
6.	atrazine	83.1	84.1	5.9	32.0
7.	2,4-D lve; atrazine	12.1	33.5	0.6	5.7
8.	2,4-D amine; atrazine	9.2	29.4	0.0	1.1
9.	2,4-D amine; atrazine	8.4	36.7	0.0	11.2
10.	dicamba; atrazine	1.8	31.2	3.9	1.4
11.	2,4-D/m/d[§]; atrazine	1.2	35.1	0.0	3.9
12.	glyphosate; atrazine	2.3	0.1	1.4	0.8
13.	glufosinate; atrazine	76.7	14.1	0.7	1.9
14.	2,4-D lve + atrazine	11.3	44.5	0.2	6.4
15.	2,4-D amine+ atrazine	11.0	47.1	5.4	0.9
16.	2,4-D amine+ atrazine	5.1	54.4	2.3	4.9
17.	dicamba + atrazine	0.6	51.1	8.6	22.0
18.	2,4-D/m/d + atrazine	1.2	44.4	18.6	5.3
19.	glyphosate; atrazine	47.2	0.1	0.0	6.8
20.	glufosinate+ atrazine	74.5	10.2	4.7	2.6
Contrasts					
Treatments 7-13 vs 14-20		**	NS	**	NS
Fall vs spring 2,4-D lve		NS	NS	NS	NS
Fall vs spring 2,4-D amine		NS	NS	NS	NS
Fall vs spring 2,4-D amine		NS	NS	NS	NS
Fall vs spring dicamba		NS	NS	NS	NS
Fall vs spring 2,4-D/m/d		NS	NS	**	NS
Fall vs spring glyphosate		**	NS	NS	NS
Fall vs spring glufosinate		NS	NS	NS	NS
CV %		79.4	40	223	128
SD		17.3	11.8	6.4	19.9

[†] days after spring preemergence herbicide application, 7.5, 9.5 months after fall herbicide application;

[‡] atrazine was always applied with 1% Kornoil concentrate® and applied twice in a season;

[§] 2,4-D/mecoprop/dicamba;

ALF= alfalfa, QGS= quackgrass, lve= low volatile ester;

*,** means differ at $p<0.05$ and 0.01 respectively, NS not significant.

Table 18. Effect of level of alfalfa control on corn grain yield and ear moisture in 1988 and 1989.

#	Treatment	Grain yield† 1988	Grain yield† 1989	Ear moisture 1988	Ear moisture 1989
		—— kg.ha^{-1} ——		——— % ———	
Fall ploughed treatments					
1.	atrazine‡	9920	9470	22.2	24.2
2.	atrazine	10910	9760	21.7	24.0
3.	control, no herbicide	3860	5890	32.3	27.5
No-till treatments					
5.	atrazine	4320	7790	33.6	25.7
6.	atrazine	7480	6700	31.0	32.3
7.	2,4-D lve; atrazine	6550	9790	33.9	25.3
8.	2,4-D amine; atrazine	6840	10280	30.6	25.2
9.	2,4-D amine; atrazine	7530	10080	27.6	24.5
10.	dicamba; atrazine	8530	9870	27.9	24.8
11.	2,4-D/m/d§; atrazine	8490	9740	27.1	25.0
12.	glyphosate; atrazine	8600	10170	25.1	24.5
13.	glufosinate; atrazine	8430	9670	27.9	25.0
14.	2,4-D lve + atrazine	7790	10490	29.6	25.3
15.	2,4-D amine+ atrazine	8070	10000	27.1	24.8
16.	2,4-D amine+ atrazine	8090	9860	29.2	25.7
17.	dicamba + atrazine	7490	9790	29.9	25.1
18.	2,4-D/m/d + atrazine	6540	10230	30.6	24.3
19.	glyphosate; atrazine	10610	9770	24.8	23.6
20.	glufosinate+ atrazine	9490	9950	26.7	24.8
Contrasts					
Treatments 7-13 vs 14-20		NS	NS	NS	NS
Fall vs spring 2,4-D lve		NS	NS	NS	NS
Fall vs spring 2,4-D amine		NS	NS	NS	NS
Fall vs spring 2,4-D amine		NS	NS	NS	NS
Fall vs spring dicamba		NS	NS	NS	NS
Fall vs spring 2,4-D/m/d		NS	NS	NS	NS
Fall vs spring glyphosate		NS	NS	NS	NS
Fall vs spring glufosinate		NS	NS	NS	NS
Treatment 2 vs 19		NS	NS	NS	NS
Treatment 2 vs 20		NS	NS	NS	NS
Treatment 1 vs 2		NS	NS	NS	NS
Treatment 2 vs 6		**	**	*	**
SD		1720	960	5.5	2.3

† grain yield at 15.5% moisture;

‡ atrazine was always applied with 1% Kornoil concentrate® and applied twice in a season;

§ 2,4-D/mecoprop/dicamba;

*,** means differ at $p<0.05$ and 0.01 respectively, NS not significant.

3.7 RECOMMENDATIONS

On the basis of field experiments conducted at different sites from 1987 to 1990 the following recommendations are suggested for burndown of cover crops in no-till crop production systems:

3.7.1 SOYBEANS

3.7.1.1 Alfalfa burndown

! Spring applied tank-mixture of glyphosate at 0.90 $kg.ha^{-1}$ + 2,4-D (amine or ester) at 1.0 $kg.ha^{-1}$ can provide excellent established alfalfa control. The dandelion may be more efficiently controlled by the ester formulation of 2,4-D.

3.7.1.2 Winter wheat

! For control of winter wheat, apply glyphosate at 0.45 to 0.90 $kg.ha^{-1}$ or paraquat at 1.0 $kg.ha^{-1}$ to wheat seedlings up to 4 leaf stage of growth.

3.7.2 WINTER WHEAT BURNDOWN WITH GLYPHOSATE

! Winter wheat burndown was found to be dependent upon the growth stage of wheat at the time of herbicide application, herbicide dose and additives.

- Apply glyphosate at 0.30 $kg.ha^{-1}$ + ammonium sulphate at 2 $l.ha^{-1}$ + Agral® 90 at 0.1% (v/v) to winter wheat seedlings in 2 to 3 leaf (12-14 cm tall) stage of the growth.
- Apply glyphosate at 0.45 $kg.ha^{-1}$ + ammonium sulphate at 2 $l.ha^{-1}$ + Agral® 90 at 0.1% (v/v) to winter wheat seedlings in 3 to 4 leaf (12-14 cm tall) stage of the growth.
- Apply glyphosate at 0.60 $kg.ha^{-1}$ + ammonium sulphate at 2 $l.ha^{-1}$ + Agral® 90 at 0.1% (v/v) or glyphosate alone at 0.90 $kg.ha^{-1}$ to winter wheat seedlings in 4 to 5 leaf (12-14 cm tall) stage of the growth.

3.7.3 CORN

3.7.3.1 Red Clover Burndown

The following herbicides are recommended for established red clover burndown in corn. These herbicides should be tank-mixed with 1% (v/v) Kornoil concentrate®.

- 2,4-D (ester or amine) at 0.50 to 1.0 $kg.ha^{-1}$ + atrazine at 1.50 $kg.ha^{-1}$ + metolachlor at 1.92 $kg.ha^{-1}$ before the emergence of corn.
- Glufosinate at 1.0 $kg.ha^{-1}$ + metolachlor at 1.68 $kg.ha^{-1}$ + atrazine at 1.50 $kg.ha^{-1}$ or dicamba at 0.60 $kg.ha^{-1}$ applied preemergence to corn.
- Paraquat at 1.0 $kg.ha^{-1}$ + metolachlor at 1.68 $kg.ha^{-1}$ + atrazine at 1.50 $kg.ha^{-1}$ or dicamba at 0.60 $kg.ha^{-1}$ applied preemergence to corn.
- Dicamba at 0.60 $kg.ha^{-1}$ + atrazine at 1.50 $kg.ha^{-1}$ + metolachlor at 1.92 $kg.ha^{-1}$ preemergence to corn.

! Glyphosate at 0.90 kg.ha^{-1} followed by metolachlor at 1.68 kg.ha^{-1} + atrazine at 1.50 kg.ha^{-1} or dicamba at 0.60 kg.ha^{-1}.

Precaution: Glyphosate was applied as pre-split with metolachlor + atrazine or dicamba.

3.7.3.2 Alfalfa burndown

! Apply glyphosate at 1.5 kg.ha^{-1} in the fall followed by a spring application of atrazine at 2.0 kg.ha^{-1}.

! Apply atrazine at 2.0 kg.ha^{-1} in the fall and again at 2.0 kg.ha^{-1} the following spring.

! Dicamba at 0.6 kg.ha^{-1} + atrazine at 2.0 kg.ha^{-1} applied in the spring prior to the corn planting.

! 2,4-D/mecoprop/dicamba at 1.1 kg.ha^{-1} + atrazine at 2.0 kg.ha^{-1} applied in the spring prior to the corn planting.

! Glufosinate at 1.5 kg.ha^{-1} in the fall followed by a spring application of atrazine at 2.0 kg.ha^{-1} or as a tank-mix of glufosinate + atrazine applied in the spring prior to corn planting.

OBJECTIVE # 2

4.0 ANTAGONISM OF BURNDOWN HERBICIDES WITH RESIDUAL HERBICIDES IN CONSERVATION TILLAGE SYSTEMS

Weed population dynamics may be altered by the elimination of tillage. The weed flora in a no-till cropping system is often more diverse than in a conventional tillage system. The successful establishment of the crop is very dependent upon herbicides for the control of weeds.

The majority of recommended herbicides control only a limited spectrum of weeds. Therefore, to manage a diverse weed flora, various herbicide combinations may be required. The ability to safely tank-mix herbicides can reduce trips across the field, ultimately saving money and fuel for the farmers. However, not all of the herbicides can be tank-mixed. Herbicides usually have chemical and physical properties which, upon mixing, may affect herbicidal activity.

To overcome these challenges a series of field experiments were initiated in Ontario with tank-mixes of various burndown and residual herbicides. The objective of these experiments was to study the interaction of tank-mixing various burndown herbicides with residual preemergence herbicides for annual weed control in corn and soybeans in various conservative tillage systems.

4.1 METHODS AND MATERIALS

Field experiments were conducted to evaluate the effect of the tank-mixing of burndown and residual herbicides on weed control in no-till systems. The details of experimental procedures followed and material used are described briefly.

4.1.1 Experimental Locations

Details of experimental locations and soil types are described in Table 19.

Table 19. Details of experiment locations and soil types for experiments conducted from 1987 to 1990.

Crop	Experiment			Soil					
	#	Site	Location	Type	Sand	Silt	Clay	O.M.	pH
					%				
Corn	4.2[†]	Dealtown	42E 15'N 82E 5 'W	Fox Gravelly Loam	59	31	10	2.8	6.1
Corn	4.3[†]	Dealtown	42E 15'N 82E 5 'W	Fox Gravelly Loam	59	31	10	2.8	6.1
Soybeans	4.4[†]	Dealtown	42E 15'N 82E 5 'W	Fox Gravelly Loam	59	31	10	2.8	6.1
Soybeans	4.5	Dealtown	42E 15'N 82E 5 'W	Fox Gravelly Loam	59	31	10	2.8	6.1
Fallow/ Quackgrass	4.6	Elora	42E 27'N 81E 53'W	Guelph Loam	29	53	18	4.3	7.5

[†] Experiment was conducted at Mr. Art Wardle's farm, Ridgetown, Ontario on Brookston clay loam soil in 1987.

4.1.2 Agronomy

Experiments were conducted using standard agronomic practices (OMAF publication 296, Field Crop Recommendations) in no-till plots. Soil samples were taken from each field at the beginning of the crop season and were analyzed for soil available nutrient status. Fertilization was done according to soil tests and requirements of individual crop. Fertilizer was placed at the time of sowing of the crop with minimum soil surface disturbances.

Corn cv. Renk® R148, Dekalb® 524, Renk® R138, Pioneer® 3790 were planted at their respective recommended seeding densities in 76 cm rows in 1987, 1988, 1989 and 1990, respectively. The individual corn plot size was 6 x 1.5 m.

Soybeans cv. Hodgson and Elgin were planted at a seeding rate of 80 kg/ha in 38 cm rows in 1987 and 1988, 1989, 1990; respectively. The individual soybeans plot size was 6 x 1.5 m.

The quackgrass experiment was established using the quackgrass biotype found at Elora Research Station, Elora, Ontario. The individual size of quackgrass plots was 6 x 2 m.

Corn and soybeans were harvested from the centre of plots leaving side border rows at Elora site and from whole plot at Dealtown site. Final yield was later converted and expressed at 14% and 15.5% moisture content for soybeans and corn, respectively.

The details of dates of planting, spraying and crop harvesting are presented in Table 20.

Table 20. Planting, spraying and harvesting dates of corn and soybeans from 1987 to 1990.

Crop	Expt.	Year	Date(s)		#Planting
			Spraying	Harvesting	
Corn	4.2	1987	May 13	May 16 & 18	-
		1988	May 12	May 17 & 19	-
		1989	May 10	May 9 & 16	Nov. 9
		1990	June 5	May 9 & 14	-
Corn	4.3	1987	May 13	May 16 & 18	-
		1988	May 12	May 17 & 19	-
		1989	May 10	May 9 & 12	Nov. 9
		1990	June 5	May 9 & 14	-
Soybeans	4.4	1987	May 13	May 18 & 19	-
		1988	May 19	May 19 & 20	-
		1989	May 15	May 9 & 17	Oct. 27
		1990	May 15	May 14 & 22	-
Soybeans	4.5	1988	May 1	May 20 & 24	-
		1989	May 15	May 9 & 17	Oct. 27
		1990	May 15	May 15 & 22	Nov. 1
Fallow/ Quackgrass	4.6	1987	-	June 2-4 & 5	-
		1988	-	June 8 & 10	-

4.1.3 Spraying Equipment and Procedures

Individual plots were sprayed using a 'bicycle sprayer' at Elora site and by an 'Oxford Precision Sprayer' at Dealtown site. The quantity of spray solution used for the bicycle sprayer was 225 $l.ha^{-1}$ at 180 kPa. The 'Oxford Precision Sprayer' used 200 $l.ha^{-1}$ of spray solution at 240 kPa.

4.1.4 Experiment Design and Analysis

All experiments were conducted in randomized complete block design (RCBD) with 4 replications. Results were analyzed using analysis of variance (ANOVA) procedures and means were then separated using least significant difference (LSD) at 5% level of significance.

4.2 PARAQUAT AND GLUFOSINATE ANTAGONISM WITH RESIDUAL HERBICIDES IN NO-TILL CORN

RESEARCH SUMMARY:

Excellent weed burndown was achieved with paraquat, glufosinate and metolachlor + atrazine or cyanazine + additives. However, the tank-mix of paraquat plus dicamba or atrazine (liquid formulation) failed to burndown weeds in 1990.

Residual broadleaf weed control by various herbicide combinations was excellent in 1989 and 1990. Weather in 1987 and 1988 was very dry in the beginning of the season and thus some herbicide combinations failed to provide satisfactory broadleaf weed-control. Atrazine provided excellent broadleaf weed control in these dry years except when it was applied with metolachlor in the absence of burndown herbicides. Cyanazine when tank-mixed with other herbicides also failed to provide satisfactory weed control in 1987 and 1988.

Annual grass control by various herbicides was excellent in 1989 and 1990. All herbicide combinations gave poor to very poor grass control in 1987. However, the grass control was satisfactory to excellent in 1988 except when metolachlor + cyanazine + oil failed to provide grass control.

Corn yields were similar whether paraquat was applied separately or tank-mixed with residual herbicides. However, among separately applied residual herbicides with paraquat, corn yields were significantly less in metribuzin treated plots as compared to atrazine treated plots. Similarly, among tank-mixed residual and paraquat treatments, atrazine (WG) treated plots had significantly higher corn yields as compared to metribuzin or dicamba treated plots.

Among glufosinate treated plots, atrazine when tank-mixed with the higher dosage of glufosinate resulted in significantly less corn yields than the identical treatment applied at the lower glufosinate dosage. Corn yields resulting from atrazine or cyanazine with additives were not affected due to the absence of burndown herbicides.

Table 21. Corn yield as affected by various treatments in 1989.

#	Treatment[†]	Dose kg a.i./ha	Yield
		—— kg/ha ——	
1	Paraquat; metolachlor + atrazine (WG)[‡]	0.5; 2.4 + 1.5	7780
2	Paraquat; metolachlor + cyanazine (WP)	0.5; 2.4 + 2.0	6710
3	Paraquat; metolachlor + dicamba	0.5; 2.4 + 0.6	5860
4	Paraquat; metolachlor + metribuzin (DF)	0.5; 2.4 + .75	5200
5	Paraquat + metolachlor + atrazine (WG)	0.5 + 2.4 + 1.5	8820
6	Paraquat + metolachlor + atrazine (L)	0.5 + 2.4 + 1.5	7190
7	Paraquat + metolachlor + cyanazine (WP)	0.5 + 2.4 + 2.0	8210
8	Paraquat + metolachlor + cyanazine (L)	0.5 + 2.4 + 2.0	6700
9	Paraquat + metolachlor + dicamba	0.5 + 2.4 + 0.6	6500
10	Paraquat + metolachlor + metribuzin (DF)	0.5 + 2.4 + 0.75	4480
11	Paraquat + metolachlor + metribuzin (L)	0.5 + 2.4 + 0.75	3560
12	Glufosinate; metolachlor + atrazine (WG)	0.5 + 2.4 + 1.5	7890
13	Glufosinate; metolachlor + atrazine (WG)	0.75+ 2.4 + 1.5	8660
14	Glufosinate + metolachlor + atrazine (WG)	0.5 + 2.4 + 1.5	5680
15	Glufosinate + metolachlor + atrazine (WG)	0.75+ 2.4 + 1.5	8420
16	Metolachlor + atrazine + oil	2.4 + 1.5 + 10 L	7100
17	Metolachlor + atrazine + oil conc.	2.4 + 1.5 + 2 L	7720
18	Metolachlor + cyanazine + oil	2.4 + 2.25 + 10 L	7250
19	Metolachlor + cyanazine + oil conc.	2.4 + 2.25 + 2 L	7800
20	Weedy check		2520
	LSD 5%		2130

[†] in treatments 1 to 4, 11 and 12 residual and burndown herbicides were applied separately. In the rest of the treatments herbicides were tank-mixed at time of herbicide application.

[‡] WG= wettable granules, WP= wettable powder, DF= dry flowable, L= liquid

Table 22. Initial weed burndown ratings expressed as percent of weedy check as affected by selected tank-mix herbicide combinations in 1988, 1989 and 1990.

#	Treatment†	Visual weed burndown		
		1988	1989	1990
		%		
1	Paraquat; metolachlor + atrazine (WG)	99	100	96
2	Paraquat; metolachlor + cyanazine (WP)	100	96	94
3	Paraquat; metolachlor + dicamba	100	99	94
4	Paraquat; metolachlor + metribuzin (DF)	98	99	99
5	Paraquat + metolachlor + atrazine (WG)	100	100	96
6	Paraquat + metolachlor + atrazine (L)	100	98	68
7	Paraquat + metolachlor + cyanazine (WP)	99	99	83
8	Paraquat + metolachlor + cyanazine (L)	99	89	85
9	Paraquat + metolachlor + dicamba	98	99	65
10	Paraquat + metolachlor + metribuzin (DF)	100	100	100
11	Paraquat + metolachlor + metribuzin (L)	98	95	98
12	Glufosinate; metolachlor + atrazine (WG)	97	99	99
13	Glufosinate; metolachlor + atrazine (WG)	99	100	98
14	Glufosinate + metolachlor + atrazine (WG)	98	92	91
15	Glufosinate + metolachlor + atrazine (WG)	100	98	89
16	Metolachlor + atrazine + oil	96	97	95
17	Metolachlor + atrazine + oil conc.	94	100	83
18	Metolachlor + cyanazine + oil	91	100	86
19	Metolachlor + cyanazine + oil conc.	93	100	82
20	Weedy check	0	0	0
	LSD 5%	8	9	19

† in treatments 1 to 4, 11 and 12 residual and burndown herbicides were applied separately. In the rest of the treatments herbicides were tank-mixed at time of herbicide application.

Table 23. Annual broadleaf weed control ratings expressed as percent of weedy check as affected by selected tank-mix herbicide combinations in 1987, 1988, 1989 and 1990.

#	Treatment†	Broadleaf visual control			
		1987	1988	1989	1990
		%			
1	Paraquat; metolachlor + atrazine (WG)	89	80	100	85
2	Paraquat; metolachlor + cyanazine (WP)	89	84	100	89
3	Paraquat; metolachlor + dicamba	88	83	100	88
4	Paraquat; metolachlor + metribuzin (DF)	65	75	100	96
5	Paraquat + metolachlor + atrazine (WG)	90	85	100	95
6	Paraquat + metolachlor + atrazine (L)	84	71	99	68
7	Paraquat + metolachlor + cyanazine (WP)	83	55	100	85
8	Paraquat + metolachlor + cyanazine (L)	64	48	100	83
9	Paraquat + metolachlor + dicamba	81	80	99	64
10	Paraquat + metolachlor + metribuzin (DF)	76	79	100	98
11	Paraquat + metolachlor + metribuzin (L)	89	81	100	98
12	Glufosinate; metolachlor + atrazine (WG)	86	78	100	99
13	Glufosinate; metolachlor + atrazine (WG)	84	81	100	99
14	Glufosinate + metolachlor + atrazine (WG)	90	83	91	93
15	Glufosinate + metolachlor + atrazine (WG)	88	76	98	92
16	Metolachlor + atrazine + oil	64	74	97	96
17	Metolachlor + atrazine + oil conc.	31	75	100	91
18	Metolachlor + cyanazine + oil	85	48	100	81
19	Metolachlor + cyanazine + oil conc.	65	60	97	88
20	Weedy check	0	0	0	0
	LSD 5%	30	17	5	15

† in treatments 1 to 4, 11 and 12 residual and burndown herbicides were applied separately. In the rest of the treatments herbicides were tank-mixed at time of herbicide application.

Table 24. Annual grass weed control ratings expressed as percent of weedy check as affected by selected tank-mix herbicide combinations in 1987, 1988, 1989 and 1990.

#	Treatment†	Annual grass control			
		1987	1988	1989	1990
		%			
1	Paraquat; metolachlor + atrazine (WG)	43	88	100	100
2	Paraquat; metolachlor + cyanazine (WP)	30	86	95	100
3	Paraquat; metolachlor + dicamba	18	90	99	100
4	Paraquat; metolachlor + metribuzin (DF)	40	83	95	100
5	Paraquat + metolachlor + atrazine (WG)	50	81	100	100
6	Paraquat + metolachlor + atrazine (L)	41	88	99	100
7	Paraquat + metolachlor + cyanazine (WP)	40	75	99	100
8	Paraquat + metolachlor + cyanazine (L)	51	78	100	100
9	Paraquat + metolachlor + dicamba	36	85	100	100
10	Paraquat + metolachlor + metribuzin (DF)	33	80	100	100
11	Paraquat + metolachlor + metribuzin (L)	28	76	100	100
12	Glufosinate; metolachlor + atrazine (WG)	28	80	100	100
13	Glufosinate; metolachlor + atrazine (WG)	28	88	100	100
14	Glufosinate + metolachlor + atrazine (WG)	53	79	100	100
15	Glufosinate + metolachlor + atrazine (WG)	0	80	100	100
16	Metolachlor + atrazine + oil	35	78	100	100
17	Metolachlor + atrazine + oil conc.	39	88	100	100
18	Metolachlor + cyanazine + oil	13	69	100	100
19	Metolachlor + cyanazine + oil conc.	41	85	100	100
20	Weedy check	0	0	0	0
	LSD 5%	NS	14	4	0.3

† in treatments 1 to 4, 11 and 12 residual and burndown herbicides were applied separately. In the rest of the treatments herbicides were tank-mixed at time of herbicide application.

4.3 GLYPHOSATE ANTAGONISM WITH RESIDUAL HERBICIDES IN NO-TILL CORN

RESEARCH SUMMARY:

Glyphosate was applied at four application rates: 0.30, 0.45, 0.68 and 0.90 kg/ha, to evaluate the potential for antagonism when tank-mixed with atrazine or cyanazine. Atrazine and cyanazine wettable granules (WG) or liquid (L) formulations were tank-mixed with glyphosate. Glyphosate was always applied with ammonium sulphate and Agral® 90 additives. Residual herbicide metolachlor at 2.4 kg.ha^{-1} was applied with every herbicide treatments.

Burndown of annual weeds was not affected at any tested glyphosate application rates and/or tank-mixing of atrazine or cyanazine in any tested formulations. However, when dicamba replaced atrazine or cyanazine as the residual herbicide with glyphosate, a significant reduction in weed burndown occurred, compared to atrazine or cyanazine with glyphosate.

Annual broadleaf weed control by various treatments was generally fair to excellent. However, there were few exceptions. Tank-mixed atrazine (L) with a high dose of glyphosate (0.90 kg.ha^{-1}) provided significantly less broadleaf weed control than atrazine (WG) + glyphosate in 1987 or as a split application of atrazine (WG) + glyphosate in 1988. Dicamba treated plots also had significantly less broadleaf weed control than atrazine or cyanazine treated plots.

Annual grass control in 1989, 1990 was better than 1987, 1988. Weather in first two years was extremely dry and thus may have affected herbicidal activity. Tank-mixed atrazine gave poor grass control as compared to the split application. Cyanazine when tank-mixed with lower doses of glyphosate failed to control annual grasses in 1987.

Corn yields were significantly reduced in plots treated with dicamba. Glyphosate at high application rates consistently provided higher corn yields and its performance was similar whether it was applied with residual herbicides in split application or was tank-mixed.

Table 25. Corn yield as affected by various treatments in 1989.

#	Treatment†	Dose kg a.i./ha	Yield 1989
			– kg/ha –
1	Weedy check		1460
2	Glyphosate‡; metolachlor + atrazine (WP)	.30; 2.4 + 1.5	5660
3	Glyphosate; metolachlor + atrazine (WP)	.45; 2.4 + 1.5	4180
4	Glyphosate; metolachlor + atrazine (WP)	.68; 2.4 + 1.5	5290
5	Glyphosate; metolachlor + atrazine (WP)	.90; 2.4 + 1.5	6670
6	Glyphosate + metolachlor + atrazine (WP)	.30 + 2.4 + 1.5	5840
7	Glyphosate + metolachlor + atrazine (WP)	.45 + 2.4 + 1.5	6750
8	Glyphosate + metolachlor + atrazine (WP)	.68 + 2.4 + 1.5	6870
9	Glyphosate + metolachlor + atrazine (WP)	.90 + 2.4 + 1.5	7030
10	Glyphosate + metolachlor + atrazine (L)	.30 + 2.4 + 1.5	6890
11	Glyphosate + metolachlor + atrazine (L)	.45 + 2.4 + 1.5	6470
12	Glyphosate + metolachlor + atrazine (L)	.68 + 2.4 + 1.5	6130
13	Glyphosate + metolachlor + atrazine (L)	.90 + 2.4 + 1.5	6070
14	Glyphosate; metolachlor + cyanazine (WP)	.45; 2.4 + 2.0	6810
15	Glyphosate; metolachlor + cyanazine (WP)	.90; 2.4 + 2.0	5850
16	Glyphosate + metolachlor + cyanazine (WP)	.45 + 2.4 + 2.0	4490
17	Glyphosate + metolachlor + cyanazine (WP)	.90 + 2.4 + 2.0	5800
18	Glyphosate + metolachlor + cyanazine (L)	.45 + 2.4 + 2.0	6330
19	Glyphosate + metolachlor + cyanazine (L)	.90 + 2.4 + 2.0	6220
20	Glyphosate + metolachlor + dicamba	.45 + 2.4 + 0.6	2790
	LSD		2210

† treatments 2 to 5, 14 and 15 were applied in split. In other treatments herbicides were tank-mixed at the time of application.

‡ Glyphosate was always applied with ammonium sulphate at 2 $kg.ha^{-1}$ + Agral® 90 at 0.5% (v/v).

Table 26. Initial weed burndown ratings expressed as percent of weedy check as affected by tank-mixing of glyphosate and additives with residual herbicides in 1988, 1989 and 1990.

#	Treatment†	Weed burndown ratings		
		1988	1989	1990
		%		
1	Weedy check	0	0	0
2	Glyphosate; metolachlor + atrazine (WP)	91	86	99
3	Glyphosate; metolachlor + atrazine (WP)	82	71	100
4	Glyphosate; metolachlor + atrazine (WP)	89	82	100
5	Glyphosate; metolachlor + atrazine (WP)	100	92	100
6	Glyphosate + metolachlor + atrazine (WP)	97	69	92
7	Glyphosate + metolachlor + atrazine (WP)	99	92	97
8	Glyphosate + metolachlor + atrazine (WP)	88	97	98
9	Glyphosate + metolachlor + atrazine (WP)	90	86	100
10	Glyphosate + metolachlor + atrazine (L)	94	96	97
11	Glyphosate + metolachlor + atrazine (L)	97	89	96
12	Glyphosate + metolachlor + atrazine (L)	91	97	98
13	Glyphosate + metolachlor + atrazine (L)	96	99	100
14	Glyphosate; metolachlor + cyanazine (WP)	78	100	99
15	Glyphosate; metolachlor + cyanazine (WP)	79	93	100
16	Glyphosate + metolachlor + cyanazine (WP)	75	95	97
17	Glyphosate + metolachlor + cyanazine (WP)	85	89	98
18	Glyphosate + metolachlor + cyanazine (L)	92	99	93
19	Glyphosate + metolachlor + cyanazine (L)	85	94	98
20	Glyphosate + metolachlor + dicamba	88	51	70
	LSD 5%	15	27	22

† Glyphosate was always applied with ammonium sulphate at 2 kg.ha^{-1} + Agral® 90 at 0.5% (v/v).

Table 27. Annual broadleaf weed control ratings expressed as percent of weedy check as affected by tank-mixing glyphosate and additives with residual herbicides in 1987, 1988, 1989 and 1990.

#	Treatment†	Broadleaf weed control			
		1987	1988	1989	1990
		%			
1	Weedy check	0	0	0	0
2	Glyphosate; metolachlor + atrazine (WP)	84	80	99	97
3	Glyphosate; metolachlor + atrazine (WP)	79	79	100	98
4	Glyphosate; metolachlor + atrazine (WP)	86	85	100	98
5	Glyphosate; metolachlor + atrazine (WP)	85	88	100	98
6	Glyphosate + metolachlor + atrazine (WP)	76	75	97	95
7	Glyphosate + metolachlor + atrazine (WP)	75	75	92	96
8	Glyphosate + metolachlor + atrazine (WP)	83	73	97	99
9	Glyphosate + metolachlor + atrazine (WP)	81	75	98	99
10	Glyphosate + metolachlor + atrazine (L)	86	79	98	98
11	Glyphosate + metolachlor + atrazine (L)	75	81	100	99
12	Glyphosate + metolachlor + atrazine (L)	84	83	100	100
13	Glyphosate + metolachlor + atrazine (L)	16	66	99	100
14	Glyphosate; metolachlor + cyanazine (WP)	86	78	95	90
15	Glyphosate; metolachlor + cyanazine (WP)	84	76	100	95
16	Glyphosate + metolachlor + cyanazine (WP)	80	71	91	90
17	Glyphosate + metolachlor + cyanazine (WP)	80	61	93	88
18	Glyphosate + metolachlor + cyanazine (L)	81	65	95	87
19	Glyphosate + metolachlor + cyanazine (L)	80	43	93	89
20	Glyphosate + metolachlor + dicamba	83	86	71	64
	LSD	12	18	12	19

† Glyphosate was always applied with ammonium sulphate at 2 kg.ha^{-1} + Agral® 90 at 0.5% (v/v).

Table 28. Annual grass weed control ratings expressed as percent of weedy check as affected by tank-mixing glyphosate and additives with residual herbicides in 1987, 1988, 1989 and 1990.

#	Treatment†	Grass control ratings			
		1987	1988	1989	1990
		%			
1	Weedy check	0	0	0	0
2	Glyphosate; metolachlor + atrazine (WP)	54	85	100	100
3	Glyphosate; metolachlor + atrazine (WP)	28	85	100	100
4	Glyphosate; metolachlor + atrazine (WP)	74	85	99	99
5	Glyphosate; metolachlor + atrazine (WP)	76	90	99	100
6	Glyphosate + metolachlor + atrazine (WP)	39	75	99	100
7	Glyphosate + metolachlor + atrazine (WP)	58	77	99	100
8	Glyphosate + metolachlor + atrazine (WP)	40	71	100	100
9	Glyphosate + metolachlor + atrazine (WP)	51	76	100	100
10	Glyphosate + metolachlor + atrazine (L)	39	76	99	99
11	Glyphosate + metolachlor + atrazine (L)	40	88	100	100
12	Glyphosate + metolachlor + atrazine (L)	36	78	99	100
13	Glyphosate + metolachlor + atrazine (L)	55	88	100	100
14	Glyphosate; metolachlor + cyanazine (WP)	73	80	93	99
15	Glyphosate; metolachlor + cyanazine (WP)	71	79	100	98
16	Glyphosate + metolachlor + cyanazine (WP)	0	70	100	100
17	Glyphosate + metolachlor + cyanazine (WP)	74	75	99	100
18	Glyphosate + metolachlor + cyanazine (L)	50	81	98	99
19	Glyphosate + metolachlor + cyanazine (L)	80	79	99	97
20	Glyphosate + metolachlor + dicamba	73	68	98	75
	LSD 41	13	3	23	

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† Glyphosate was always applied with ammonium sulphate at 2 kg.ha^{-1} + Agral® 90 at 0.5% (v/v).

4.4 PARAQUAT AND GLUFOSINATE ANTAGONISM WITH RESIDUAL HERBICIDES IN NO-TILL SOYBEANS

RESEARCH SUMMARY:

Excellent weed burndown was recorded with all herbicide treatments. However, paraquat when tank-mixed with chloramben SG (soluble granules) provided significantly less weed burndown as compared to tank-mixed paraquat with linuron or metribuzin in 1988 and with paraquat + metribuzin in 1989. Similarly, a single application of linuron + oil failed to adequately control weeds in 1990.

Residual herbicides provided excellent control of annual weeds in 1989 and 1990 but poor to satisfactory annual weed control in 1987 and 1988. Weather in the first two years was very dry in the beginning of crop season and thus resulted in erratic herbicidal activity. Residual herbicides, chloramben and metolachlor/metobromuron when tank-mixed with paraquat resulted in poor broadleaf weed control as compared to paraquat tank-mixed with linuron or metribuzin. Similarly, tank-mixed paraquat + chloramben, or glufosinate + metribuzin + oil; separately applied paraquat + linuron or paraquat + chloramben failed to control annual grasses in different years.

Soybean yields were not affected due to reduction in glufosinate dosage or whether it was tank-mixed with other residual herbicides. Paraquat treated plots generally had the same trend. Tank-mixed paraquat with metribuzin (L) or linuron (WP) significantly reduced soybeans yields as compared to a separate application of paraquat followed by either metribuzin (DF) or linuron (WP) in 1990.

Table 29. Soybeans yield as affected by various treatments in 1989 and 1990.

#	Treatment[†]	Dose	Yield	
		kg a.i./ha	1989	1990
			— kg.ha^{-1} —	
1	Paraquat; metola.[‡] + metri.[§] (DF)	0.5; 2.4 + .56	3140	3490
2	Paraquat; metola. + linuron (WP)	0.5; 2.4 + 1	3520	3420
3	Paraquat; metola. + chloramben (SG)	0.5; 2.4 + 3	3400	2670
4	Paraquat; metola./metobromuron (EC)	0.5; 4.25	3460	2430
5	Paraquat + metola. + metri. (DF)	0.5 + 2.4 + .56	3030	3430
6	Paraquat + metola. + metri. (L)	0.5 + 2.4 + .56	3040	1870
7	Paraquat + metola. + linuron (WP)	0.5 + 2.4 + 1	2850	2080
8	Paraquat + metola. + linuron (L)	0.5 + 2.4 + 1	3100	2280
9	Paraquat + metola. + chloramben (SG)	0.5 + 2.4 + 3	2930	2230
10	Paraquat + metola. + metri. (DF)	1.0 + 2.4 + .56	3290	2660
11	Paraquat + metola./metobromuron (EC)	0.5 + 4.25	2970	2690
12	Glufosinate; metola. + metri. (DF)	0.5 + 2.4 + .56	3220	2920
13	Glufosinate; metola. + metri. (DF)	0.75 + 2.4 + .56	3340	2400
14	Glufosinate; metola. + metri. (DF)	0.5 + 2.4 + .56	3500	3330
15	Glufosinate + metola. + metri. (DF)	0.75 + 2.4 + .56	2950	3070
16	Glufosinate + metola. + metri. (L)	0.75 + 2.4 + .56	3320	2630
17	Glufosinate + metri. (DF) + oil	0.75 + 1 + 10 L	3300	2920
18	Glufosinate + metri. (DF) + oil conc.	0.75 + 1 + 2 L	4160	2690
19	Linuron + oil	2.0 + 10 L	2600	1740
20	Weedy check		1920	0820
	LSD 5%		1080	1320

[†] in treatments 1 to 4, 12 and 13 residual and burndown herbicides were applied separately. Remaining herbicide treatments were tank-mixed at the time of spray.

[‡] Metolachlor,

[§] Metribuzin

Table 30. Initial weed burndown expressed as percent of weedy check as affected by tank-mixing burndown and residual herbicides in 1988, 1989 and 1990.

#	Treatment	Initial burndown ratings		
		1988	1989	1990
		—— % ——		
1	Paraquat; metolachlor + metribuzin (DF)	98	100	95
2	Paraquat; metolachlor + linuron (WP)	96	100	90
3	Paraquat; metolachlor + chloramben (SG)	93	100	97
4	Paraquat; metolachlor/metobromuron (EC)	95	100	99
5	Paraquat + metolachlor + metribuzin (DF)	97	100	98
6	Paraquat + metolachlor + metribuzin (L)	96	100	90
7	Paraquat + metolachlor + linuron (WP)	96	98	90
8	Paraquat + metolachlor + linuron (L)	100	97	96
9	Paraquat + metolachlor + chloramben (SG)	89	90	97
10	Paraquat + metolachlor + metribuzin (DF)	92	96	98
11	Paraquat + metolachlor/metobromuron (EC)	95	100	98
12	Glufosinate; metolachlor + metribuzin (DF)	95	89	95
13	Glufosinate; metolachlor + metribuzin (DF)	97	95	97
14	Glufosinate; metolachlor + metribuzin (DF)	99	100	100
15	Glufosinate + metolachlor + metribuzin (DF)	100	100	99
16	Glufosinate + metolachlor + metribuzin (L)	100	100	100
17	Glufosinate + metribuzin (DF) + oil	98	100	99
18	Glufosinate + metribuzin (DF) + oil conc.	99	100	100
19	Linuron + oil	95	95	86
20	Weedy check	0	0	0
	LSD 5%	5	8	6.4

Table 31. Annual broadleaf weeds burndown ratings expressed as percent of weedy check as affected by tank-mixing burndown and residual herbicides in 1987, 1988, 1989 and 1990.

#	Treatment	Broadleaf control ratings			
		1987	1988	1989	1990
		%			
1	Paraquat; metolachlor + metribuzin (DF)	84	50	92	83
2	Paraquat; metolachlor + linuron (WP)	86	46	90	94
3	Paraquat; metolachlor + chloramben (SG)	85	45	95	86
4	Paraquat; metolachlor/metobromuron (EC)	84	34	93	86
5	Paraquat + metolachlor + metribuzin (DF)	86	40	93	95
6	Paraquat + metolachlor + metribuzin (L)	88	40	90	98
7	Paraquat + metolachlor + linuron (WP)	88	50	91	81
8	Paraquat + metolachlor + linuron (L)	88	61	83	86
9	Paraquat + metolachlor + chloramben (SG)	84	35	85	94
10	Paraquat + metolachlor + metribuzin (DF)	86	43	94	97
11	Paraquat + metolachlor/metobromuron (EC)	78	45	95	91
12	Glufosinate; metolachlor + metribuzin (DF)	85	48	86	98
13	Glufosinate; metolachlor + metribuzin (DF)	88	54	95	81
14	Glufosinate; metolachlor + metribuzin (DF)	86	46	95	99
15	Glufosinate + metolachlor + metribuzin (DF)	86	50	92	94
16	Glufosinate + metolachlor + metribuzin (L)	86	49	92	93
17	Glufosinate + metribuzin (DF) + oil	86	58	97	96
18	Glufosinate + metribuzin (DF) + oil conc.	90	63	95	99
19	Linuron + oil	90	73	91	94
20	Weedy check	0	0	0	0
	LSD 5%	7	12	11	16

Table 32. Annual grass weeds burndown ratings expressed as percent of weedy check as affected by tank-mixing burndown and residual herbicides in 1987, 1988, 1989 and 1990.

#	Treatment	Annual grass control ratings			
		1987	1988	1989	1990
		%			
1	Paraquat; metolachlor + metribuzin (DF)	48	53	100	96
2	Paraquat; metolachlor + linuron (WP)	19	53	99	97
3	Paraquat; metolachlor + chloramben (SG)	54	46	99	72
4	Paraquat; metolachlor/metobromuron (EC)	61	41	100	96
5	Paraquat + metolachlor + metribuzin (DF)	50	48	100	99
6	Paraquat + metolachlor + metribuzin (L)	54	45	98	99
7	Paraquat + metolachlor + linuron (WP)	40	53	100	99
8	Paraquat + metolachlor + linuron (L)	38	65	98	98
9	Paraquat + metolachlor + chloramben (SG)	33	51	100	99
10	Paraquat + metolachlor + metribuzin (DF)	61	48	99	99
11	Paraquat + metolachlor/metobromuron (EC)	56	49	100	98
12	Glufosinate; metolachlor + metribuzin (DF)	40	50	100	99
13	Glufosinate; metolachlor + metribuzin (DF)	40	46	100	99
14	Glufosinate; metolachlor + metribuzin (DF)	58	49	99	99
15	Glufosinate + metolachlor + metribuzin (DF)	60	53	99	99
16	Glufosinate + metolachlor + metribuzin (L)	39	54	99	99
17	Glufosinate + metribuzin (DF) + oil	16	62	99	99
18	Glufosinate + metribuzin (DF) + oil conc.	38	65	100	99
19	Linuron + oil	13	80	91	98
20	Weedy check	0	0	0	0
	LSD 5%	36	12	4	15

4.5 GLYPHOSATE ANTAGONISM WITH RESIDUAL HERBICIDES IN NO-TILL SOYBEANS

RESEARCH SUMMARY:

Glyphosate was applied at four application rates: 0.30, 0.45, 0.68 and 0.90 kg/ha, to evaluate the potential for antagonism when tank-mixed with metribuzin or linuron. Metribuzin DF or liquid (L) formulations and linuron WP or L formulations were tank-mixed with glyphosate. Glyphosate was always applied with additives ammonium sulphate and Agral 90 and residual herbicides with metolachlor for all treatments.

Glyphosate at lower application rates when tank-mixed with metribuzin provided lower initial weed burndown as compared to their separate application in 1988. This phenomenon was observed whether metribuzin was applied in the dry flowable (DF) or in liquid (L) formulations. Similarly, glyphosate when tank-mixed with the wettable powder (WP) or liquid (L) formulations of linuron also provided lower initial weed burndown ratings as compared to their separate application in 1989.

Late season control of grassy and broadleaf weeds were similar when glyphosate was tank-mixed with residual herbicides in their various formulations. However, poor weed control ratings of annual weeds was recorded when linuron and/or chloramben was applied with glyphosate. This may be due to the lower application rates of these residual herbicides.

Soybeans yields were not affected due to tank-mixing glyphosate and residual herbicides in 1988 and 1989. However, lower soybeans yields were recorded from the plots where poor annual weed control was achieved due to the lower application rates of residual herbicides.

Table 33. Soybeans yield as affected by various treatments in 1989 and 1990.

#	Treatment[‡]	Dose	Yield	
		kg a.i./ha	1989	1990
			— kg.ha^{-} —	
1	Weedy check		1630	750
2	Glyphosate[‡]; metol.[§]+ metribuzin (DF)	.30; 2.4 + .56	3380	1540
3	Glyphosate; metol. + metribuzin (DF)	.45; 2.4 + .56	3270	2470
4	Glyphosate; metol. + metribuzin (DF)	.68; 2.4 + .56	3270	2890
5	Glyphosate; metol. + metribuzin (DF)	.90; 2.4 + .56	2730	2270
6	Glyphosate + metol. + metribuzin (DF)	.30 + 2.4 + .56	2590	2320
7	Glyphosate + metol. + metribuzin (DF)	.45 + 2.4 + .56	2770	1570
8	Glyphosate + metol. + metribuzin (DF)	.68 + 2.4 + .56	3140	1890
9	Glyphosate + metol. + metribuzin (DF)	.90 + 2.4 + .56	3730	2410
10	Glyphosate + metol. + metribuzin (L)	.30 + 2.4 + .56	2780	1780
11	Glyphosate + metol. + metribuzin (L)	.45 + 2.4 + .56	3230	2420
12	Glyphosate + metol. + metribuzin (L)	.68 + 2.4 + .56	3150	2270
13	Glyphosate + metol. + metribuzin (L)	.90 + 2.4 + .56	3150	2980
14	Glyphosate; metol. + linuron (WP)[¶]	.45; 2.4 + 1.0	2630	2960
15	Glyphosate; metol. + linuron (WP)	.90; 2.4 + 1.0	3510	2490
16	Glyphosate + metol. + linuron (WP)	.45 + 2.4 + 1.0	2310	1670
17	Glyphosate + metol. + linuron (WP)	.90 + 2.4 + 1.0	2350	1840
18	Glyphosate + metol. + linuron (L)	.45 + 2.4 + 1.0	2400	1830
19	Glyphosate + metol. + linuron (L)	.90 + 2.4 + 1.0	2370	2280
20	Glyphosate + chloramben + linuron (L)	.45 + 3.0 + 1.0	1490	1120
	LSD		810	1190

[†] treatments 2 to 5, 14 and 15 were applied in split. In other treatments herbicides were tank-mixed at the time of application.

[‡] Glyphosate was always applied with ammonium sulphate at 2 kg.ha^{-1} + Agral® 90 at 0.5% (v/v).

[§] metolachlor

[¶] linuron was applied at 0.56 kg.ha^{-1} in 1989.

Table 34. Initial weed burndown ratings expressed as percent of weedy check as affected by tank-mixing of glyphosate and additives with residual herbicides in 1988, 1989 and 1990.

#	Treatment†	Weed burndown ratings	
		1988	1989
		%	%
1	Weedy check	0	0
2	Glyphosate; metolachlor + metribuzin (DF)	90	99
3	Glyphosate; metolachlor + metribuzin (DF)	88	100
4	Glyphosate; metolachlor + metribuzin (DF)	93	100
5	Glyphosate; metolachlor + metribuzin (DF)	79	100
6	Glyphosate + metolachlor + metribuzin (DF)	78	99
7	Glyphosate + metolachlor + metribuzin (DF)	84	98
8	Glyphosate + metolachlor + metribuzin (DF)	73	79
9	Glyphosate + metolachlor + metribuzin (DF)	76	100
10	Glyphosate + metolachlor + metribuzin (L)	64	99
11	Glyphosate + metolachlor + metribuzin (L)	76	93
12	Glyphosate + metolachlor + metribuzin (L)	78	100
13	Glyphosate + metolachlor + metribuzin (L)	86	99
14	Glyphosate; metolachlor + linuron (WP)	94	72
15	Glyphosate; metolachlor + linuron (WP)	98	96
16	Glyphosate + metolachlor + linuron (WP)	83	53
17	Glyphosate + metolachlor + linuron (WP)	86	60
18	Glyphosate + metolachlor + linuron (L)	94	63
19	Glyphosate + metolachlor + linuron (L)	80	61
20	Glyphosate + chloramben + linuron (L)	86	20
	LSD 5%	14	25

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† Glyphosate was always applied with ammonium sulphate at 2 kg.ha^{-1} + Agral® 90 at 0.5% (v/v).

Table 35. Annual broadleaf weed control ratings expressed as percent of weedy check as affected by tank-mixing of glyphosate and additives with residual herbicides in 1988, 1989 and 1990.

#	Treatment[†]	Broadleaf control ratings	1988	1989	1990
			%	%	%
1	Weedy check		0	0	0
2	Glyphosate; metolachlor + metribuzin (DF)		53	91	97
3	Glyphosate; metolachlor + metribuzin (DF)		58	94	99
4	Glyphosate; metolachlor + metribuzin (DF)		61	89	99
5	Glyphosate; metolachlor + metribuzin (DF)		35	96	98
6	Glyphosate + metolachlor + metribuzin (DF)		18	93	96
7	Glyphosate + metolachlor + metribuzin (DF)		38	95	94
8	Glyphosate + metolachlor + metribuzin (DF)		45	71	96
9	Glyphosate + metolachlor + metribuzin (DF)		54	93	94
10	Glyphosate + metolachlor + metribuzin (L)		30	93	96
11	Glyphosate + metolachlor + metribuzin (L)		38	96	97
12	Glyphosate + metolachlor + metribuzin (L)		31	94	93
13	Glyphosate + metolachlor + metribuzin (L)		54	91	97
14	Glyphosate; metolachlor + linuron (WP)		63	60	90
15	Glyphosate; metolachlor + linuron (WP)		71	89	95
16	Glyphosate + metolachlor + linuron (WP)		56	60	86
17	Glyphosate + metolachlor + linuron (WP)		68	55	83
18	Glyphosate + metolachlor + linuron (L)		70	69	81
19	Glyphosate + metolachlor + linuron (L)		63	54	81
20	Glyphosate + chloramben + linuron (L)		63	20	86
	LSD 5%		27	23	4

[†] Glyphosate was always applied with ammonium sulphate at 2 kg.ha^{-1} + Agral® 90 at 0.5% (v/v).

Table 36. Annual grass control ratings expressed as percent of weedy check as affected by tank-mixing of glyphosate and additives with residual herbicides in 1988, 1989 and 1990.

#	Treatment†	Grass control ratings		
		1988	1989	1990
		%		
1	Weedy check	0	0	0
2	Glyphosate; metolachlor + metribuzin (DF)	71	95	97
3	Glyphosate; metolachlor + metribuzin (DF)	66	98	99
4	Glyphosate; metolachlor + metribuzin (DF)	69	96	99
5	Glyphosate; metolachlor + metribuzin (DF)	63	97	99
6	Glyphosate + metolachlor + metribuzin (DF)	63	98	97
7	Glyphosate + metolachlor + metribuzin (DF)	60	97	97
8	Glyphosate + metolachlor + metribuzin (DF)	59	94	98
9	Glyphosate + metolachlor + metribuzin (DF)	69	96	99
10	Glyphosate + metolachlor + metribuzin (L)	64	96	96
11	Glyphosate + metolachlor + metribuzin (L)	58	97	99
12	Glyphosate + metolachlor + metribuzin (L)	64	97	98
13	Glyphosate + metolachlor + metribuzin (L)	71	96	99
14	Glyphosate; metolachlor + linuron (WP)	69	70	95
15	Glyphosate; metolachlor + linuron (WP)	81	95	98
16	Glyphosate + metolachlor + linuron (WP)	70	92	96
17	Glyphosate + metolachlor + linuron (WP)	71	85	95
18	Glyphosate + metolachlor + linuron (L)	58	73	95
19	Glyphosate + metolachlor + linuron (L)	46	90	92
20	Glyphosate + chloramben + linuron (L)	50	58	90
	LSD 5%	21	25	5

† Glyphosate was always applied with ammonium sulphate at 2 kg.ha^{-1} + Agral® 90 at 0.5% (v/v).

4.6 COMPATIBILITY OF BURNDOWN AND RESIDUAL HERBICIDES FOR QUACKGRASS CONTROL

RESEARCH SUMMARY:

OBJECTIVE : To determine the compatibility of various burn-down and residual herbicide combinations on quackgrass.

RESULTS :

1) Quackgrass shoot control (as a % of the untreated shoot dry weight) for two doses of glyphosate, paraquat or glufosinate averaged over three years).
2) Comparisons of split vs. tank-mixed combinations.

Note: -ve sign in tables indicates loss of control when tank-mixed, +ve sign indicates increase in control when tank-mixed.

Table 37. Impact of tank-mixing burndown and residual herbicides on quackgrass control ratings in 1987, 1988 and 1989.

GLYPHOSATE

Residual herbicide		Glyphosate dose (kg/ha)		Average
Herbicide	Dose	0.45	0.90	response of doses
		%		
Linuron (L)	2.25 kg/ha	- 5.6	- 27.6	- 16.6
Atrazine (DF)	1.50 kg/ha	- 0.8	- 10.2	- 5.5
Metribuzin (DF)	0.60 kg/ha	- 5.4	- 41.7	- 23.5
Metolachlor	2.64 kg/ha	+ 13.9	+ 10.2	+ 12.1

Table 37 continued ......

PARAQUAT

Residual herbicide		Paraquat dose (kg/ha)		Average
Herbicide	Dose	0.50	1.00	response of doses
		%		
Linuron (L)	2.25 kg/ha	- 14.8	+ 6.4	- 4.2
Atrazine (DF)	1.50 kg/ha	+ 4.5	+ 7.7	+ 6.1
Metribuzin (DF)	0.60 kg/ha	+ 6.4	+ 10.1	+ 8.3
Metolachlor	2.64 kg/ha	+ 8.8	+ 5.6	+ 7.2

GLUFOSINATE

Residual herbicide		Glufosinate dose (kg/ha)		Average
Herbicide	Dose	0.50	1.00	response of doses
		%		
Linuron (L)	2.25 kg/ha	+ 2.4	- 8.3	- 2.9
Atrazine (DF)	1.50 kg/ha	+ 15.7	+ 17.4	+ 16.5
Metribuzin (DF)	0.60 kg/ha	- 4.4	+ 17.7	+ 6.7
Metolachlor	2.64 kg/ha	+ 13.1	- 5.4	+ 3.9

OTHER RESIDUAL HERBICIDES

Residual herbicide		Burndown herbicide		
Herbicide	Dose	Glyphosate (0.90 kg/ha)	Paraquat (0.50 kg/ha)	Glufosinate (1.0 kg/ha)
		%		
2,4-D amine	0.50 kg/ha[†]	- 14.6	- 13.9	- 8.0
2,4-D ester	0.50 kg/ha	- 2.4	- 0.6	+ 2.6
Dicamba	0.60 kg/ha	+ 0.5	+ 0.5	- 1.6

2,4-D was applied at 1.50 kg/ha in 1989

4.7 RECOMMENDATIONS

On the basis of field experiments conducted at different sites from 1987 to 1990 the following recommendations are suggested for tank-mixing of various burndown and residual herbicides in no-till crop production systems:

4.7.1 Paraquat and Glufosinate Antagonism with Residual Herbicides in Corn.

! Paraquat at 0.5 kg.ha^{-1} can be tank-mixed with recommended label rates of metolachlor + atrazine (WP or liquid) or cyanazine (WP or liquid) for annual weed control in corn.

! Glufosinate (0.5 to 0.75 kg.ha^{-1}) can be tank-mixed with recommended label rates of metolachlor + atrazine WG for annual weed control in corn.

4.7.2 Glyphosate Antagonism with Residual Herbicides in the Presence of Additives in No-till Corn.

! Glyphosate from 0.30 to 0.90 kg.ha^{-1} + ammonium sulphate at 0.2% (v/v) + Agral® 90 at 0.5% (v/v) may be tank-mixed with metolachlor + atrazine, cyanazine, or dicamba at labelled rates for weed burndown and residual control of annual weeds in corn.

4.7.3 Paraquat and Glufosinate Antagonism with Residual Herbicides in Soybeans.

! Paraquat at 0.5 kg.ha^{-1} can be tank-mixed with recommended label rates of metolachlor + metribuzin or linuron for annual weed burndown and subsequent residual weed control.

! Glufosinate at 0.50 to 0.75 $kg.ha^{-1}$ can be tank-mixed with recommended labelled rates of metolachlor + metribuzin or linuron for annual weed burndown and subsequent residual weed control.

4.7.4 Glyphosate Antagonism with Residual Herbicides in the Presence of Additives in No-till Soybeans.

! Glyphosate from 0.45 to 0.90 $kg.ha^{-1}$ + ammonium sulphate at 2 $l.ha^{-1}$ + Agral® 90 at 0.1% (v/v) may be tank-mixed with residual herbicides metolachlor + metribuzin or linuron at labelled rates for burndown and residual control of annual weeds in soybeans.

4.7.5 Antagonism of Paraquat, Glyphosate and Glufosinate with Various Residual Herbicides for Quackgrass Control

! The herbicidal activity of glyphosate was antagonised with tank-mixtures of linuron (L), atrazine (DF), metribuzin (DF), dicamba or 2,4-D in amine or ester salts at recommended labelled rates.

! The herbicidal activity of glyphosate was synergised when tank-mixed with metolachlor at recommended labelled rates.

! The herbicidal activity of paraquat was antagonised with tank-mixtures of linuron (L) or 2,4-D in amine or ester salts at recommended labelled rates.

! The dose of paraquat can be reduced to 0.50 $kg.ha^{-1}$ from 1.0 $kg.ha^{-1}$ if tank-mixed with atrazine, metolachlor or metribuzin at currently recommended rates.

! The herbicidal activity of glufosinate was antagonised with tank-mixtures of linuron (L), dicamba or amine salt of 2,4-D at recommended labelled rates.

! The herbicidal activity of glufosinate was synergised when tank-mixed with atrazine (DF), metribuzin (DF), metolachlor or ester salt of 2,4-D at recommended labelled rates.

OBJECTIVE # 3

5.0 IMPACT OF TANK-MIXES OF BURNDOWN AND RESIDUAL HERBICIDES WITH ADDITIVES ON WEED CONTROL IN CONSERVATION TILLAGE SYSTEMS.

Herbicides are marketed in various formulations to improve herbicidal efficacy, shelf-life and to facilitate their mixing in water. Herbicide formulations usually contain the parent herbicide molecule and various additives and fillers. However, some of these additives and fillers are unstable and may react among themselves. Therefore, materials which may not be included in the manufacturer's formulation may be added to the spray solution just before its actual use. Some of these additives may be beneficial in terms of improving herbicide efficacy, its spectrum and economics. It is well documented that various additives may be tank-mixed with herbicides at the time of spray to increase herbicidal activity or to widen the herbicidal spectrum (O'Sullivan et al. 1983, Turner 1984, Harrison et al. 1986). The use of additives led to an improvement in herbicidal activity due to enhanced in uptake and translocation of herbicides (Nalewaja and Skrzyczak 1986, Chandrasena and Sagar 1986). However, some of the additives may also decrease the biological activity of herbicides on weeds (Harrison et al. 1986, Hallgren and Nilsson 1986) or reduce crop yields (Witt et al. 1984, Harrison et al. 1986).

This knowledge opened a new horizon of using herbicides with various additives to improve the weed control in no-till cropping systems. Weed management under a no-till crop management system is more complex and weed control may be highly variable (Weber and Lowder, 1985). It was hypothesized that the use of additives in combination with various burndown and residual herbicides would improve weed management in no-till corn and soybeans in Ontario. Therefore, a series of field experiments were initiated to study the effect of tank-mixing various herbicides with additives for the control of weeds in conservation tillage.

5.1 METHODS AND MATERIALS

Field experiments were conducted to evaluate the effect of various herbicides with additives on the weed burndown effects in no-till systems. The details of experimental procedures followed and material used are described briefly.

5.1.1. Experimental Locations

Details of experimental locations and soil types of various trials are presented in Table 38.

Table 38. Details of experimental locations and soil types for experiments conducted from 1987 to 1990.

Crop	Experiment			Soil					
	#	Site	Location	Type	Sand	Silt	Clay	O.M.	pH
					%				
Corn	5.2	Dealtown	42E 15'N 82E 5' W	Fox Gravelly Loam	59	31	10	2.8	6.1
Corn	5.3[†]	Dealtown	42E 15'N 82E 5' W	Fox Gravelly Loam	59	31	10	2.8	6.1
Corn	5.4	Clinton (1988)	43E 5' N 81E 5' W	Burford loam	67	23	10	3.9	6.4
		Woodstock (1989)	43E 8' N 80E 45'W	Sandy loam	53	34	13	3.3	6.8
Soybeans	5.5	Dealtown	42E 15'N 82E 5' W	Fox Gravelly Loam	59	31	10	2.8	6.1
Soybeans	5.6	Clinton (1988)	43E 5' N 81E 5' W	Burford loam	67	23	10	3.9	6.4
		Woodstock (1989)	43E 8'N 80E 45'W	Sandy loam	53	34	13	3.3	6.8
Fallow/ Quackgrass	5.7	Elora	42E 27'N 81E 53'W	Guelph loam	29	53	18	4.3	7.4

[†] Experiment was conducted at Mr. Art Wardle's farm, Ridgetown on Brookston clay loam soil in 1987.

5.1.2. Agronomy

Experiments were conducted using standard agronomic practices (OMAF publication 296, Field Crop Recommendations) in no-till plots. Soil samples were taken from each field at the beginning of the crop season and were analyzed for available nutrient status. Fertilization was done according to soil tests and requirements of individual crops. Fertilizers, if required were placed at the time of sowing of the crop with minimum soil surface disturbances.

Corn cv. Renk® R148, Dekalb® 524, Renk® R138, Pioneer® 3790, were planted at their recommended seeding densities in 75 cm rows in 1987, 1988, 1989 and 1990, respectively at Dealtown or Ridgetown sites. The corn cultivars Pioneer® 3790 and Pioneer® 3925 were planted at their recommended seeding rates in 76 cm rows at Clinton and Woodstock sites, respectively. The individual plot size at Dealtown and Ridgetown sites were 6 x 1.5 m and at Clinton and Woodstock sites 6 x 3 m.

Soybeans cv. Elgin, KG 60 and Pioneer® 0877 were planted in 40 cm rows at a seeding rate of 70 to 100 $kg.ha^{-1}$ at Dealtown, Clinton and Woodstock sites, respectively. The individual soybeans plot sizes were 6 x 1.5 m at Dealtown and at Clinton and Woodstock sites 6 x 3 m.

The quackgrass experiment was established using the quackgrass biotype found at Elora Research Station, Elora, Ontario. The individual size of quackgrass plots was 6 x 2 m.

Corn and soybeans were harvested from the centre of plots leaving side border rows at Clinton, Elora and Woodstock sites and from whole plot at Dealtown site. Final yield was later converted and expressed at 14% and 15.5% moisture content for soybeans and corn, respectively.

Planting, spraying and crop harvesting dates are presented in Table 39.

Table 39. Planting, spraying and crop harvesting dates for experiments conducted in 1987, 1988, 1989 and 1990.

Crop	Expt. #	Year	Date(s) Planting	Spraying	Harvesting
Corn	5.2	1988	May 12	May 17	-
		1989	May 10	May 15	Nov. 9
		1990	June 5	May 9	-
Corn	5.3	1987	May 13	May 18	-
		1988	May 12	May 17	-
		1989	May 10	May 17	Nov. 9
		1990	June 5	May 9	-
Corn	5.4	1988	May 6	May 6	Oct. 20
		1989	May 17	May 17	Oct. 27
Soybeans	5.5	1988	May 19	May 20	-
		1989	May 15	May 17	Oct. 27
		1990	May 15	May 14	-
Soybeans	5.6	1988	May 22	May 25	Oct. 3
		1989	May 29	May 25	Oct. 12
Fallow/	5.7	1986	-	Nov. 11 & 17	-
Quackgrass†		1987	-	Nov. 10	-

† Spring applied herbicides were sprayed on May 5, 1987 and May 17, 1988.

5.1.3 Spraying Equipment and Procedures

Individual plots were sprayed using a 'bicycle sprayer' at Elora, Clinton and Woodstock site and by an 'Oxford Precision Sprayer' at Dealtown site. The quantity of spray solution used for the bicycle sprayer was 225 $l.ha^{-1}$ at 180 kPa. The 'Oxford Precision Sprayer' used 200 $l.ha^{-1}$ of spray solution at 240 kPa.

5.1.4 Experiment Design and Analysis

All experiments were conducted in randomized complete block design (RCBD) with 4 replications. Results were analyzed using analysis of variance (ANOVA) procedures and means were then separated using least significant difference (LSD) at 5% level of significance.

5.2 The Role of Additive with Residual Herbicides in Corn

RESEARCH SUMMARY:

Additives Agral® 90, Kornoil concentrate® and Kornoil® when used with different herbicides provided excellent initial weed burndown and excellent seasonal control of grassy and broadleaf weeds. Residual herbicides when applied with fertilizer 10-34-0 at higher application rate (110 $L.ha^{-1}$) provided average burndown in 1988 and thus this additive was deleted from treatments in subsequent years. Fertilizer based additives such as 28% N, 10-34-0, Aqua 21% N, Liquid cyanamid® when applied with residual herbicides also facilitated excellent initial burndown and subsequent weed control. However, there were some weed escapes.

Overall, the addition of dicamba with metolachlor + atrazine had no additional impact on the weed control. Dicamba with additives Aqua 21% N or Kornoil concentrate® (COC) significantly reduced corn yield in 1989.

Table 40. Corn yield as affected by various treatments in 1989.

#	Treatment	Dose kg a.i./ha	Yield 1989
			– $kg.ha^{-1}$ –
1	check		1720
2	Metol.[†]+ atra.[‡]+ Agral 90	2.4 + 1.5 + .1%	6780
3	Metol. + atra. + COC	2.4 + 1.5 + 1%	6700
4	Metol. + atra. + oil	2.4 + 1.5 + 10 L	5970
5	Metol. + atra. + 28% N	2.4 + 1.5 + 10 L	5280
6	Metol. + atra. + 28% N	2.4 + 1.5 + 500 L	7810
7	Metol. + atra. + 10-34-0	2.4 + 1.5 + 10 L	6920
8	Metol. + atra.	2.4 + 1.5	7450
9	Metol. + atra. + aqua 21% N	2.4 + 1.5 + 10 L	6870
10	Metol. + atra. + L.C.[§]	2.4 + 1.5 + 10 L	5650
11	Metol. + atra. + dicamba + Agral 90	2.4 + 1 + .6 + .1%	6220
12	Metol. + atra. + dicamba + COC	2.4 + 1 + .6 + 1 %	4730
13	Metol. + atra. + dicamba + oil	2.4 + 1 + .6 + 10 L	5290
14	Metol. + atra. + dicamba + 28% N	2.4 + 1 + .6 + 10 L	5780
15	Metol. + atra. + dicamba + 28% N	2.4 + 1 + .6 + 500 L	6300
16	Metol. + atra. + dicamba + 10-34-0	2.4 + 1 + .6 + 10 L	5920
17	Metol. + atra. + dicamba	2.4 + 1 + .6	6240
18	Metol. + atra. + dicamba + aqua 21% N	2.4 + 1 + .6 + 10 L	4950
19	Metol. + atra. + dicamba + L.C.	2.4 + 1 + .6 + 10 L	6300
20	Metol. + atra. + dicamba + 28% N + COC	2.4 + 1 + .6 + 10 L+1%	6280
	LSD 5%		1530

[†] metolachlor

[‡] atrazine

[§] Liquid cyanamid®

Table 41. Initial annual weed burndown ratings expressed as percent of weedy check as affected by residual herbicides with additives in 1988, 1989 and 1990.

#	Treatment	Weed burndown ratings		
		1988	1989	1990
		%		
1	Weedy check	0	0	0
2	Metol.[†]+ atrazine + Agral 90	97	98	98
3	Metol. + atrazine + COC	96	93	91
4	Metol. + atrazine + oil	98	86	89
5	Metol. + atrazine + 28% N	97	65	86
6	Metol. + atrazine + 28% N	91	99	91
7	Metol. + atrazine + 10-34-0	99	90	86
8	Metol. + atrazine	75	90	88
9	Metol. + atrazine + aqua 21% N	93	99	78
10	Metol. + atrazine + L.C.[‡]	84	95	91
11	Metol. + atrazine + dicamba + Agral 90	99	96	97
12	Metol. + atrazine + dicamba + COC	99	95	98
13	Metol. + atrazine + dicamba + oil	87	99	93
14	Metol. + atrazine + dicamba + 28% N	96	99	88
15	Metol. + atrazine + dicamba + 28% N	93	97	87
16	Metol. + atrazine + dicamba + 10-34-0	79	96	76
17	Metol. + atrazine + dicamba	74	99	79
18	Metol. + atrazine + dicamba + aqua 21% N	88	88	83
19	Metol. + atrazine + dicamba + L.C.	76	97	91
20	Metol. + atrazine + dicamba + 28% N + COC	91	97	95
	LSD 5%	20	21	16

[†] metolachlor

[‡] Liquid cyanamid®

Table 42. Broadleaf weed control ratings expressed as percent of weedy check as affected by residual herbicides with additives in 1988, 1989 and 1990.

#	Treatment	Broadleaf control ratings		
	1988	1989	1990	
			%	
1	Weedy check	0	0	0
2	Metol.[†]+ atrazine + Agral 90	82	98	99
3	Metol. + atrazine + COC	80	98	95
4	Metol. + atrazine + oil	78	98	97
5	Metol. + atrazine + 28% N	77	65	96
6	Metol. + atrazine + 28% N	75	99	96
7	Metol. + atrazine + 10-34-0	80	93	96
8	Metol. + atrazine	78	98	96
9	Metol. + atrazine + aqua 21% N	93	100	93
10	Metol. + atrazine + L.C.[‡]	80	99	98
11	Metol. + atrazine + dicamba + Agral 90	82	99	98
12	Metol. + atrazine + dicamba + COC	83	96	90
13	Metol. + atrazine + dicamba + oil	83	99	92
14	Metol. + atrazine + dicamba + 28% N	80	99	95
15	Metol. + atrazine + dicamba + 28% N	80	99	96
16	Metol. + atrazine + dicamba + 10-34-0	80	96	91
17	Metol. + atrazine + dicamba	80	100	93
18	Metol. + atrazine + dicamba + aqua 21% N	77	99	93
19	Metol. + atrazine + dicamba + L.C.	68	98	96
20	Metol. + atrazine + dicamba + 28% N + COC	67	98	97
	LSD 5%	17	15	7

[†] metolachlor

[‡] Liquid cyanamid®

Table 43. Grassy weed control ratings expressed as percent of weedy check as affected by residual herbicides with additives in 1988, 1989 and 1990.

#	Treatment	Grass control ratings		
	1988	1989	1990	
		%		
1	Weedy check	0	0	0
2	Metol.[†]+ atrazine + Agral 90	93	98	99
3	Metol. + atrazine + COC	93	98	98
4	Metol. + atrazine + oil	93	98	98
5	Metol. + atrazine + 28% N	87	73	98
6	Metol. + atrazine + 28% N	90	99	95
7	Metol. + atrazine + 10-34-0	92	96	97
8	Metol. + atrazine	82	96	98
9	Metol. + atrazine + aqua 21% N	80	99	94
10	Metol. + atrazine + L.C.[‡]	77	99	97
11	Metol. + atrazine + dicamba + Agral 90	92	99	99
12	Metol. + atrazine + dicamba + COC	93	97	90
13	Metol. + atrazine + dicamba + oil	77	99	99
14	Metol. + atrazine + dicamba + 28% N	92	99	98
15	Metol. + atrazine + dicamba + 28% N	87	99	99
16	Metol. + atrazine + dicamba + 10-34-0	88	99	94
17	Metol. + atrazine + dicamba	83	99	96
18	Metol. + atrazine + dicamba + aqua 21% N	83	99	97
19	Metol. + atrazine + dicamba + L.C.	77	97	99
20	Metol. + atrazine + dicamba + 28% N + COC	75	98	98
	LSD 5%	4	16	6

[†] metolachlor

[‡] Liquid cyanamid®

Table 44. Total weed biomass accumulation as affected by various treatments in 1989 and 1990.

#	Treatment	Total weed biomass			
		Broadleaf		Grasses	
		1989	1990	1989	1990
		$g.m^{-1}$			
1	check	1442	1363	658	6
2	Metol.[†] + atra.[‡] + Agral 90	128	279	100	66
3	Metol. + atra. + COC	174	383	200	129
4	Metol. + atra. + oil	76	539	78	0
5	Metol. + atra. + 28% N	496	405	86	2
6	Metol. + atra. + 28% N	186	270	134	49
7	Metol. + atra. + 10-34-0	276	762	172	0
8	Metol. + atra.	126	187	194	63
9	Metol. + atra. + aqua 21% N	34	623	110	8
10	Metol. + atra. + L.C.[§]	96	12	110	392
11	Metol. + atra. + dicamba+ Agral 90	110	202	236	4
12	Metol. + atra. + dicamba + COC	102	494	286	12
13	Metol. + atra. + dicamba + oil	152	166	168	33
14	Metol. + atra. + dicamba + 28% N	386	79	98	142
15	Metol. + atra. + dicamba + 28% N	214	542	30	52
16	Metol. + atra. + dicamba + 10-34-0	108	548	84	111
17	Metol. + atra. + dicamba	134	272	176	4
18	Metol. + atra. + dicamba + aqua 21% N	206	260	104	48
19	Metol. + atra. + dicamba + L.C.	282	341	656	6
20	Metol. + atra. + dicamba + 28% N + COC	114	154	82	119
	LSD 5%	436	593	364	213

[†] metolachlor

[‡] atrazine

[§] Liquid cyanamid®

5.3 Herbicides for Burndown and Residual Control of Annual Weeds in No-till Corn

RESEARCH SUMMARY:

Residual herbicides provided satisfactory to excellent burndown of annual and perennial weed species. Cyanazine with atrazine or glufosinate provided excellent early-season weed burndown. Burndown herbicides glufosinate and paraquat in combination with residual herbicides metolachlor, dicamba, metribuzin, cyanazine, atrazine or SAN S82 were also excellent treatments for broad spectrum burndown activity.

Late emerging broad-leaved weed control by various residual herbicides was also satisfactory to excellent. Atrazine + linuron or metribuzin with burndown herbicides were very effective in controlling late-emerging broadleaf weeds in 1988, 1989 and 1990. However, in 1987 scentless chamomile escaped these herbicides resulting in overall poor broadleaf weed control. Similarly, redroot pigweed escaped glufosinate + cyanazine in 1988. Linuron alone or in combination with metolachlor or glufosinate failed to control pineapple weed in 1989.

Residual herbicides provided excellent control of late emerging grasses. However, there were a few exceptions. Atrazine + DPX 6316 failed to control barnyardgrass in 1988 and green foxtail in 1989. Similarly, barnyard grass, green foxtail and downeybrome escaped linuron or metribuzin treated plots in 1989.

Corn yields were significantly reduced in treatments receiving linuron or atrazine/dicamba in 1989. This may be due to a poor weed control provided by these herbicides. Metribuzin treated plots also had poor corn yields as this herbicide caused significant crop injury at the beginning of the growing season.

Table 45. Corn yield as affected by various treatments in 1989.

#	Treatment[†]	Dose kg a.i./ha	Yield 1989
			– kg/ha –
1	Weedy check		1880
2	Atrazine	1.5	5110
3	Cyanazine	2.5	5020
4	Cyanazine + atrazine	2.5 + 1.5	7100
5	Linuron	2.0	2450
6	Metribuzin	0.75	3930
7	Linuron + metribuzin	1 + 0.5	4620
8	Metolachlor + linuron	2.4 + 1.0	3660
9	Metolachlor + metribuzin	2.4 + 0.5	4900
10	Metolachlor + atrazine + linuron	2.4 + 1 + 1	6850
11	CGA 180937 + atrazine + linuron	2.3 + 1 + 1	5670
12	CGA 180937 + metribuzin	2.3 + 0.5	4610
13	Dicamba/atrazine	1.75	3810
14	Dicamba/atrazine	1.75	3720
15	Glufosinate + linuron	0.75 + 2	2990
16	Glufosinate + metolachlor + dicamba	0.75 + 2.4 + .6	5140
17	Glufosinate + metribuzin	0.75 + 0.75	3970
18	Glufosinate + cyanazine	0.75 + 2.25	7060
19	DPX M6316 + atrazine	0.012 + 1.5	5820
20	Paraquat + SAN 582 + atrazine	0.5 + 1.25 + 1	5750
	LSD 5%		1850

[†] treatments except 12 were applied with Kornoil concentrate® at 1% (v/v).

Table 46. Initial weed burndown ratings expressed as percent of weedy check as affected by various treatments in 1988,1989 and 1990.

#	Treatment		Weed burndown ratings		
			1988	1989	1990
			%		
1	Weedy check		0	0	0
2	Atrazine + COC[†]		100	94	69
3	Cyanazine + COC		83	94	81
4	Cyanazine + atrazine + COC	96	100	99	
5	Linuron + COC		99	63	88
6	Metribuzin + COC		91	88	69
7	Linuron + metribuzin + COC	98	97	89	
8	Metolachlor + linuron + COC	99	60	55	
9	Metolachlor + metribuzin + COC	96	91	78	
10	Metolachlor + atrazine + linuron + COC	84	93	83	
11	CGA 180937 + atrazine + linuron + COC	98	92	67	
12	CGA 180937 + metribuzin + COC	99	97	56	
13	Dicamba/atrazine		87	79	93
14	Dicamba/atrazine + COC		99	75	95
15	Glufosinate + linuron + COC	91	46	94	
16	Glufosinate + metolachlor + dicamba + COC	99	71		92
17	Glufosinate + metribuzin + COC	97	96	99	
18	Glufosinate + cyanazine + COC	92	99	100	
19	DPX M6316 + atrazine + COC	86	98	96	
20	Paraquat + SAN 582 + atrazine + COC		92	99	97
	LSD 5%		12	19	24

[†] Kornoil concentrate®

Table 47. Broadleaf weed control ratings expressed as percent of weedy check as affected by preemergence herbicides with additives in 1987, 1988, 1989 and 1990.

#	Treatment		Broadleaf weed control			
			1987	1988	1989	1990
			%			
1	Weedy check		0	0	0	0
2	Atrazine + COC†		85	70	85	80
3	Cyanazine + COC		85	66	85	82
4	Cyanazine + atrazine + COC	80	78	97	98	
5	Linuron + COC		81	66	83	85
6	Metribuzin + COC		80	74	97	95
7	Linuron + metribuzin + COC		81	78	98	96
8	Metolachlor + linuron + COC	81	76	68	95	
9	Metolachlor + metribuzin + COC		83	80	90	98
10	Metolachlor + atrazine + linuron + COC	81	79	89	98	
11	CGA 180937 + atrazine + linuron + COC	60	73	98	97	
12	CGA 180937 + metribuzin + COC		74	71	98	97
13	Dicamba/atrazine		80	80	83	97
14	Dicamba/atrazine + COC		81	82	81	98
15	Glufosinate + linuron + COC	83	78	53	95	
16	Glufosinate + metolachlor + dicamba + COC	81	84	71	91	
17	Glufosinate + metribuzin + COC		83	75	95	98
18	Glufosinate + cyanazine + COC		83	60	85	92
19	DPX M6316 + atrazine + COC		81	56	90	98
20	Paraquat + SAN 582 + atrazine + COC		83	76	97	84
	LSD 5%			14	20	24
	16					

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† Kornoil concentrate®

Table 48. Annual grass control ratings expressed as percent of weedy check as affected by preemergence herbicides with additives in 1987, 1988, 1989 and 1990.

#	Treatment	Grass weed control			
		1987	1988	1989	1990
		%			
1	Weedy check	0	0	0	0
2	Atrazine + COC[†]	13	85	75	79
3	Cyanazine + COC	0	79	78	87
4	Cyanazine + atrazine + COC	0	84	90	98
5	Linuron + COC	0	81	50	82
6	Metribuzin + COC	0	89	61	94
7	Linuron + metribuzin + COC	0	89	90	98
8	Metolachlor + linuron + COC	0	89	91	98
9	Metolachlor + metribuzin + COC	0	89	95	99
10	Metolachlor + atrazine + linuron + COC	13	84	94	99
11	CGA 180937 + atrazine + linuron + COC	25	85	94	99
12	CGA 180937 + metribuzin + COC	0	89	93	98
13	Dicamba/atrazine	19	74	66	95
14	Dicamba/atrazine + COC	0	90	70	87
15	Glufosinate + linuron + COC	6	86	74	99
16	Glufosinate + metolachlor + dicamba + COC	0	88	90	98
17	Glufosinate + metribuzin + COC	20	79	95	91
18	Glufosinate + cyanazine + COC	0	75	91	98
19	DPX M6316 + atrazine + COC	0	63	73	92
20	Paraquat + SAN 582 + atrazine + COC	13	78	95	95
	LSD 5%	NS	12	19	17

[†] Kornoil concentrate®

5.4 Annual Weed Control in No-till Corn by Residual Herbicides Applied With Additives

RESEARCH SUMMARY:

Experiments were conducted at Clinton in 1988 and at the Woodstock Research Station in 1989. Common ragweed (Ambrosia artemisiifolia L.) was the pre-dominant weed species at Clinton and lamb's-quarters (Chenopodium album L.) at Woodstock, redroot pigweed (Amaranthus retroflexus L.) and common ragweed.

All residual herbicides provided excellent annual weed control in 1988. However, in 1989, atrazine resistant redroot pigweed and lamb's-quarters biotypes escaped all atrazine treatments. Linuron and dicamba provided excellent lamb's-quarters control but dicamba failed to control redroot pigweed which continued to emerge later in the season. Linuron failed to provide control of Canada fleabane.

Corn yields were not affected by the presence of weeds in 1988. However, in 1989, crop injury resulting from dicamba + metolachlor significantly reduced corn yield.

The addition of 28% N and Kornoil concentrate® had no impact on weed control in both years. However, in contrast additives increased corn injury by dicamba + metolachlor, which resulted in further corn yield losses.

Table 49. Corn yield as affected by various treatments in 1988 and 1989.

#	Treatment	Dose kg a.i./ha	Corn yield 1988	 1989
			—— kg.ha^{-1} ——	
1	Weedy		6150	3880
2	Paraquat	1.0	6720	7190
3	Paraquat + atrazine + metol.[†]	1.0 + 2.0 + 2.64	5660	8500
4	Atrazine	1.5	6000	9090
5	Atrazine + metol.	1.5 + 1.92	6530	7140
6	Cyanazine + metol.	2.0 + 1.92	6670	8170
7	Linuron + metol.	1.1 + 1.92	5680	7490
8	Dicamba + metol.	0.6 + 1.92	6510	6650
9	Atrazine + 28% N	1.5 + 5%	5790	7640
10	Atrazine + metol. + 28% N	1.5 + 1.92 + 5%	7000	8180
11	Cyanazine + metol. + 28% N	2.0 + 1.92 + 5%	6780	9050
12	Linuron + metol. + 28% N	1.1 + 1.92 + 5%	6080	7870
13	Dicamba + metol. + 28% N	0.6 + 1.92 + 5%	5920	6400
14	Atrazine + COC[‡]	1.5 + 1%	7340	8360
15	Atrazine + metol. + COC	1.5 + 1.92 + 1%	7040	8270
16	Cyanazine + metol. + COC	2.0 + 1.92 + 1%	7170	9280
17	Linuron + metol. + COC	1.1 + 1.92 + 1%	5810	8120
18	Dicamba + metol. + COC	0.6 + 1.92 + 1%	6000	6160
	LSD 5%		NS	1520

[†] metolachlor

[‡] Kornoil concentrate®

Table 50. Annual weed control ratings expressed as percent of weedy check as affected by preemergence herbicides with additive in 1988 and 1989.

#	Treatment	Weed control ratings				
		Ragweed		Pigweed	LQ[†]	Fleabane
		1988	1989	1989	1989	1989
		%				
1	Weedy check	0	0	0	0	0
2	Paraquat	65	98	5	60	53
3	Paraquat + atrazine + metol.[‡]	99	100	55	45	100
4	Atrazine	95	98	43	43	100
5	Atrazine + metol.	98	100	78	8	100
6	Cyanazine + metol.	95	100	38	38	100
7	Linuron + metol.	93	100	70	98	0
8	Dicamba + metol.	96	88	23	88	100
9	Atrazine + 28% N	93	100	75	38	100
10	Atrazine + metol. + 28% N	99	100	58	30	100
11	Cyanazine + metol. + 28% N	98	100	35	28	100
12	Linuron + metol. + 28% N	89	100	85	93	0
13	Dicamba + metol. + 28% N	100	93	45	95	100
14	Atrazine + COC[§]	100	100	18	23	100
15	Atrazine + metol. + COC	100	100	68	33	100
16	Cyanazine + metol. + COC	95	100	20	50	100
17	Linuron + metol. + COC	94	88	63	88	20
18	Dicamba + metol. + COC	98	100	33	80	100
	LSD 5%	14	11	33	33	13

[†] lamb's-quarters

[‡] metolachlor

[§] Kornoil concentrate®

5.5 Burndown and Residual Weed Control in Soybeans

RESEARCH SUMMARY:

Excellent weed burndown was achieved by various combinations of herbicides and additives in this experiment. Metribuzin with the additive Agral® 90 gave poor burndown in 1988, average in 1990 but satisfactory burndown in 1989. The weather in 1989 was favourable for excellent herbicidal activity, hence additives to improve the performance of residual herbicides as burndown treatments were not required.

Linuron in combination with selected additives exhibited excellent broadleaf weed control except when used with COC in 1990. Monolinuron with additive '10-34-0 fertilizer' gave poor results in all three years.

Linuron also provided excellent grassy weed control with all additive combinations. However, grassy weed control with metribuzin and Kornoil® was unsatisfactory in all three years.

Table 51. Soybeans yield as affected by various preemergence herbicides applied with additives in 1989.

#	Treatment	Dose kg a.i./ha	Yield 1989
			– kg/ha –
1	Check		1120
2	Metolachlor + metribuzin + Agral 90	2.4 + 0.6 + .1%	3080
3	Metolachlor + metribuzin + COC	2.4 + 0.6 + 1%	2660
4	Metolachlor + metribuzin + oil	2.4 + 0.6 + 10 L	3200
5	Metolachlor + metribuzin + 28% N	2.4 + 0.6 + 10 L	3300
6	Metolachlor + metribuzin + Aqua 21% N†	2.4 + 0.6 + 10 L	2930
7	Metolachlor + metribuzin + 10-34-0	2.4 + 0.6 + 10 L	2980
8	Metolachlor + metribuzin + Liq. cyanamid®	2.4 + 0.6 + 10 L	2930
9	Metolachlor + linuron + Agral 90	2.4 + 2.0 + 0.1%	3090
10	Metolachlor + linuron + COC	2.4 + 2.0 + 1%	3180
11	Metolachlor + linuron + oil	2.4 + 2.0 + 10 L	2810
12	Metolachlor + linuron + 28% N	2.4 + 2.0 + 10 L	2740
13	Metolachlor + linuron + Aqua 21% N	2.4 + 2.0 + 10 L	3170
14	Metolachlor + linuron + 10-34-0	2.4 + 2.0 + 10 L	2870
15	Metolachlor + linuron + Liq. cyanamid®	2.4 + 2.0 + 10 L	2440
16	Metolachlor + monolinuron + COC	2.4 + 2.0 + 1 %	2970
17	Metolachlor + monolinuron + oil	2.4 + 2.0 + 10 L	3000
18	Metolachlor + monolinuron + 28% N	2.4 + 2.0 + 10 L	2430
19	Metolachlor + monolinuron + 10-34-0	2.4 + 2.0 + 10 L	2520
20	Metolachlor + monolinuron + Liq. cyanamid®	2.4 + 2.0 + 10 L	2520
	LSD 5%		800

† aqua 21% N was tank-mixed in 1988 only.

Table 52. Initial weed burndown expressed as percent of weedy check as affected by various treatments in 1988, 1989 and 1990.

#	Treatment	Weed burndown ratings		
		1988	1989	1990
		%		
1	Weedy check	0	0	0
2	Metolachlor + metribuzin + Agral 90	63	100	71
3	Metolachlor + metribuzin + COC	60	100	72
4	Metolachlor + metribuzin + oil	57	100	72
5	Metolachlor + metribuzin + 28% N	82	99	86
6	Metolachlor + metribuzin + Aqua 21% N†	78	100	80
7	Metolachlor + metribuzin + 10-34-0	82	100	97
8	Metolachlor + metribuzin + Liq. cyanamid®	65	100	88
9	Metolachlor + linuron + Agral 90	80	99	93
10	Metolachlor + linuron + COC	83	99	73
11	Metolachlor + linuron + oil	82	100	40
12	Metolachlor + linuron + 28% N	85	99	61
13	Metolachlor + linuron + Aqua 21% N	93	98	38
14	Metolachlor + linuron + 10-34-0	90	99	94
15	Metolachlor + linuron + Liq. cyanamid®	88	99	88
16	Metolachlor + monolinuron + COC	85	100	84
17	Metolachlor + monolinuron + oil	80	97	85
18	Metolachlor + monolinuron + 28% N	90	92	82
19	Metolachlor + monolinuron + 10-34-0	82	89	68
20	Metolachlor + monolinuron + Liq. cyanamid®	82	94	80
	LSD 5%	19	6	36

† aqua 21% N was tank-mixed in 1988 only.

Table 53. Annual broadleaf weed control ratings expressed as percent of weedy check as affected by various treatments in 1988, 1989 and 1990.

#	Treatment	Broadleaf ratings		
		1988	1989	1990
		%		
1	Weedy check	0	0	0
2	Metolachlor + metribuzin + Agral 90	25	88	91
3	Metolachlor + metribuzin + COC	35	88	87
4	Metolachlor + metribuzin + oil	37	88	82
5	Metolachlor + metribuzin + 28% N	35	91	88
6	Metolachlor + metribuzin + Aqua 21% N†	40	91	93
7	Metolachlor + metribuzin + 10-34-0	40	92	94
8	Metolachlor + metribuzin + Liq. cyanamid®	18	88	86
9	Metolachlor + linuron + Agral 90	43	96	72
10	Metolachlor + linuron + COC	45	97	62
11	Metolachlor + linuron + oil	50	96	80
12	Metolachlor + linuron + 28% N	48	97	88
13	Metolachlor + linuron + Aqua 21% N	42	96	87
14	Metolachlor + linuron + 10-34-0	50	98	94
15	Metolachlor + linuron + Liq. cyanamid®	52	95	74
16	Metolachlor + monolinuron + COC	37	96	84
17	Metolachlor + monolinuron + oil	37	92	88
18	Metolachlor + monolinuron + 28% N	35	87	90
19	Metolachlor + monolinuron + 10-34-0	30	85	64
20	Metolachlor + monolinuron + Liq. cyanamid®	32	94	59
	LSD 5%	20	9	22

† aqua 21% N was tank-mixed in 1988 only.

Table 54. Annual grassy weed control ratings expressed as percent of weedy check as affected by various treatments in 1988, 1989 and 1990.

#	Treatment	Grass control ratings		
		1988	1989	1990
		%		
1	Weedy check	0	0	0
2	Metolachlor + metribuzin + Agral 90	37	96	98
3	Metolachlor + metribuzin + COC	37	90	98
4	Metolachlor + metribuzin + oil	23	82	88
5	Metolachlor + metribuzin + 28% N	40	93	98
6	Metolachlor + metribuzin + Aqua 21% N†	30	96	99
7	Metolachlor + metribuzin + 10-34-0	33	95	99
8	Metolachlor + metribuzin + Liq. cyanamid®	33	97	99
9	Metolachlor + linuron + Agral 90	43	97	97
10	Metolachlor + linuron + COC	53	99	99
11	Metolachlor + linuron + oil	53	96	92
12	Metolachlor + linuron + 28% N	50	97	98
13	Metolachlor + linuron + Aqua 21% N	43	97	99
14	Metolachlor + linuron + 10-34-0	47	99	99
15	Metolachlor + linuron + Liq. cyanamid®	47	99	94
16	Metolachlor + monolinuron + COC	37	97	98
17	Metolachlor + monolinuron + oil	43	94	98
18	Metolachlor + monolinuron + 28% N	33	97	99
19	Metolachlor + monolinuron + 10-34-0	40	93	99
20	Metolachlor + monolinuron + Liq. cyanamid®	43	96	96
	LSD 5%	15	10	8

† aqua 21% N was tank-mixed in 1988 only.

5.6 Annual Weed Control in No-till Soybeans by Residual Herbicides Applied With Additives

RESEARCH SUMMARY:

Imazethapyr provided excellent control of yellow nut sedge, wild buckwheat; satisfactory control of common ragweed and lamb's-quarters, but poor control of Canada fleabane. Linuron was very effective on lamb's-quarters but gave very poor control of yellow nut sedge and Canada fleabane. Metribuzin failed to control lamb's-quarters and yellow nut sedge. Ragweed was controlled by various herbicides with the exception of the lower dose of linuron + metribuzin. Most of the ragweed emerged at the time of herbicide application (prior to crop emergence). Paraquat provided excellent control of all emerged weed species. Additives did not have a major impact on weed control.

Soybean yields were not affected by weeds in 1988 as the predominant weed species, ragweed was present at very low densities (1-2 weeds.m^{-2}). Soybean yields from all herbicide treatments were not significantly reduced compared to the yields of the weed-free treatments. Linuron at higher doses or metribuzin applied without additives were not able to control the pre-dominant weed species of yellow nut sedge and lamb's-quarters, respectively. As a result, soybeans yields in these treatments were reduced compared to the weed-free soybeans yields.

Table 55. Soybeans yield as affected by various treatments in 1988 and 1989.

#	Treatment	Dose kg a.i./ha	Soybeans yield 1988	 1989
			—— $kg.ha^{-1}$ ——	
1	Weedy		2860	640
2	Paraquat	1.0	3180	1900
3	Paraquat + linuron + metol.†	1.0 + 0.85 + 1.68	3250	2870
4	Imazethapyr	0.15	3150	1610
5	Linuron	2.25	3110	1000
6	Metribuzin	0.60	3000	1300
7	Linuron + metol.	0.85 + 1.68	2970	1440
8	Metribuzin + metol.	0.85 + 1.68	2980	2380
9	Imazethapyr+ COC‡	0.15 + 1%	3230	1610
10	Linuron + COC	2.25 + 1%	2930	1070
11	Metribuzin + COC	0.60 + 1%	2970	1980
12	Linuron + metol. + COC	0.86 + 1.68 + 1%	2850	2300
13	Metribuzin + metol. + COC	0.60 + 1.68 + 1%	3220	1970
14	Imazethapyr+ 28% N	0.15 + 5%	3170	1460
15	Linuron + 28% N	2.25 + 5%	3060	1080
16	Metribuzin + 28% N	0.60 + 5%	3080	1610
17	Linuron + metol. + 28% N	0.85 + 1.68 + 5%	2950	2050
18	Metribuzin + metol. + 28% N	0.60 + 1.68 + 5%	3260	2040
	LSD 5%		NS	930

† metolachlor

‡ Kornoil concentrate®

Table 56. Weed control ratings expressed as percent of weedy check as affected by herbicides with additives in 1988 and 1989.

#	Treatment	Weed control ratings				
		Ragweed		Nutsedge	Buckweed	Fleabane
		1988	1989	1989	1989	1989
		%				
1	Weedy check	0	0	0	0	0
2	Paraquat	81	23	30	90	43
3	Paraquat + linuron+ metol.†	84	40	100	95	70
4	Imazethapyr	80	99	100	73	8
5	Linuron	89	13	100	100	0
6	Metribuzin	85	25	100	0	100
7	Linuron + metol.	64	63	100	100	8
8	Metribuzin + metol.	78	38	100	28	95
9	Imazethapyr + COC‡	69	99	100	88	25
10	Linuron + COC	83	23	100	100	0
11	Metribuzin + COC	88	40	100	38	75
12	Linuron + metol. + COC	60	60	100	100	25
13	Metribuzin + metol. + COC	78	35	100	30	73
14	Imazethapyr + 28% N	84	98	100	63	23
15	Linuron + 28% N	93	8	100	100	3
16	Metribuzin + 28% N	73	23	100	25	100
17	Linuron + metol.+ 28% N	73	88	100	98	25
18	Metribuzin + metol.+ 28% N	84	83	100	35	95
	LSD 5%	17	36	12	38	36

† metolachlor

‡ Kornoil concentrate®

5.7 Preemergence and Postemergence Herbicides for Control of Quackgrass

RESEARCH SUMMARY:

Quackgrass control was significantly improved with spring applied glyphosate or quizalofop as compared to the fall application. Quackgrass control early in the season by spring applied glyphosate or quizalofop was similar in both years. However, by late August, glyphosate treated plots had significantly fewer quackgrass plants.m^{-2} as compared to the quizalofop treated plots.

Glyphosate or quizalofop when applied in fall as pre-harvest application had better early-season quackgrass control than their post-harvest application. However, later in the season, there was no apparent difference in quackgrass control by either pre-harvest or post-harvest herbicide application.

The additive Frigate® enhanced quackgrass control by glyphosate. A lower dose of glyphosate (0.9 l.ha^{-1}) with Frigate had statistically similar quackgrass control as compared to a higher dose of glyphosate (1.8 l.ha^{-1}) without Frigate. Glyphosate at 0.45 kg.ha^{-1} was also very effective when applied in the spring.

Table 57. Quackgrass shoot control ratings expressed as percent of weedy check as affected by the time of application of various burndown herbicides in 1987 and 1988.

#	Treatment[†]	Dose kg a.i./ha	Applied	Quackgrass Control			
				1987[‡]			1988
				%			
1	Weedy Check			0	0	0	0
2	Quizalofop	0.096	Pre- harvest	68	24	0	15
3	Quizalofop	0.096	Post-harvest	15	3	0	18
4	Quizalofop	0.144	Pre- harvest	73	6	0	8
5	Quizalofop	0.144	Post-harvest	38	3	0	15
6	Quizalofop	0.192	Pre- harvest	76	26	3	19
7	Quizalofop	0.192	Post-harvest	33	13	3	24
8	Glyphosate + Frigate	0.450 + 0.5%	Pre- harvest	83	56	15	29
9	Glyphosate + Frigate	0.450 + 0.5%	Post-harvest	54	11	0	28
10	Glyphosate + Frigate	0.900 + 0.5%	Pre- harvest	84	71	18	25
11	Glyphosate + Frigate	0.900 + 0.5%	Post-harvest	70	26	3	40
12	Glyphosate	1.800	Pre- harvest	85	70	25	43
13	Glyphosate	1.800	Post-harvest	73	40	3	48
14	Quizalofop	0.096	Spring	-	85	23	94
15	Quizalofop	0.144	Spring	-	89	30	94
16	Quizalofop	0.192	Spring	-	88	46	94
17	Glyphosate + Frigate	0.450 + 0.5%	Spring	-	94	73	96
18	Glyphosate + Frigate	0.900 + 0.5%	Spring	-	95	80	95
19	Glyphosate	1.800	Spring	-	95	81	96
	LSD 5%			14	11	6	15

[†] Quizalofop was applied with Canplus® 411 at 1% (v/v). Treatment 8, 9 and 17were applied with ammonium sulphate at 3 l.ha^{-1}.

[‡] quackgrass control ratings were recorded on may 5, june 15 and aug 25 in 1987 and on june 27 in 1988.

5.8 RECOMMENDATIONS

On the basis of field experiments conducted at various sites from 1987 to 1990 the following recommendations are suggested for the use of additives with various residual and burndown herbicides in no-till crop management systems.

5.8.1 The Role of Additives With Residual Herbicides in No-till Corn

! Metolachlor + atrazine or metolachlor + atrazine + dicamba at labelled rates may be sprayed with additives Agral® 90 at 0.1% (v/v), Kornoil concentrate® at 1% (v/v), Kornoil® at 10 $l.ha^{-1}$, 28% N at 500 $l.ha^{-1}$, 10-34-0 at 10 $l.ha^{-1}$, Aqua 21% N at 10 $l.ha^{-1}$ for burndown and residual annual weed control in corn.

5.8.2 Herbicides for Burndown and Residual Control of Annual Weeds in No-till Corn

! Atrazine at 1.5 $kg.ha^{-1}$, cyanazine at 2.5 $kg.ha^{-1}$ or atrazine at 1.5 $kg.ha^{-1}$ + cyanazine at 2.5 $kg.ha^{-1}$ with 1% solution (v/v) of Kornoil concentrate®.

! Linuron at 1 $kg.ha^{-1}$ + metribuzin at 0.5 $kg.ha^{-1}$ or linuron at 1 $kg.ha^{-1}$ + atrazine (1 $kg. ha^{-1}$) + metolachlor (2.4 $kg.ha^{-1}$) with 1% Kornoil concentrate®.

! Glufosinate at 0.75 $kg.ha^{-1}$ + metribuzin at 0.75 $kg.ha^{-1}$ with 1% solution (v/v) of Kornoil concentrate®.

5.8.3 Annual Weed Control in No-till Corn by Residual Herbicides AppliedWith Additives

- ! For control of common ragweed seedlings, atrazine, cyanazine, linuron or dicamba at labelled rates, applied preemergence to corn.
- ! Additives such as 28% N at 5% (v/v) or Kornoil concentrate® at 1% (v/v) may be added with these herbicides.

5.8.4 Burndown and Residual Weed Control in No-till Soybeans

- ! Metolachlor (2.4 kg.ha^{-1}) + metribuzin (0.6 kg.ha^{-1}) should be applied with additives 28% N or 10-34-0 at 10 l.ha^{-1} for effective annual weed control in soybeans.
- ! Metolachlor at 2.4 kg.ha^{-1} + linuron at 2 kg.ha^{-1} should be applied with additives Agral® 90 at 0.1% (v/v), 10-34-0 at 10 l.ha^{-1}, or Liquid cyanamid® at 10 l.ha^{-1} for effective annual weed control in soybeans.
- ! Metolachlor at 2.4 kg.ha^{-1} + monolinuron at 2 kg.ha^{-1} should be applied with additive Kornoil concentrate® at 1 % (v/v), oil at 10 l.ha^{-1}, 28% N at 10 l.ha^{-1} or Liquid cyanamid® at 10 l.ha^{-1} for effective annual weed control in soybeans.

5.8.5 Annual Weed Control in No-till Soybeans by Residual Herbicides Applied With Additives

! Linuron, metribuzin and imazethapyr do not require additives such as Kornoil concentrate® at 1% (v/v) or 28% N solution at 5% (v/v) to control common ragweed.

! Ragweed control by metolachlor + linuron or metribuzin increases in the presence of additive 28% N at 5% (v/v).

5.8.6 Preemergence and Postemergence Herbicides for Control of Quackgrass

! Glyphosate dosage may be reduced from 1.8 kg.ha^{-1} to 0.9 kg.ha^{-1} if applied with additive Frigate® at 0.5% (v/v).

! Glyphosate dosage may be reduced from 1.8 kg.ha^{-1} to 0.45 kg.ha^{-1} if applied with additives Frigate® at 0.5% (v/v) + Ammonium Sulphate at 3 l.ha^{-1}.

OBJECTIVE # 5

6.0 INTEGRATED WEED MANAGEMENT IN NO-TILL CROPPING SYSTEMS

In Ontario, one of the most significant changes occurring in agriculture today is the increased awareness and acceptance by the agricultural community of conservation tillage practices. These tillage practices enhance soil conservation, improve water management and may reduce energy use on agricultural lands. This reduction in the energy is mainly due to the extensive use of the herbicides under no-till cropping systems. However, in recent years, consumer awareness of food production practices has increased. This increased awareness has clearly been expressed relative to the potential misuse of pesticides. In order to address these concerns, Ontario provincial government has mandated to reduce pesticide use in general and herbicide use in particular by 50% of their present day use level by year 2002.

Therefore, in order to address these concerns, it was hypothesised that herbicide requirements for weed control under any given tillage system were similar. It was also hypothesised that a supplement of inter-row cultivation along with herbicides in a band over the crop rows would provide weed management similar to those with total herbicide coverage. Moreover, this practice may be more economical under no-till systems as it will allow fertilizer incorporation in the soil and may also control perennial weeds more efficiently. Therefore, a series of field experiments were initiated to study:

1. the weed management under various tillage systems.
2. the impact of tillage on the quackgrass rhizome placement in the soil.

3. the impact of inter-row cultivation and banding of herbicides over the crop rows on annual weed control in no-till cropping systems.
4. the residual effect of 2,4-D formulations, rate and time of application on growth and yield of soybeans.

6.1 METHODS AND MATERIALS

Field experiments were conducted to establish an integrated weed management in corn in 1987, 1989 and 1990, and to study the residual effect of 2,4-D on soybeans in 1989 and 1990. The details of experimental procedures followed and material used are described briefly.

6.1.1 Experimental Locations

Details of experimental locations and soil types are described in Table 58.

Table 58. Details of experimental locations and soil types for experiments conducted in 1987, 1989 and 1990.

Crop	Experiment				Soil				
	#	Site	Location	Type	Sand	Silt	Clay	O.M.	pH
					%				
Corn	6.2	Fingal	42^0 5' N 81^0 5' W	Beverly silt loam					
Soybeans	6.4	Dealtown	42^0 15'N 82^0 5' W	Fox Gravelly loam	59	31	10	2.8	6.1

† Details of method and material for experiment 6.3 and 6.5 are described in their respective sections.

6.1.2 Agronomy

Experiments were conducted using standard agronomic practices (OMAF publication 296, Field Crop Recommendations) in no-till plots. Soil samples were taken from each field at the beginning of the crop season and were analyzed for soil available nutrient status. Fertilization was done according to soil tests and requirements of individual crop. Fertilizers, if required were placed at the time of sowing of the crop with minimum soil surface disturbances.

Corn cv. Pioneer® 3737 and Northrop King® 3624 were planted at their recommended seeding densities in 75 cm rows at Fingal. The individual plot size at Ridgetown was 1.9 x 9 m in 1989 and 1990. However, at Fingal, individual plot size was 2 x 6 m.

Soybeans cv. Elgin were planted in 40 cm rows at a seeding rate of 80 kg. ha^{-1}. The individual soybeans plot size was 1.5 x 7 m in both years.

Corn and soybeans were harvested from the centre of plots leaving side border rows at Fingal site and from whole plot at Dealtown site. Final yield was later converted and expressed at 14% and 15.5% moisture content for soybeans and corn, respectively.

The details of dates of planting, spraying and crop harvesting are presented in Table 59.

6.1.3 Spraying Equipment and Procedures

Individual plots were sprayed using a 'bicycle sprayer' at fingal site and by an 'Oxford Precision Sprayer' at Dealtown site. The quantity of spray solution used for the bicycle sprayer was 225 $l.ha^{-1}$ at 180 kPa. The 'Oxford Precision Sprayer' used 200 $l.ha^{-1}$ of spray solution at 240 kPa.

Table 59. Planting, spraying and crop harvesting dates in 1989 and 1990.

Crop	Expt. #	Year	Date(s)		
			Planting	Spraying	Harvesting
Corn	6.2	1989	April 30	April 30	Oct. 21
		1990	April 29	April 29	Oct. 19
Soybeans	6.4	1989	June 2	May 9 to June 2	Oct. 28
		1990	June 5	May 22 to June 5	Oct. 31

6.1.4. <u>Experiment Design and Analysis</u>

All experiments were conducted in randomized complete block design (RCBD) with 4 replications. Results were analyzed using analysis of variance (ANOVA) procedures and means were then separated using least significant difference (LSD) at 5% level of significance.

6.2 TILLAGE 2000: Weed control under various tillage systems

Tillage improved weed control compared to the no-till system. Control of lamb's-quarters by atrazine and cyanazine was poor in 1989. This phenomenon was similar across all tillage systems and may be due to a possible development of triazine resistant lamb's-quarters populations. However, an addition of metolachlor significantly improved lamb's-quarters control. Linuron failed to adequately control ragweed. Foxtail control was excellent in all tilled plots. Cyanazine provided poor foxtail control in no-till treatments. However, addition of metolachlor improved foxtail control.

There was no significant tillage by herbicide interaction on crop yield. The corn yield losses due to uncontrolled population of weeds were greatest in the no-till system.

Table 61. Weed control in moldboard plough tillage system expressed as percent of weedy check as affected by various treatments in 1987 and 1989.

#	Treatment	Lambsquarters		Ragweed		Foxtail	
		1987	1989	1987	1989	1987	1989
		%					
1	Weedy control	0	0	0	0	0	0
2	Atrazine	100	60	77	100	73	9
3	Cyanazine	100	80	88	83	90	77
4	Linuron	93	100	57	83	83	93
5	Atrazine + cyanazine	100	93	100	97	87	97
6	Atrazine + linuron	100	93	77	100	87	90
7	Cyanazine + linuron	97	97	97	97	87	100
8	Cyanazine + dicamba	100	100	100	93	83	90
9	Atrazine + metolachlor	100	93	80	100	100	97
10	Atrazine + metolachlor	100	100	100	100	87	100
11	Cyanazine + metolachlor	93	100	80	77	80	93
12	Cyanazine + metolachlor	93	97	77	60	98	80
13	Linuron + metolachlor	83	100	63	87	90	90
14	Linuron + metolachlor	97	100	60	93	100	93
15	Atrazine + dicamba + metolachlor	100	100	97	100	100	100
16	Dicamba + metolachlor	100	100	98	93	100	97
LSD 5%		8	24	21	21	NS	14

Table 62. Weed control in chisel plough tillage system expressed as percent of weedy check as affected by various treatments in 1987 and 1989.

#	Treatment	Lambsquarters		Ragweed		Foxtail	
		1987	1989	1987	1989	1987	1989
				%			
1	Weedy control	0	0	0	0	0	0
2	Atrazine	93	3	90	90	70	77
3	Cyanazine	100	50	80	67	57	20
4	Linuron	100	90	73	80	67	13
5	Atrazine + cyanazine	100	0	100	95	80	70
6	Atrazine + linuron	100	93	97	97	77	90
7	Cyanazine + linuron	93	87	93	63	63	40
8	Cyanazine + dicamba	90	97	97	90	87	80
9	Atrazine + metolachlor	97	60	98	97	100	97
10	Atrazine + metolachlor	100	67	90	90	100	93
11	Cyanazine + metolachlor	100	47	83	57	93	63
12	Cyanazine + metolachlor	100	47	87	63	80	63
13	Linuron + metolachlor	97	93	87	60	93	93
14	Linuron + metolachlor	100	90	78	87	100	80
15	Atrazine + dicamba + metolachlor	100	90	100	100	97	100
16	Dicamba + metolachlor	87	93	100	77	93	90
	LSD 5%	NS	33	16	31	29	35

Table 63. Weed control in ridge tilled treatments expressed as percent of weedy heck as affected by various treatments in 1987 and 1989.

#	Treatment	Lambsquarters		Ragweed		Foxtail	
		1987	1989	1987	1989	1987	1989
		%					
1	Weedy Control	0	0	0	0	0	0
2	Atrazine	97	57	95	60	95	97
3	Cyanazine	97	87	93	80	97	97
4	Linuron	100	98	85	68	97	97
5	Atrazine + cyanazine	93	90	92	97	87	97
6	Atrazine + linuron	100	93	92	80	100	100
7	Cyanazine + linuron	98	63	92	57	98	97
8	Cyanazine + dicamba	98	73	88	57	98	100
9	Atrazine + metolachlor	98	100	98	87	90	100
10	Atrazine + metolachlor	100	90	95	93	100	93
11	Cyanazine + metolachlor	100	97	80	60	100	87
12	Cyanazine + metolachlor	100	90	90	87	97	100
13	Linuron + metolachlor	98	80	95	83	98	100
14	Linuron + metolachlor	97	93	70	23	82	100
15	Atrazine + dicamba + metolachlor	98	60	87	87	80	100
16	Dicamba + metolachlor	100	83	87	77	97	100
	LSD 5%	21	45	NS	44	NS	26

Table 64. Weed control in no-till treatments expressed as percent of weedy check as affected by various treatments in 1987 and 1989.

#	Treatment	Lambsquarters		Ragweed		Foxtail	
		1987	1989	1987	1989	1987	1989
				%			
1	Weedy control	0	0	0	0	0	0
2	Atrazine	100	13	67	97	53	73
3	Cyanazine	97	30	67	60	13	30
4	Linuron	93	97	23	23	53	10
5	Atrazine + cyanazine	53	43	83	97	68	87
6	Atrazine + linuron	93	83	93	100	65	43
7	Cyanazine + linuron	100	87	73	87	23	0
8	Cyanazine + dicamba	100	93	100	73	17	0
9	Atrazine + metolachlor	73	30	90	97	70	90
10	Atrazine + metolachlor	30	53	80	97	72	87
11	Cyanazine + metolachlor	33	33	58	0	47	53
12	Cyanazine + metolachlor	83	30	87	30	45	70
13	Linuron + metolachlor	100	97	45	13	53	67
14	Linuron + metolachlor	100	97	27	20	60	43
15	Atrazine + dicamba + metolachlor	97	60	97	97	73	83
16	Dicamba + metolachlor	100	90	90	50	23	97
	LSD 5%	37	43	32	31	30	37

6.3 EFFECT OF TILLAGE ON CONTROL OF QUACKGRASS (Agropyron repens (L.) Beauv.)

INTRODUCTION

Tillage practices in Ontario are changing in response to environmental concerns of soil degradation. Reduced and no-tillage practices are being adopted by farmers in an attempt to address these issues. However as tillage practices change, the habitat in which weeds grow is altered as well. The reduction in primary tillage has been suggested by numerous authors to lead to an increase in the occurrence of perennial weeds such as quackgrass (Agropyron repens (L.) Beauv.). Quackgrass is a perennial weed that favours an undisturbed soil environment (Cussans 1975, Pollard and Cussans 1976, Shimming and Messersmith 1988). Winter survival of underground rhizome buds and rhizome growth is reported to be greater under no-tillage conditions than in cultivated soil (Cussans 1975). Traditionally, quackgrass was controlled by frequent summer cultivations. The systematic stimulation and burial of shoots depleted plant food reserves and exposed rhizomes to desiccation (Dunham et al. 1956). Bachtaler (1974) identified the failure to control quackgrass as the limiting factor in the adoption of no-tillage cereal production in West Germany. However, with the introduction of glyphosate in the 1970's, control of quackgrass became possible in soybeans and corn without excessive cultivation or the rotational restrictions associated with triazines such as atrazine [2-chloro-4-(ethylamino)-6-(ospropylamino)s-triazine]. Glyphosate is a non-selective postemergence herbicide, providing greatest activity when applied to quackgrass with four or more leaves (Baird and Begeman 1972, Brockeman et al. 1973, Ivany 1975, Ivany 1981, Rioux et al. 1974). The correct timing of the application of glyphosate to actively growing quackgrass in relation to the timing and type of tillage is essential in order to achieve optimum control.

This study was initiated to determine the implications of change in tillage practices on quackgrass control. The objectives were to compare in a soybeans and corn rotation: a) the effects of time and type of tillage on biomass accumulation of quackgrass shoots and rhizomes and b) to determine the influence of the time of glyphosate application on the level of quackgrass control achieved within each tillage system.

MATERIALS AND METHODS

A field experiment was conducted from 1985 and 1989 at the Elora Research Station, Elora, Ontario, on a Guelph series loam soil (Glossoboric Hapludalf; 29% sand, 52% silt, 19% clay, 4.4% organic matter, pH 7.5). The site had been fallow for 2 years and was heavily infested with a naturally occurring population of quackgrass. A split-plot experimental design was used with four replications. Main plots were 18 m long by 6 m wide, sub-plots were 6 m long by 6 m wide.

The main plot treatments consisted of fall or spring moldboard plough, fall or spring soil-saver (modified chisel plough, with twisted shovels), and no-tillage. Glyphosate, applied at 0.9 kg a.i.ha^{-1} in the fall or spring, and an untreated control were the sub-plot treatment. Glyphosate was applied in 225 L.ha^{-1} of spray solution at 180 kPa using a bicycle-wheel plot sprayer. Dates of herbicide applications, tillage and harvested are listed in Table 65.

Table 65. Tillage, planting and harvest dates of quackgrass, corn and soybeans from 1985 to 1989.

	Year				
Treatment	1985	1986	1987	1988	1989
Spring applied glyphosate	May 15	May 5	May 11	May 13	
Spring tillage	May 29	May 10	May 17	May 18	
Crop	**Soybeans**	**Corn**	**Soybeans**	**Corn**	
Seeding	June 3	May 14	May 31	May 19	
Quackgrass harvest	Oct. 16	Aug. 14	Sept. 3	Aug. 23	Aug. 25
Crop harvest	Oct. 31	Sept. 25	Sept. 29	Oct. 5	
Fall applied glyphosate	Oct. 11	Oct. 11	Oct. 24	Oct. 14	-
Fall tillage	Oct. 21	Nov. 4	Nov. 2	Nov. 2	-

Plots were tilled with the moldboard plough or the soil saver to a depth of 15 cm, a minimum of 5 days after the application of glyphosate. Secondary tillage following the moldboard plough and soil-saver treatments consisted of a single pass with a tandem-disk and a culti-packer immediately before planting. Soybeans cv. Maple Arrow were seeded at 100 kg.ha^{-1} in 20 cm rows in 1986 and 1988 with a Tye Pastuer Pleaser grain drill. Corn cv. Pioneer® 3851 was planted at 73,00 plants.ha^{-1} in 76 cm rows in 1987 and 1989 with a John Deere® 7000 conservation planter. At time of planting, residue remaining from the previous year's crop was not removed from the crop row.

Phosphorus and potassium were both applied according to soil test recommendations, at 40 kg.ha^{-1} each year. Fertilizer was broadcast prior to soybean planting or applied in a band 5 cm below and to the side of the corn seed. Nitrogen formulated as a 34% (NH_4NO_3) was side-dressed onto the soil surface to 30 cm tall corn (leaf extended). Annual weeds were controlled with 2.0 kg.ha^{-1} of metolachlor (2-cloro-N-(2-ethyl-6-methylphenyl)-N--(2-methoxy-1-methylethyl)acetamide) plus 1.0 kg.ha^{-1} of linuron (3-3-(3,4-dichlorophyenyl)-1-methoxy-1-methylurea) applied preemergence to both soybeans and corn.

The initial level of quackgrass infestation averaged 275 shoots.m^{-2} on October 16, 1985. Control in subsequent years was assessed between mid-August and early September. Quackgrass shoots within a 0.25 m^2 quadrat were clipped at the soil surface and oven dried to a constant weight. Three consecutive 7.5 cm layers of soil, to a depth of 22.5 cm were removed using a flat shovel from within a 0.04 m^2 quadrat placed in the centre of the clipped area. Quackgrass rhizomes and roots from each layer were separated from the soil using a 1 cm screen, then washed in tap water and oven dried. Dry weights for both above and below ground plant components were expressed in g.m^{-2}. Quackgrass control was determined by the reduction in total dry weight compared to the treatment receiving neither glyphosate nor tillage within each year. Rhizome distribution data was log transformed for analysis and mean separation, then retransformed for presentation. Crops were harvested for yield at maturity. Soybeans plants from 4 m of each of the centre 4 rows were hand clipped then machine threshed. Corn ears from 4 m of each of the centre 2 rows were hand-harvested. Soybeans and corn yields were calculated at 14% and 15.5% moisture respectively. After yield samples were taken, a commercial combine harvester was used to remove the remaining crop.

RESULTS AND DISCUSSION

Seasonal patterns of precipitation influenced growth and competitiveness of quackgrass. Total precipitation for the months of June, July and August for 1986 to 1989 are reported in Figure

1. In 1986 and 1987 the months of June, July and August received above average rainfall. However 1988 was an unusually dry year, receiving only 76% of normal precipitation. In 1989, the month of July was extremely droughty, having received only 9 mm of rainfall.

Quackgrass rhizomes appeared to be more affected by changing patterns of precipitation than top growth of shoots (Figure 1). From August 1987 to August 1988, total rhizome biomass decreased from approximately 765 to 323 g.m^{-2}. However the shoot dry weight remained relatively constant.

The effect of quackgrass interference on crop yield was greatly influenced by changing patterns of precipitation within each tillage system. For example in 1987, in plots moldboard ploughed only, yield losses due to quackgrass averaged 7% under conditions of adequate rainfall, compared to 33% in 1989 under dry conditions. Similar results have been reported by other researchers (Brockeman et al. 1973, Sikkema and Dekker 1987, Young et al. 1984).

In the final year of the study, fall or spring moldboard plough, and fall or spring soil-saver tillage alone provided 88%, 78%, 64% and 31% control of quackgrass respectively, compared to no-tillage (Table 66). These results were similar to those reported by Merivani and Wyse (1984) who found that conventional and reduced tillage decreased rhizome bud number by 83% and 35% respectively. Spring tillage using either the mouldboard plough or the soil-saver was less effective than fall tillage for controlling quackgrass. Exposure of rhizomes to temperature extremes and/or desiccation is greatest when tillage is performed in the fall (Shimming and Messersmith, 1988). Majek et al. (1984) concluded that overwintering increased rhizome susceptibility to tillage. Older rhizomes are more susceptible to injury from low temperatures (Dunhan et al. 1956) and desiccation (Dexter, 1942) than new rhizomes. Although quackgrass rhizome buds are relatively resistant to freezing (Shimming and Messersmith 1988, Stoller 1977), Schimming and Messersmith suggested that resistance to cold temperatures may be achieved at a high metabolic cost. For example, earlier work by Arny (1932), found that in early spring, total rhizome carbohydrates were 50% lower than in the fall. The additional stress of relatively deep burial, imposed on the overwintered rhizome buds by spring moldboard ploughing may be the critical factor accounting for the difference in control between spring moldboard plough and soil-saver tillage.

Averaged across all four years of the experiment, the proportion of total plant dry weight allocated to shoot growth was significantly greater in fall or spring moldboard ploughed or fall soil-saver treatments than in no-tillage (Table 67). For example, in 1989, the spring moldboard ploughed treatment had 74% of the total plant dry weight allocated to shoots compared to 47% in the no-till treatments. However, this response appears to be an indirect effect of the greater control achieved with these tillage treatments. A linear correlation was determined between relative log transformed quackgrass rhizome and shoot dry weights (Figure 2). The lower the rhizome dry weight the greater the shoot dry weight per unit area and conversely, as rhizome dry weight increases shoot dry weight decreases per unit area. Other researchers have also reported an inverse correlation between shoot and rhizome growth (Baird et al. 1972, Williams 1973). At high density levels, quackgrass rhizome bud dormancy may be greater, or a process of self-thinning may occur (Merivani and Wyse 1984). As well, Baird et al. (1972 and 1974), found that the activity of a translocated post emergence herbicide, such as glyphosate, may be reduced when applied to shoots of quackgrass occurring at high density. The dosage of glyphosate is often increased to achieve adequate control of dense stands of quackgrass. However our data would suggest that rhizome biomass per unit area has a direct influence on shoot density. Therefore knowledge of the rhizome population may be a useful tool in determining the dosage of herbicide required to achieve effective control.

Table 67. Effect of tillage alone on % shoot dry weight[1] of quackgrass.

	shoot dry weight				
Tillage	1986	1987	1988	1989	x
Fall moldboard plough	34	49	69	65	54
Spring moldboard plough	36	35	69	74	54
Fall soil-saver	33	55	70	51	52
Spring soil-saver	26	49	46	59	45
No-till	20	33	46	47	36
LSD 0.05 NS	16	NS	19	10	

[1] Shoot dry weight expressed as a % of total quackgrass biomass.

The distribution of quackgrass rhizomes within the soil profile was greatly influenced by the type of tillage (Figure 3). In the no-till and plots tilled in the spring with the soil-saver the largest percentage of the rhizome biomass was found close to the soil surface. In no-till treatments, approximately 82, 17 and less than 1% of the quackgrass rhizome dry weight was excavated from the top 7.5, 7.5 to 15 and 15 to 22.5 cm soil profile depths, respectively. This compares to fall or spring moldboard ploughing which resulted in 35 and 43% respectively, of the total rhizome biomass being distributed in the top 15 cm of the soil profile. Moldboard ploughing placed a significantly greater amount of rhizome biomass in the 15 to 22.5 cm depth than the soil-saver or no-tillage. All tillage treatments reduced rhizome weight in the 0-7.5 and 7.5-15 cm depth zones compared to the no-till treatments. These differences may be a direct result of the process of soil inversion associated with moldboard ploughing, or due to the creation of conditions favouring rhizome development at greater depths with this form of tillage (Stobbe, 1976).

The use of glyphosate increased the percent control of quackgrass and the average additional yield response of both corn and soybeans in all tillage systems compared to tillage alone (Table 68). However, the percent increase in quackgrass control and the associated additional crop yield response was dependent upon the tillage system. For example, in 1987, 1988 and 1989, the additional crop yield response due to the control of quackgrass by glyphosate, increased as tillage was reduced. In 1989 a 12% increase in control of quackgrass was recorded for glyphosate applied in the fall prior to fall ploughing, compared to an 81% increase in control in response to fall applied glyphosate in a no-till system. In no-till systems the additional control of quackgrass due to spring or fall applied glyphosate was significantly different in 1987 only. Additionally crop yields were significantly increased in 1989 only, when glyphosate was spring applied compared to the fall application. Within other tillage systems, fall or spring applications of glyphosate did not differ significantly in control of quackgrass or in the resulting improved crop yields. These results indicate that although excellent control of quackgrass can be achieved in both reduced and no-tillage systems, the reliance on glyphosate for control of quackgrass is increased as tillage is reduced.

6.4 Residual Effect of 2,4-D on the Soybeans

Research Abstract

Field experiments were conducted in 1989 and 1990 to investigate the effects of 2,4-D applied prior to planting on soybeans yields.

No visible crop injury was observed from carry-over of 2,4-D on soybeans in either year of the experiment. The soybeans yield was not reduced due to 2,4-D at any time of application prior to planting of the soybeans in 1989. However, in 1990, soybeans yields were significantly reduced on the same day of soybean planting or treatments where 2,4-D amine salts were sprayed one week prior to soybean planting.

Table 69. Soybeans yield as affected by 2,4-D in 1989 and 1990.

#	Treatment	Dose kg.ha^{-1}	Time of Application	Yield	
				1989	1990
				kg.ha^{-1}	
1	Check			2640	1270
2	2,4-D amine	0.5	3 wk prior to seeding	2780	-
3	2,4-D amine	1.0	3 wk prior to seeding	2800	-
4	2,4-D amine	1.5	3 wk prior to seeding	3070	-
5	2,4-D LV ester	0.5	3 wk prior to seeding	3480	-
6	2,4-D LV ester	1.0	3 wk prior to seeding	2880	-
7	**2,4-D LV ester**	**1.5**	**3 wk prior to seeding**	**2360**	**-**
8	2,4-D amine	0.5	2 wk prior to seeding	3030	1480
9	2,4-D amine	1.0	2 wk prior to seeding	3010	2140
10	2,4-D amine	1.5	2 wk prior to seeding	2730	2400
11	2,4-D LV ester	0.5	2 wk prior to seeding	2510	2280
12	2,4-D LV ester	1.0	2 wk prior to seeding	2230	2270
13	2,4-D LV ester	1.5	2 wk prior to seeding	2470	2280
14	**2,4-D amine**	**0.5**	**1 wk prior to seeding**	**3010**	**130**0
15	2,4-D amine	1.0	1 wk prior to seeding	3330	1980
16	2,4-D amine	1.5	1 wk prior to seeding	3000	1750
17	2,4-D LV ester	0.5	1 wk prior to seeding	2660	2570
18	2,4-D LV ester	1.0	1 wk prior to seeding	2570	2320
19	2,4-D LV ester	1.5	1 wk prior to seeding	3100	2110
20	**2,4-D amine**	**0.5**	**same day**	**3010**	**179**0
21	2,4-D amine	1.0	same day	3210	1620
22	2,4-D amine	1.5	same day	2270	1830
23	2,4-D LV ester	0.5	same day	3080	1860
24	2,4-D LV ester	1.0	same day	2860	1900
25	2,4-D LV ester	1.5	same day	3020	1810
	LSD 5%			NS	690

6.5 THE INTEGRATION OF BANDED HERBICIDE APPLICATIONS AND INTER-ROW CULTIVATION IN NO-TILL CORN PRODUCTION

Abstract. The acceptance of no-till crop production systems has been limited due to anticipated problems with weed management. Field experiments were established at two locations in Ontario in 1988 and 1989. Band or broadcast applications of preemergence combinations of high or low label rates of atrazine ± metolachlor, with and without inter-row cultivation, were evaluated for their effectiveness in controlling annual weeds in no-till corn. Annual weed densities and germination patterns varied at the individual research sites and therefore required different herbicide and cultivation combinations to achieve adequate weed control. Corn grain yield was equivalent regardless of whether herbicides were applied as a band or broadcast treatment at all four sites. At two of the three sites where annual weeds were present in sufficient numbers to reduce crop yields, 1 cultivation combined with herbicides applied as a band was adequate to maintain weed control and corn grain yields. Selective application of herbicides in bands represents an approximate 60% reduction in herbicide application into the environment.

Nomenclature: Atrazine, 6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine; metolachlor, 2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide; corn, Zea mays L., Pioneer® 3902, Pioneer® 3790, Hyland® 2803, and Dekalb® 524.

Additional index words. Atrazine, metolachlor, Zea mays L., integrated weed management, reduced herbicide use.

INTRODUCTION

The adoption by farmers of conservation tillage practices such as no-till is an important step towards achieving sustainable crop production (Swanton and Weise, 1991). The objective of no-till is to limit mechanical disturbance of the soil to that required for seed placement (Sprague, 1986). No-till is characterized by limited soil disturbance and increased amounts of crop residue on the soil surface resulting in decreased wind and water erosion, lower labour and fuel inputs, and increased water use efficiency by the crop (Hairston et al. 1984, Brown et al. 1989, Griffith et al. 1986).

The number of no-till hectares in the United States has increased from 5.7 million hectares in 1989 to 6.8 million hectares in 1990 (Klassen, 1991). In Ontario, approximately 83 480 ha of no-till crops were grown in 1989[†]. However, the acceptance of no-till has been limited due to anticipated problems of weed management.

Numerous authors have identified the lack of reliable and economical weed management systems as one of the major factors limiting acceptance of no-till crop production systems (Buhler 1988, Nowak 1983, Williams and Wicks 1978). As well, Koskinen and McWhorter (1986) cited findings from a 1983 grower survey which indicated inadequate weed control and herbicide costs as the two most important reasons farmers gave for opposing conservation tillage practices. No-till critics have argued that removal of tillage from the crop production system would result in the

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loss of an important method of weed control as well as alteration of the soil environment where weeds and herbicides interact. It was thought that the presence of crop residues may reduce the quantity of herbicide in contact with the soil surface (Banks and Robinson, 1982), As well, weed population dynamics may be altered by the elimination of tillage resulting in an increase in the number of species and density of perennial weeds (Froud-Williams et al. 1983, Wrucke and Arnold 1985). However, these criticisms of the no-till system may not be justified in all cases.

The weed suppressing ability of the crop residue may compensate for reduced quantities of herbicide coming in contact with the soil surface and therefore not affect overall weed control (Erbach and Lovely 1975, Johnson et al. 1989). Also, perennial weeds such as quackgrass (Agropyron repens (L.) Beauv.) have been readily controlled in a no-till system with proper herbicide selection and time of application (Chandler and Swanton, 1990). As well, the use of herbicides to achieve weed control previously gained through tillage has led to speculation that the widespread use of no-till will lead to increased herbicide use (Brock 1982, Johnson et. al. 1989, Kells and Meggitt 1985, Koskinen and McWhorter 1986, Witt 1984). However, this speculation is based on the assumption that broadcast herbicide applications are the only method of weed control in a no-till system.

Alternative weed control measures in no-till may include the selective application of herbicides in a band, reduced herbicide rates and inter-row cultivation. The possibility of utilizing shallow cultivation as a means of controlling annual weeds while maintaining crop residue on the soil surface may be a viable option in reducing the total amount of herbicide applied in no-till production systems (Fawcett, 1983). Inter-row cultivation is carried out after the period of time when soil is most vulnerable to erosion. In a previous study cited in Gebhardt and Fornstrom (1985), residue levels remained as high as 80% after cultivation with 30 to 45 cm wide sweeps. Inter-row cultivation in combination with selective placement of herbicides in a banded application over the crop row, could effectively reduce the quantity of herbicide applied for annual weed control in no-till production systems.

The utilization of banded herbicide applications in conjunction with inter-row cultivation is common in conventional tillage crop production. However, there are no reports in the literature of this weed control combination being applied to a no-till system. Therefore, the objective of this study was to evaluate the integration of banded herbicide applications, inter-row cultivation, and reduced herbicide dosage in no-till corn production in Ontario.

MATERIALS AND METHODS

General Procedure

On-farm field experiments were conducted in 1988 and 1989 at Clinton and Ridgetown, Ontario. A description of soil types and precipitation data from the research locations is recorded in Table 70 and 71, respectively.

Fields selected at both locations had a history of 3 to 5 years of no-tillage involving a corn-soybeans-winter wheat rotation. The crop grown previous to the year of experimentation was soybeans except at Clinton in 1989 where winter wheat was the preceding crop. The fields were also known to have a natural population.

Densities of the species present at each research site are listed in Table 72.

Prior to planting of corn in the spring of each year the experimental sites were sprayed to control perennial weeds. Paraquat [1,1'-dimethyl-4,4'-bipyridinium ion] was applied at a dose of 1.0 kg ha^{-1} on May 1, 1988 at Clinton. Glyphosate [N-(phosphonomethyl)glycine] was applied at 0.9 kg ha^{-1} on May 7, 1989 at Clinton and at Ridgetown on May 2 and May 8, 1988 and 1989, respectively. Applications were made with field-type sprayers equipped with SS8002LP[†] and SS11003LP tips at Clinton and Ridgetown, respectively. At Clinton, corn variety Pioneer® 3902 was planted on May 7, 1988 at a seeding rate of 70 000 seeds ha^{-1} using a double frame Kinze®[‡], no-till planter. Corn variety Pioneer® 3790 was seeded at 67 500 seeds ha^{-1} on May 17, 1989 using a 900 International®[§] no-till planter. At Ridgetown, corn variety Hyland® 2803 was planted on May 5, 1988 at a seeding rate of 65 000 seeds ha^{-1} and variety Dekalb® 524 was seeded at 75 000 seeds ha^{-1} on May 11, 1989 using a double frame Kinze®, no-till planter.

Table 70. Soil characteristics at Clinton and Ridgetown, 1988 and 1989.

Site	Soil type	Texture (%)			Percent organic matter	pH
		Sand	Silt	Clay		
Clinton, 1988	Harriston silt loam	33	46	21	4.5	6.7
Clinton, 1989	Harriston silt loam	38	47	15	4.0	7.3
Ridgetown, 1988	Fox gravelly loam	60	30	10	2.1	5.3
Ridgetown, 1989	Brookston clay	31	40	29	3.0	6.5

[†] Spraying system co., Wheaton, IL.

[‡] Kinze Mfg., Williamsburg, IA.

[§] JI Case Co., Racine, WI.

Table 71. Mean and percent of normal precipitation accumulation by month at Clinton and Ridgetown, 1988 and 1989.

	Precipitation†			
	1988		1989	
Month	mm	Percent of normal‡	mm	Percent of normal‡
Clinton				
May	76.0	103	100.1	136
June	17.5	23	99.5	133
July	62.7	82	2.0	3
August	93.0	97	87.5	91
September	138.5	157	69.0	78
Ridgetown				
May	45.3	67	132.6	197
June	15.0	19	89.0	115
July	65.8	91	35.0	48
August	78.5	99	90.1	113
September	74.5	108	49.2	71

† Data from Canada, Dept. of Transport., Meteorological Branch. 1990. Meteorological Observations in Canada - Monthly Record.

‡ 50 year average.

Table 72. Range in weed densities of species present at Clinton and Ridgetown research sites in 1988 and 1989.

Site	Weed density						
	ABUTH[†]	AMARE	AMBEL	CHEAL	POLPE	SETLU	SETVL
	----------------------no. m^{-2}----------------------						
Clinton 1988	...	1-34	0-9	0-4	...	0-20	1-105
Ridgetown 1988	0-20	0-44	...	360-900	...	...	...
Ridgetown 1989	0-9	0-230	0-7	0-23	0-5	...	...

1) Abbreviations: ABUTH, velvetleaf (Abutilon theophrasti Medik.); AMARE, redroot pigweed (Amaranthus retroflexus L.); AMBEL, common ragweed (Ambrosia artemisiifolia L.); CHEAL, common lamb's-quarters Chenopodium album L.); POLPE, lady's-thumb (Polygonum persicaria L.); SETLU, yellow foxtail (Setaria glauca (L.) Beauv.); SETVI, green foxtail (Setaria viridis (L.) Beauv.).

Recommended cultural practices for corn grain production were used (OMAF publication 296, Field Crop Recommendations). Corn was planted in 76 cm rows, with each plot consisting of four, 12 m long rows. Each treatment was replicated four times in a randomized complete block design.

Herbicide treatments were applied in both years with a bicycle wheel plot sprayer calibrated to deliver 225 L ha^{-1} of spray solution at a pressure of 180 kPa. Herbicide bands applied over the crop row were made using SS8001EV spray tips, while SS8002LP tips were utilized for broadcast herbicide applications. The banded application widths were 25 and 30 cm in 1988 and 1989, respectively. The herbicide band width was increased in 1989 to attain proper overlap between the herbicide band and cultivated areas. Herbicide treatments consisting of atrazine ± metolachlor were applied preemergence on May 14 and May 27 at Clinton, and on May 11 and May 16 at Ridgetown, 1988 and 1989, respectively. The two dosages of atrazine and metolachlor represent the high and low label rates for the herbicides in Ontario corn production

(Ontario Weeds Committee, 1988). The weedy control had no herbicide applied or cultivation and the weed-free control was hand weeded as weeds emerged.

Inter-row cultivations were performed using a Hiniker® (Hiniker Co., Mankato, MN.), 4-row, sweep-type cultivator with the mid-points of the sweep teeth set to operate at a depth of 3 to 5 cm. The cultivator sweep teeth were increased in width from 45 cm in 1988 to 50 cm in 1989, to achieve better overlap between the herbicide band and cultivated areas. Two inter-row cultivations were performed at each research site with the timing corresponding to the 7 and 13 leaf stage of corn growth. A new leaf stage was determined to have been reached when the leaf appeared in the corn whorl. The first inter-row cultivation was delayed until the 10 leaf stage of the corn crop in 1989 due to rainfall. Cultivations occurred at Clinton and Ridgetown on June 13 and July 4 in 1988, and June 27 and July 6 in 1989, respectively.

Observations

Only corn grain yield from the 1989 Clinton site is presented, due to extremely low weed populations. The results and discussion section will be focused on the three remaining research locations.

Weed observations were taken from a 1.0 m^2 quadrat centred over one of the middle rows in each plot approximately 2 weeks after the second inter-row cultivation. Weed density by species was recorded and the above ground biomass by species was clipped at the soil surface, oven dried for 5 days at 80^0C, and dry weights recorded. This occurred at Clinton on July 18 in 1988, and at Ridgetown on July 20 and July 13, in 1988 and 1989, respectively. Weed density and biomass measurements were repeated at Clinton on September 12 in 1988, and at Ridgetown on September 21 and September 12, in 1988 and 1989, respectively. Weed density and biomass by species were grouped into total broadleaf and total grass for presentation purposes.

Corn grain yield was determined by harvesting a 3.0 m length from the middle 2 rows of each plot. Harvesting occurred on October 20, 1988 and October 16, 1989 at Clinton, and October 15, 1988 and October 13, 1989 at Ridgetown. Corn ears were hand-picked, fresh weight determined, dried for 7 days at 80^0C, weighed, shelled, and reweighed. Grain yield was calculated based on 15.5% moisture content and expressed in kg ha^{-1}.

Statistical Analysis

The experimental results were analyzed separately for each location and year of this study due to a year by treatment interaction. Weed density and biomass data were subjected to square root(x+1) and $\log_{10}(x+0.5)$ transformations, respectively, to fit the data to a more normal distribution. Treatment means were separated using transformed data and original data means were used for presentation. Transformation was not necessary for corn grain yield data, therefore original data was used for analysis. With the control treatments excluded, all data were subjected to analyses of variance, and main effects and interactions were tested for significance. Orthogonal comparisons were performed utilizing SAS (Statistical analysis system, SAS institute inc., Cary, NC.) procedures to investigate significant interactions among main effects and linear contrasts of treatment means were also performed.

RESULTS AND DISCUSSION

Corn grain yield and weed biomass and density measurements were analyzed and presented in terms of herbicide application method, number of inter-row cultivations and herbicide combination and dose required. After determining the best weed control treatment at each research site, comparisons were made between that treatment and other individual treatments utilizing linear contrasts.

Yields were low at the 1989 Ridgetown site because of seasonal drought conditions. Annual weed densities and germination patterns varied at the individual research sites and therefore required different herbicide and cultivation combinations to achieve adequate weed control.

Herbicide Application Method

Corn grain yield did not differ significantly regardless of whether herbicides were applied as a band or broadcast treatment at all four research sites (Tables 75, 76, 77). Previous work by Moomaw and Martin (1978) found that when 2,4-D [(2,4-dichlorophenoxy)acetic acid] was applied prior to planting, slot-planted corn yields were not significantly different between band or broadcast preemergence herbicide treatments when used in combination with cultivation.

Banded treatments required cultivation as indicated by the cultivation by application interaction which was significant for corn grain yield and total broadleaf weed biomass and density at three of the four research sites, excluding the 1989 Clinton site, where weed pressure was very low (Tables 73, 74, 77 and 78). This interaction was expected because herbicides applied in a band combined with 0 cultivations resulted in lower corn yields and higher total broadleaf weed biomass and density. For example, at Ridgetown in 1989, corn grain yields for banded treatments combined respectively with 0, 1 and 2 cultivations, were 3610, 4830 and 4810 kg ha^{-1}. A non orthogonal linear contrast was utilized to compare banded to broadcast herbicide applications averaged over 1 and 2, and 0, 1 and 2 cultivations, respectively. Banded treatments combined with 1 or 2 cultivations were equal to broadcast treatments except for broadleaf weed control at Ridgetown in 1988 (Tables 75 and 79). Here, herbicides applied in bands had higher total broadleaf weed biomass and density because of weed escapes which were due to a lack of proper overlap between the herbicide band and cultivated areas. This demonstrated the need for adequate overlap between the cultivated and herbicide banded areas, especially in a situation of high weed density.

Cultivation

The number of cultivations in combination with banded herbicide treatments required to maintain weed control and corn grain yield varied between sites. To determine the number of cultivations required, orthogonal contrasts were made to compare between 0, 1 and 2 cultivations within banded herbicide application treatments.

At Ridgetown in 1988 and 1989, a significant quadratic contrast revealed that banded herbicide treatments combined with 1 cultivation was adequate to maintain corn grain yield (Tables 77 and 78). Even though the first cultivation was delayed until the 10 leaf stage of the corn crop in 1989 due to an extended period of rainfall, corn yield was not affected because there was adequate moisture for both the weeds and corn, and the weed population was not excessive.

At the 1988 Clinton site, a significant linear contrast showed that two cultivations combined with herbicides applied in bands resulted in significantly greater corn grain yield (Table 73). Moomaw and Martin (1978) found that two cultivations rather than one tended to increase yields of no-till corn. However, the planting and cultivating systems used in their study differed from those used in our work. The extremely low weed population at the 1989 Clinton site resulted in corn grain yields being equivalent across all treatments (Table 76). Cultivation had no significant effect on corn grain yield in the absence of weeds.

To significantly reduce weed biomass and density in banded herbicide treatments, cultivation was essential. Similar to corn grain yield, the number of cultivations required to achieve adequate weed control varied between sites. In both years of experimentation, there was little precipitation between the time of first cultivation and full canopy closure of the corn crop. In a year where substantial rainfall after the first cultivation stimulated weed germination, a second cultivation may be required.

At Clinton in 1988, two cultivations combined with herbicides applied in bands resulted in significantly lower weed biomass and density (Tables 73 and 74). Later germinating annual grass and broadleaf weeds were controlled by the second cultivation.

At Ridgetown in 1988 and 1989, one cultivation combined with banded herbicide treatments was adequate to maintain weed control (Tables 77 and 78). The exception to this was in 1988 when two cultivations resulted in lower broadleaf weed biomass in September. Weed escapes did occur in treatments containing one cultivation, however corn grain yield was not affected. Generally part these weed escapes could be attributed to the lack of overlap between the herbicide band and cultivated areas which was experienced in 1988. The presence of these weeds could present a problem with respect to contribution to the soil seed bank. However, weed seeds dropping on the soil surface may not be as much of a problem in Ontario no-till conditions because of seed viability loss over the winter months. Typically seed decline is more rapid following shallow rather than deep burial (Froud-Williams 1987). For example, Thomas et al. (1986) showed that less than 1% of green foxtail seed sown on the soil surface was viable after six years, whereas buried seeds remained viable up to 17 years.

Non orthogonal, linear contrasts were performed to evaluate the weed control efficacy of cultivation alone without a herbicide treatment present. Comparisons were drawn between the treatment containing the optimal banded herbicide application and cultivation combination, and the control treatments containing one and two cultivations, treatments twenty and twenty one, respectively. At both sites in 1988, cultivation alone did not adequately control weeds (Tables 75 and 79). Significantly higher levels of weed control and corn grain yields were recorded for treatments containing herbicides applied in a band plus cultivation. At the 1989 Ridgetown site, significantly greater weed control was achieved where the treatment contained a banded herbicide application, although final corn grain yield did not differ significantly from the cultivation alone treatments (Table 79).

Herbicide Combination and Dose

Atrazine or tank-mixtures of atrazine + metolachlor applied at high and low label dosages were evaluated in terms of weed control and corn grain yield. At Clinton in 1988 and 1989 and Ridgetown in 1989 weed control and corn grain yield did not differ significantly regardless of the herbicide combination or dosage of herbicide applied.

At the 1988 Clinton site, corn grain yield and total broadleaf weed biomass and density were equivalent regardless of the herbicide combination or dosage of herbicide applied (Tables 73 and 74). However, total grass biomass and density was significantly reduced when metolachlor was included. This annual grass pressure did not reduce corn grain yield but contribution to the soil seed bank remains a possible problem.

At Ridgetown in 1988, corn grain yields were significantly higher and total broadleaf weed measurements taken in July were significantly lower, where the high label rates of atrazine and metolachlor were used (Table 77). Non orthogonal linear contrasts comparing herbicide treatments within banded herbicide applications indicated similar results. In cases of high weed densities as was found at this site, high rates of herbicides applied in a band may be required to achieve weed control because of the potential for herbicide dilution out of the band due to lateral movement in the soil. At the 1989 Ridgetown site, atrazine alone applied at the low label rate was a sufficient herbicide treatment to maintain weed control and corn grain yield (Table 78). Annual grass pressure at this site was minimal.

Herbicides applied in banded applications combined with inter-row cultivation can provide adequate weed control and corn grain yields in a no-till production system. The herbicide combination and use rates required in the banded applications, and the number of cultivations will be specific to each grower's situation. Varying factors will include weed species, density and emergence patterns as influenced by precipitation, efficacy of the herbicide and cultivation treatments and management level of the grower.

For growers adopting the banded herbicide application and inter-row cultivation system, a minimum herbicide band width of 30 cm and maintaining high label dosage is recommended. Dilution of the herbicide band could arise through lateral herbicide movement in the soil or variations in the boom height when applying the herbicide band. After experience with the new system is gained, herbicide dosage and possibly the width of the band may be reduced in order to minimize herbicide use.

Application of herbicides in 30 cm bands on 76 cm wide corn rows represents an approximate 60% reduction of herbicide application into the environment and an immediate economical savings for the no-till corn producer. As well, it is possible that corn yields may benefit from lower herbicide use achieved through banded applications. Each herbicide represents a physiological stress with respect to energy used by the crop plant for metabolism of the herbicide. As corn roots grow out of the herbicide banded area, the plants may well be less stressed. Another possible benefit of banded herbicide applications in no-till crop production is a reduced chance of herbicides gaining entry into ground water or surface water runoff[†]. (Personal communication. T.J. Vyn, Assoc. Prof., Dept. Crop Sci., Univ. of Guelph, Ontario, N1G 2W1.) Kenimer et al. (1987) found that under no-till conditions, atrazine and 2,4-D [(2,4-dichlorophenoxy)acetic acid] losses in surface water runoff were 0.3 and 0.02%, respectively, of applied amount. These losses would have been even less if the herbicides had been applied in a band.

Herbicide use for annual weed control in no-till corn production would be quite minimal if conditions such as were found at the 1989 Clinton site were more prevalent. Besides the application of glyphosate to control perennial and early-germinating annual weeds, no other weed control method was required. The low annual weed pressure at this site can be attributed chiefly to two factors: good management of a no-till cropping system for five years which probably decreased the number of viable weed seeds in the germination zone near the soil surface and effective use of glyphosate to control the early flush of annual weed seedlings.

The integration of banded herbicide applications, inter-row cultivation, and reduced herbicide dosage represents a viable cropping alternative that integrates optimal herbicide use with the environmental benefits of no-till.

6.6 RECOMMENDATIONS

On the basis of field experiments conducted at various sites from 1987 to 1990 the following recommendations are suggested for the integrated weed management in corn and use of 2,4-D in soybeans in no-till crop management systems.

6.6.1 Tillage 2000: Preemergence Herbicides for Annual Weed Control in Various Tillage Systems

- Currently registered herbicides at labelled rates provide similar weed control in all tillage systems (no-till, ridge tillage, chisel or moldboard plough).
- There is no justification for increasing herbicide dosages in any given tillage system in corn.

6.6.2 Quackgrass Control in No-till Corn

! Under no-till system 82% of quackgrass rhizomes were found within top 7.5 cm of soil surface.

! Apply glyphosate at 0.9 kg.ha^{-1} in the spring to actively growing quackgrass in the 3 to 5 leaf stage of growth.

6.6.3 Residual Effect of 2,4-D on the Soybeans

! Apply 2,4-D ester or amine formulation at 0.5 to 1.5 kg.ha^{-1} two weeks prior to soybean planting or apply 2,4-D ester formulation only, one week prior to soybean planting.

OBJECTIVE # 7

7.0 TO STUDY THE COST/BENEFIT RATIO STRATEGIES UNDER NO-TILL CROPPING SYSTEMS

7.1 ECONOMIC COMPARISON OF ALTERNATIVE TILLAGE SYSTEMS UNDER RISK

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Canadian Journal of Agricultural Economics

May 1991

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ECONOMIC COMPARISON OF ALTERNATIVE TILLAGE SYSTEMS UNDER RISK

INTRODUCTION

The adoption of conservation tillage techniques have been widely recommended as a remedy for the problem of soil erosion (Brady, 1984). By improving water quality, recreational value and drainage of the surrounding streams and lakes through its reduction in soil loss, the use of conservation tillage techniques can provide a net total benefit to society (Clark et al. 1985, Fox and Dickson 1990). However, these off-farm benefits may be incurred at increased costs to farmers from increased herbicide usage or from incremental machinery investment. Business and financial risk may also increase if the new production system increases yield variability.

Previous studies which have compared the profitability of alternative tillage systems in Ontario include Baffoe et al. 1987, Henderson and Stonehouse 1988, Stonehouse et al. 1987, Zantinge et al. 1986. The general conclusion of these studies is that conventional tillage is more profitable than conservation tillage systems in producing monoculture corn. Studies comparing the net returns of corn and soybeans cropping systems have been conducted for American conditions (Doster et al. 1983, Duffy and Hawthorn 1984, Klemme 1983) and have generally concluded that the farm level economic feasibility conservation tillage systems depends largely on the managerial skills necessary to produce yields comparable to conventional tillage systems. However, these studies have not incorporated yield variability and the associated riskiness involved with each tillage system which may play a major role in determining the most efficient system for an individual producer (Fox et al. 1991). Several studies in the U.S. Corn Belt (Klemme, 1985) and Great Plains (Mikesell et al. 1989, Williams 1988) have assessed the income-risk trade-off from different tillage systems and concluded that conservation tillage methods would be preferred by risk averse farmers. This conclusion, however, may not be appropriate to Ontario since the importance of soil moisture retention in the High Plains region may give conservation tillage a comparative advantage over conventional tillage.

The purpose of this study is to compare the production costs and income risk of three conservation tillage systems; chisel plough, ridge till and no till, with a conventional moldboard plough tillage system for a southern Ontario corn and soybean cash crop farm under alternative scenarios. The next section of the paper defines the alternative farm scenarios which are distinguished on the basis of size and soil type. The minimum costs for each scenario and tillage system are then developed in consideration of timeliness restrictions, machinery complement size and other relevant crop production data. The method of generalized stochastic dominance used to carry out the analysis of income risk is then described. The comparison of production costs and income risk is then presented followed by implications of the results for public policy.

METHODS

Net Farm Returns

Case Farm Scenarios

The field operations carried out under each of the four tillage systems to be examined in this study are summarized in Table 80. Conventional tillage is defined by Christensen and Magleby (1983) as a tillage system where 100 percent of the topsoil is mixed or inverted by ploughing. It involves two stages with primary tillage breaking up the soil and burying the crop residue with a moldboard plough. The second stage of secondary tillage produces a fine seedbed by further breaking down soil particles by a series of passes using implements such as disks or cultivators. The chisel plough tillage system is similar to the conventional system but it replaces the fall moldboard plough with a chisel plough cultivator and completes the initial secondary field operation with a heavier cultivator. However, it can be classified as a conservation tillage system since at least 30 percent of the previous year's crop residue is on the soil surface after planting.

In ridge-till and no till systems, there is no pre-plant cultivation. Before planting, ridge-till and no-till fields are sprayed with a contact herbicide. In ridge tillage, a conventional planter used in the previous two systems is modified with sweeps and disk openers. During planting, the top few inches of soil from each ridge are removed and the residue pushed aside to expose a raised seedbed. The ridge is maintained during the growing season by inter-row crop cultivation so that the post-planting operations are similar to the moldboard plough and chisel plough tillage systems. The only soil manipulation required in the no-till system is the opening of a slit wide enough to receive a seed which is then covered and packed with soil. In contrast to the ridge-till system, no inter-row cultivation is done under a no-till system.

The net farm returns for each of the four tillage systems on a southern Ontario corn and soybean farm are to be compared for six alternative farm scenarios established on the basis of farm size and soil type for each tillage system. Farm sizes were split into three groups of 80, 160 and 240 hectares in order to account for differing timeliness restrictions encountered for each size of farm and the associated effect this will have on the sizing of machinery complements. In addition, two soil types, clay-loam and sand, are also used to define alternative case farm scenarios since the different soil types will affect available field work days and the yield performance of the tillage systems. Thus, 24 farm scenarios are to be considered; 4 tillage systems, 3 farm sizes and 2 soil types.

Machinery Complement

Each of the four tillage systems described previously requires a unique machinery complement to complete the required field operations for each particular case farm scenario. The machinery complement must match the tractor size with the required machine widths for each field operation and enable the farmer to finish these operations efficiently within the critical time periods. The first step is determining the time available to complete the field operations. The total amount of time for each seven day period was estimated by multiplying the available field work days (OMAF Agdex 8ll, 1988) by the work hours per day. Within this time period, the field operations must be completed to ensure there is no loss in maximum yield. The size of each implement can then be determined using a procedure outlined in Kay (1986) which depends on the speed and field efficiency of the machine and the rate at which the operation must be completed as determined by farm size and total working time available. Tractor size was then matched to the power requirements of the implement.

Minimum Cost Structure

With the identification of the optimal machinery complement, the costs of owning that machinery can be determined. The machinery fixed costs consist of an annual depreciation value, an interest on investment and a value for insurance and housing. Annual depreciation was calculated on a declining balance method with a 20% rate for combines, a 15% rate for tractors and a 10% rate for non-powered machines. All equipment was assumed to be 5 years old with the current values obtained by using the above depreciation rates on the present list prices for the equipment. The investment cost on machinery was calculated as a weighted average cost of capital multiplied by the average life time market value of the equipment. Machinery insurance and housing was assumed to be based on 1.5%

of the purchase price. A land rental charge and general overhead expense was also charged equally for all tillage systems.

Variable input costs for seed, fertilizer and harvesting were assumed to be the same across all tillage systems. The variable machinery costs for repairs and fuel depend on the hours of use, tractor size and the type of field operation which vary under the alternative scenarios. These factors will also influence the total amount of labour used which was valued at $8 per hour. Herbicide costs for each tillage system were based on the optimum treatment for each system.

Prices and Yields

The final element necessary to calculate net farm returns for each farm scenario is gross revenue. Prices for corn and soybeans were the 1983-1989 average converted into 1989 day dollars. Paired yield data for corn and soybean crops grown in rotation were collected from seventeen farms throughout southern Ontario over a four year period from 1986-1989. Repeated yield observations were measured at different areas within each field. Supplementary yield data was collected from several other farms where the yield observations for the relevant tillage system and soil type were sparse.

The summary statistics for actual farm yield data under the four different tillage systems for corn and soybeans are given in Table 81. Normality of yield distributions was rejected using the Shapiro-Wilk test statistic for all scenarios with the exception of soybean yields on sandy soils and moldboard plough tillage. A non-parametric approach was therefore necessary to analyze the yield data. The results of the Wilcoxon Rank Sum Test indicated there was no difference in tillage system population locations for corn yields at the 5 percent significance level with the exception of the moldboard plough - chisel plough comparison on clay loam soils. On clay soils, soybean yields with no-till were significantly lower than either moldboard or chisel plough tillage system yield populations. On sandy soils, the soybean yields for these two fall tillage systems were significantly lower than ridge till. The results of the Moses dispersion test comparing the ratio of scale parameters between tillage system and yield population suggested that there is less variability between tillage systems on sandy soils than clay loam soils.

Stochastic Dominance

Due to the variability in yields under alternative tillage systems, there is a probability distribution associated with net returns for each farm scenario. The tillage system which maximizes producer utility from uncertain returns under alternative risk attitudes is determined using stochastic dominance. Stochastic dominance is an analytical technique which enables the ranking of two cumulative distributions for different classes of risk preferences when neither the utility function or risk aversion parameters are known. It is a more flexible approach to risk analysis than alternatives such as EV and MOTAD which assume constant absolute risk aversion decision makers and normal outcome distributions. Cochran (1986) reviewed comparisons of different risk analysis techniques and concluded that stochastic dominance is the most accurate when non-normal return distributions are being compared. The distribution of the yield data used in this study has just been shown to be non-normal which is generally the case for agricultural crop yields (Day, 1965) and for net farm returns based on price-yield values (Buccola,1986).

There are several stochastic dominance efficiency criteria distinguished largely by the risk preference interval[†]. The ordering of choices can then be achieved for the specific group of decision makers defined by the imposed restrictions on the risk preferences by elimination of the choices which do not conform to the restrictions. The remaining choices are part of the efficient set which contains the preferred choice of all the decision makers whose preferences are represented by the restrictions imposed by the efficiency criterion (Levy and Sarnat, 1972).

First degree stochastic dominance(FSD) ranks alternative choices such that if x is an outcome measure, such as net farm returns, a decision maker will always prefer more of x to less regardless of their risk preferences. Graphically, the FSD criterion can be defined where dominance (greater expected utility) is shown when the two cumulative probability density functions (CDF) never cross and the dominant CDF, lies to the right of the dominated CDF (King and Robison, 1984). The FSD criterion has very low discriminatory power, since it includes all decision makers who prefer more to less, and this results in large efficient sets, with few eliminated choices.

In addition to the assumption of a monotonically increasing utility function for the decision maker, second degree stochastic dominance (SSD) imposes the additional restriction that the utility function be strictly concave at all outcome levels. The assumption that the decision maker is averse to risk makes SSD more discriminating than FSD. Graphically, under second degree stochastic dominance the CDF's are now compared by the accumulated area under each distribution function. While SSD is more discriminatory than FSD it may still produce large efficient sets. The inclusion of decision makers with a maxi-min attitude[†] can increase the size of efficient sets due to the left hand tail problem. This results in a disproportionate weighting of the lower values of some cumulative density functions such that they cannot be excluded from the SSD efficient set.

[†] The alternative stochastic dominance efficiency criteria are reviewed by Cochran, Robinson and Lodwick (1985).

Generalised stochastic dominance (GSD) developed by Meyer (1977), is more discriminatory than FSD and SSD, and is more flexible in defining individuals preferences. GSD is expressed formally by King and Robison (1984) as the necessary and sufficient conditions under which the CDF F(x), of a function f, is preferred to the CDF G(x), of a function g, by all individuals whose absolute risk aversion functions lie everywhere between specified lower and upper bounds, $r_1(x)$ and $r_2(x)$. The absolute risk aversion function (Arrow 1971, Pratt 1964) is defined as

$$r(x) = \frac{-u''(x)}{u'(x)}$$

where $u'(x)$ and $u''(x)$ are the first and second derivatives of a monotonically increasing von Neumann-Morgenstern utility function U(x). These give a unique measure of preferences and are unaffected by arbitrary transformations of the utility function. The sign indicates risk aversion (positive), risk neutrality (zero), or risk preference (negative), and they enable interpersonal comparisons of risk aversion to be made at different outcome levels. A particular value of r(x) can be identified as the percent reduction in marginal utility per unit of x, for example if x is measured in dollars, a value of r(x) = 0.0002 indicates that marginal utility is dropping at the rate of 0.02% per dollar.

GSD allows the classes of decision makers to be identified by specifying the preference interval of their utility functions, which are bounded by lower, $r_1(x)$, and upper, $r_2(x)$ absolute risk aversion

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[†] This is a decision maker who concentrates on the worst possible outcome for each choice, and selects action that maximises the minimum gain.y

coefficients. FSD and SSD are restrictive cases of the GSD model. FSD has a large interval width with no restriction on the decision makers absolute risk aversion coefficients, such that $r_1(x) = -\infty$ and $r_2(x) = \infty$ for all values of x. SSD restricts the decision makers marginal utility to be positive, which implies $r_1(x) = 0$ and $r_2(x) = \infty$ for all values of x.

Meyer (1977) set up an optimal solution procedure for Generalised Stochastic Dominance with the Arrow-Pratt absolute risk aversion coefficient as the control variable. The problem is defined as follows;

$$Maximize \int_0^1 [F(x) - G(x)]\, u'(x)dx \qquad \textbf{(2)}$$

subject to the constraint

$$r_1(x) \leq \frac{-u''(x)}{u'(x)} \leq r_2(x) \qquad \textbf{(3)}$$

for all values of x, and the initial condition $u'(0) = 1$.

Equation (1) accounts for the difference between the expected utilities of CDF's F(x) and G(x), which represent outcome distributions f and g respectively. If for a given class of decision makers, defined by equation (2), the maximum of this difference is negative, then f dominates g by GSD for all r(x) between $r_1(x)$ and $r_2(x)$. GSD, unlike FSD and SSD, places no restrictions on the absolute risk aversion coefficients, r(x) is constrained to lie between $r_1(x)$ and $r_2(x)$, but there may be increasing, decreasing, or oscillating risk aversion utility functions within these bounds.

Accurate estimation of the risk aversion coefficient (RAC) intervals relative to the outcome variable, when the decision makers risk preferences are unknown, has been identified as being of critical importance by McCarl (1990). Calculation of the upper RAC bound from the relationship between the risk premium, expected income level and the certainty equivalent when wealth is ignored, has been suggested by McCarl and Bessler (1989). They also give examples of other studies which have incorrectly specified the RAC intervals, resulting in inaccurate classification of risk preferences.

Net farm returns per hectare were multiplied directly by farm size such that proper transformations of scale of the outcome distributions maintained correct ranking by GSD (Raskin and Cochran, 1986).

EMPIRICAL RESULTS

Net Returns Analysis

Corn and soybean yields are multiplied by their 1983-1989 average real price to obtain gross revenues. The revenues are reduced by variable and fixed production costs for each farm scenario to arrive at net returns. The returns on any farm size is the average of corn and soybean net returns which are assumed to be planted in equal proportions. The gross revenues, production costs and net returns to management for each of the 24 case farm scenarios are summarized in Table 82.

Analysis of the gross revenues for alternative tillage systems parallel the relative performance of their yields discussed previously. The variable costs for ridge-till and no-till are higher than the two fall tillage systems due to higher chemical weed control costs. However, machinery costs for the moldboard and chisel plough tillage systems are approximately double that for the other two systems. The higher fixed costs offsets the lower variable costs sufficiently to result in greater total production costs for the moldboard and chisel plough tillage systems. For all four tillage systems, production costs per hectare increase moving from the 80 hectare farm size to the 160 hectare due to the use of a custom combine operator for the smaller farm scenario versus the ownership of a combine for the larger farm sizes. Per hectare costs then fall when moving to the 240 hectare farm size due to economies of size in machinery. There is little difference in total costs per hectare between clay and sandy soils due to a "lumpiness" effect in machinery sizing. As a result, a similar complement is chosen for both soil types even though the time constraint is less critical on sandy soils.

Given that ridge-till was generally the dominant tillage system in the majority of paired yield comparisons and its relatively low cost structure, it should be expected that mean net returns are highest for the ridge-till system in all farm scenarios. To verify the differences between net returns of the alternative tillage systems, the non parametric Wilcoxon Rank Sum Test was used to compare paired population locations since the Shapiro-Wilk Test rejected the assumption of normality in the net farm returns distribution for any of the farm scenarios. On clay soils, the net return distribution is significantly different from the ridge till net return distributions for all farm sizes. The moldboard plough tillage system compared favourably at the smaller farm size but its net return location is significantly less than ridge till at the 240 hectare farm scenario due to changing machinery investment costs. On sandy soils, the relative performance of average net returns improves for no till and ridge till compared to the two fall tillage systems. The moldboard and chisel plough tillage systems have significantly lower population locations from ridge-till for all farm sizes on sandy soils.

The Shorack Ratio Estimator was used to rank the variability in net returns of the four alternative tillage systems. On clay soils, the fall tillage systems of moldboard and chisel plough had the lowest net return variability followed by no-till and ridge-till. These rankings were reversed for the sandy soil farm scenarios.

GSD Analysis of Tillage System Net Farm Returns.

The empirical net farm return distributions differ across the alternative farm scenarios. In order to select the most efficient tillage system under different farm conditions and risk attitudes of the operator, stochastic dominance risk assessment techniques are utilized.

The computer program Meyeroot developed by McCarl (1989), was used to rank the net farm return distributions for each of the four tillage systems at each farm scenario. This is a modified version of the Meyer (1975) optimal control algorithm for GSD, which ranks pair wise comparisons of cumulative density functions (CDF) when the upper and lower risk aversion coefficients (RAC) are specified. The Meyeroot program searches upward from the lower bound, and downward from the upper bound for any break-even risk aversion coefficient values, where dominance between tillage systems changes. The correct selection of upper and lower bounds relative to the scale of the outcome distribution was recognised to be an important factor in successfully running the program.

The non-negative certainty equivalent method of McCarl and Bessler (1989) was used to set approximate upper bounds for the RAC, $r_2(x)$, for each of the six case farm scenarios being considered. The upper bound value was calculated from the following equation using values of coefficient of variance (CV) and standard deviation (SD) from Table 82;

$$r_2(x) \;\tilde{}\; \frac{2}{CV\ (\ SD}$$

Pair wise comparisons of each tillage system were then carried out for incremental levels of the RAC range, to identify any multiple changes in dominance between the upper and lower RAC bounds. The Meyeroot program identified break-even risk aversion coefficient (BRAC) values where dominance changed between pairs of tillage systems and it was then possible to rank the tillage systems for each incremental risk interval within the overall RAC bounds. Tillage systems dominant in the negative risk aversion range would be preferred by risk preferring individuals. Likewise dominant tillage systems in the positive risk aversion range would be preferred by risk averse producers, with the largest positive RAC value representing the most risk averse producer.

The results of the GSD rankings for each farm scenario are illustrated below in Table 83. The break-even risk aversion coefficients (BRAC), which represent the RAC values where dominance changes between tillage systems are also given. Ridge-till systems dominate in almost every risk interval and across all farm scenarios, with the exception of the moldboard plough system which dominates in several of the slightly risk averse intervals for clay loam soil type farms.

For all three clay loam scenarios risk preferring and strongly risk averse individuals have the same preference of ridge-till, while moderately risk averse producers prefer moldboard plough tillage. This phenomena is partially explained by Grube (1986), where he notes that from game theory, the most risk preferring strategy would be chosen by a maxi-max individual and the most risk averse strategy by a maxi-min individual. This could result in distributions with lower minimums and higher maximums being preferred by both risk averse individuals and risk preferring individuals. Ridge-till does not have lower minimum net returns than moldboard plough, therefore the study by McCarl (1988) might better explain this result of alternating dominance. It was noted that the empirical distribution functions may cross several times due to the empirical data source, resulting in several changes in dominance. He also found that the utility difference approaches zero as the RAC value approaches both zero and positive infinity, for any paired comparison.

The no-till system on clay loam soils is ranked second by risk preferring and fourth by risk averse individuals. In contrast, the moldboard plough and chisel plough systems are least favoured by risk preferring individuals and more favoured by risk averters. This result concurs with the net farm return data in Table 82, where the mean net return levels are higher for the moldboard plough and chisel plough systems, yet the maximum value is highest for no-till, and would therefore be chosen by risk preferring individuals.

The moldboard plough system is preferred for three risk averse intervals over ridge-till for the 80 hectare clay loam soil farm. This decreases to only one risk aversion interval for the 240 hectare farm size and may be explained by larger increases in both the mean and standard deviation for ridge-till over moldboard plough as farm size increases for clay loam soil types.

The sandy soil GSD tillage rankings are more concise with almost equal rankings for each risk aversion interval and farm size. The ridge-till and no-till systems outrank the two fall tillage systems, indicating the advantage of reduced tillage systems on sandy soil types. Moldboard plough systems would be preferred to chisel plough systems for 80 hectare farm sizes, but risk averse individuals would prefer chisel plough to moldboard plough for the 160 and 240 hectare farm sizes.

Sensitivity of the Moldboard Plough and No-Till Comparison on Clay Loam Soils.

A sensitivity analysis was undertaken to illustrate the effect of parallel shifts in a tillage system location, and the effect on the producers risk attitudes for moldboard plough and no-till systems on clay loam soils. These two particular systems were chosen to enable a good comparison between conventional tillage and a common conservation tillage system. Also the relatively large data sets should provide a realistic representation for each system and a solid data base from which to draw any conclusions.

Increasing parallel population location shifts were applied to the 160 hectare clay loam no-till system, and repeated GSD comparisons with the moldboard plough system were carried out. The resulting changes in break-even risk aversion coefficients are charted relative to the no-till population location shift (Figure 1). These represent the RAC value at which dominance changes from no-till to the moldboard plough system.

As the no-till population location is increased, then the BRAC values increase, which results in the no-till system becoming dominant in the positive risk aversion space of the RAC bound, or it becomes relatively more favourable to risk averse producers. There is risk neutrality between +$4000 and +$6750 net returns per farm population location shifts of no-till, which indicates that risk neutral individuals would be indifferent between tillage systems in this range. The additional monetary value necessary to make no-till dominant to moldboard plough for risk averse producers is $6750. This is equivalent to a net farm return increase of $40 per hectare (from $102 ha^{-1} to $142 ha^{-1}), which equates to a 625 kg.ha^{-1} increase in average corn yield alone (8575 to 9200 kg.ha^{-1}), or a 300 kg.ha^{-1} increase in average soybean yield alone (2725 to 3025 kg.ha^{-1}), or some combination of both. The higher variability of net returns of the no-till system means that the mean net returns per hectare has to be higher, at $142 ha^{-1}, than the moldboard plough mean net return at $ 128 ha^{-1}, before the no-till system is preferred by a risk averse producer. This yield difference would be less for the chisel plough system to dominate the moldboard plough system, as it is ranked above the no-till system in the risk neutral and risk averse intervals for this particular farm scenario.

This sensitivity analysis indicates that no-till conservation tillage systems have the potential to produce higher levels of net returns, however the associated high levels of net return variability make them unattractive to risk averse producers. The rate farmers adoption levels and possible government policy implications for conservation tillage systems based on this particular comparison will depend on the individual risk attitudes of the agricultural producers. Farmers with maximin or maximax attitudes would be represented in the risk preferring interval and would require minimal incentive, if any, to adopt the no-till system. More risk averse producers would need larger financial incentives or improved production techniques before converting from conventional to conservation tillage systems.

A comparison between the ridge-till and moldboard plough systems would most likely produce opposite results from above, with ridge-till system appearing more favourable to almost all producers. Qualifying this result, by allowing for the limited data source for ridge-till, then it illustrates the fact that it is possible for conservation tillage systems to be preferred to the conventional moldboard plough system under good management production techniques. On a more practical note, resulting from personal communications with conservation tillage specialists, it is noted that the adoption of ridge-till systems is presently declining due to the difficulty in achieving consistently high soybean yields with the wide row spacing required for ridge-till systems. The results for this particular system can therefore be viewed with slightly less relevance than for the other two conservation tillage systems being considered.

CONCLUSIONS

This study has attempted to define and utilise stochastic dominance efficiency criteria to rank the net farm return distributions for four different tillage systems under six different farm scenarios. Upper and lower risk aversion coefficient (RAC) bounds were identified for each farm scenario based on the size and spread of the outcome distributions. The Meyeroot computer program was then used to carry out pair wise comparisons of tillage systems over each incremental RAC bound to identify regions where dominance may switch between tillage systems. It was then possible to rank the tillage systems relative to the risk preference interval within the overall RAC bounds.

Ridge-till systems were generally the dominant tillage system for all farm scenarios considered, however, the limited source of ridge-till yield data may unfairly weight this particular system. No-till systems on clay loam soils were more dominant in the risk preferring range and less dominant in the risk averse range, which relates to the relatively larger range of net return values and smaller mean net return values generated by this tillage system. Conversely, the moldboard plough and chisel plough systems were more dominant in risk aversion intervals and less dominant in the risk preferring intervals for clay loam soils. In sandy soil scenarios the ridge-till and no-till systems were dominant over the two fall tillage systems for all farm sizes indicating that these tillage systems are more competitive with conventional tillage systems in lighter soil type situations.

A sensitivity analysis between moldboard plough and no-till systems indicated that no-till would dominate in risk preferring intervals, and an increase in no-till net farm returns of $40 per hectare would change dominance in favour of no-till in risk averse interval space. By further considering a comparison of the ridge-till and moldboard plough systems, it is evident that it is possible for conservation tillage systems to dominate conventional tillage systems for almost all individual's risk intervals, if proper agricultural crop production techniques are undertaken.

MINIMUM COSTS OF ALTERNATIVE TILLAGE SYSTEMS

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Journal of Soil and Water Conservation

April 1991

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Funding was provided by the Technology Evaluation Program (TED) as part of the Soil and Water Environmental Enhancement Program (SWEEP) and the Agriculture Canada/NSERC Research Partnership Program.

7.2 MINIMUM COSTS OF ALTERNATIVE TILLAGE SYSTEMS

INTRODUCTION

Conservation tillage offers the potential for reducing the level of soil erosion and may therefore lead to an improvement in the recreational value and drainage of surrounding lakes and streams, a reduction in water treatment costs, and an improvement in water quality. These off-farm benefits to society may, however, be incurred at the expense of the individual producer in the form of higher production costs and reduced yields. The costs associated with conservation tillage stem from a reduction in the efficiency of machinery use and a potential increase in herbicide costs to ensure good weed control (Brady, 1989). These costs are offset by lower production costs stemming from fewer tillage operations and a smaller investment in machinery. Many studies on the profitability of alternative tillage systems have examined the cost trade offs but the costs for each system are often derived from actual farm records or constructed for an average farm in the study location. Either way, the costs will not likely represent the minimum levels possible for each system and thus may not be appropriate for comparison.

The purpose of this paper is to derive the minimum costs associated with three conservation tillage systems, chisel plough, ridge-till and no-till, and a conventional moldboard plough tillage system for hypothetical corn-soybean farms in southern Ontario differentiated by farm size and soil type. Since the trade offs in costs between alternative tillage systems deal largely with machinery and herbicides, specific emphasis will be placed on these two cost items. Machinery costs will be derived for the equipment base which will just enable the producer to complete field operations within the critical time periods without suffering yield losses while the optional pre-emergent herbicide for corn and soybeans is identified from a range of different applications for each crop.

METHODS

Case Farm Scenarios

The four tillage systems involved are a conventional tillage system using a moldboard plough and three conservation tillage systems: chisel plough, ridge till, and no-till systems. In general, ridge-till and no-till substitute the use of herbicides for fall and spring tillage operations and plant directly into the previous year's crop residue. The chisel plough cultivation system replaces the fall moldboard plough with a chisel plough cultivation. It can be classified as a conservation tillage system since at least 30 percent of the previous years crop residue remains on the soil surface after planting.

Six farm situations were defined using the variables of farm size and soil type to represent the different types of cash crop farms in Southern Ontario. Farm sizes were split into three groups of 80, 160, and 240 hectares. By choosing three different farm sizes, it is possible to take account of differing timeliness restrictions and the associated effect on the sizing of machinery complements which will be encountered for each size of farm. The two crops being studied, corn and soybeans, will be grown in rotation with each farm growing equal hectarage of both crops. Farms are also distinguished by soil type, clay or sandy, since changes in soil type will have a dramatic effect on the soil workability and the number of available field work days in the growing season. Thus, the four tillage systems will be evaluated for each of the six farm scenarios, three farm sizes, and two soil types, resulting in twenty four farm situation input cost structures to be considered. This should provide a wide representation of cash crop farm situations in southern Ontario and enable an accurate comparison of the total production costs involved for each of the tillage systems and farm scenarios.

Machinery Complement Size for Each Case Farm Scenario

Each of the four tillage systems requires a unique machinery complement to complete the required field operations for each particular case farm scenario. The machinery complement must match the tractor size with the required machine widths for each field operation and enable the farmer to finish these operations efficiently within the critical time periods. The first step involves calculating the time available for completion of a field operation which requires an estimate of the number of days weather will permit field work to occur. Number of days available to do field work on a weekly basis for both clay and sandy soils in southern Ontario were obtained from the Ontario Ministry of Agriculture and Food Agdex 811, (1988) which are based on 50 years of climatic data. Assuming 12 hour work days at planting, 10 hour work days during the summer May 10th and 8 hour work days in the fall, the total available time for each seven day period can then be calculated by multiplying work hours per day, by the available field work days.

The next step is to determine the time frame in which the field operations must be completed. Planting and harvesting dates are critical periods of crop management and have an important effect on final crop yields. Corn yields decrease by 63.50 $kg.ha^{-1}.day^{-1}$ if planting is delayed after May 10 so corn planting is assumed to be completed by this date. (OMAF Agdex 811, 1988). Similarly, soybeans must be planted between May 10 and May 23 to ensure no yield loss due to seeding time. The optimal harvest period for corn is October 11 to November 7 and September 20 to October 10 for soybeans. The organization of field operations can now be arranged so that cultivation operations are fitted around these critical planting and harvesting dates.

Calculations for sizing of the machinery complement were carried out on a spreadsheet which scheduled the field operations for both corn and soybean based on the total time available which would enable both crops to be planted within the optimal time period. Field operations for each crop must be placed in their proper order for each crop year period and seven day interval. There will be some overlapping of different operations within the same seven day interval and therefore the available time must be split into percentage allocations between operations. Where there is overlapping of field operations, then time allocations may have to be altered until the optimum machine complement size is found, such that both the planting and harvesting date restrictions for each seven day period are met.

Implement selection can now be calculated based on the required field capacities imposed by the timeliness restrictions in combination with farm size. The implement width is calculated from the following formula (Kay 1986);

$$W = F * 10 / S * E \qquad (1)$$

where W is implement width in meters, F is the effective field capacity required in hectares per hour, S is the speed in kilometres per hour and E is the field efficiency. The effective field capacity in hectares per hour is calculated by dividing the total hectares to be covered by a particular field operation as determined from farm size, by the total working time available. Field efficiency estimates and implement operating speeds were taken from the Agricultural Engineering Yearbook (1989).

The calculation of optimal machine width must take an account of the power requirements of each implement because the tractor size may be important for several operations. It is therefore necessary to consider the final whole farm machinery complement, to ensure that there are no mismatches between tractors and implements. If this does occur then it is better to oversize the machinery complement to ensure that all of the timeliness constraints are met. Table 84 illustrates the allocation of time and the final machine widths chosen for each operation and for each time period in the spring on the 160 hectare conventional tillage case farm example.

Cost Calculations

Variable Costs

Machinery Variable Costs

With the identification of optimal machinery complements, the variable, fixed and total costs associated with that machinery can be established for each case farm scenario. The calculation of the variable machinery costs consists of hourly charges for fuel, lubrication and a repair and maintenance cost. An hourly charge was calculated to take account of when similar types of machinery would be used for different lengths of time on different case farm scenarios. The total fuel cost was calculated from the total hours of use for each tractor and implement combination. The operating hours of each tractor implement combination was multiplied by tractor fuel consumption and then multiplied by the 1990 price of No. 2 diesel fuel in southern Ontario ($0.36 per litre). Oil and lubrication costs were based on 15 percent of fuel costs (OMAF report 89-05, 1989). Equipment repair and maintenance costs were calculated for each field operation using repair and maintenance coefficients based on hours of use, machine type and list price obtained from the Ontario Ministry of Agriculture and Food (Agdex 825, 1987). Total tractor repair cost was split in proportion with its use between each respective implement.

Labour Costs

The different machinery requirements for each tillage system has a resulting impact on labour use and costs. The amount of time for each field operation was determined by re-arranging equation

(1) to calculate available field capacity. An example of the labour used in the spring field operations for the 160 hectare clay farm scenario is given in Table 84. With machine width, operating speed and field efficiency known, the total time required to complete each field operation can be found for a given farm size. Total labour use was the sum of the labour required for individual operations which was then multiplied by a wage rate of $8 per hour to arrive at the cost of labour.

Herbicide Costs

The optimal herbicide treatment was calculated from the field data collected at experimental plots in Fingal, Ontario. The experiment examined the impact of sixteen different pre-emergent herbicide treatments on corn and soybeans for the four alternative tillage systems. Corn and soybeans were grown in rotation, with yield data for soybeans collected in 1988, and corn yield data collected in 1989. The optimal herbicide treatment for each tillage system was identified by comparing the net returns generated from the different crop yields while taking into account the cost of the pre-emergence herbicide treatment.

There were several herbicide treatments which resulted in similar optimal levels of net return for each tillage system. The treatment generating the highest return was the one used in the costing framework. While there were several alternative herbicide treatments which would result in similar levels of return, choices not belonging to this set can have a major impact on yield. For example, the net returns of corn herbicide treatment for systems were significantly more variable than the net returns no-till, or the ridge-till systems. The dispersion between net returns of the tillage systems and the soybean herbicide treatments was less marked but still suggest that proper pre-emergent herbicide choice was more critical for the reduced tillage systems.

Other Variable Costs

The other variable input costs were assumed to be the same across the four tillage systems and were based on actual practices employed at the experimental plots used to determine the optimal herbicide treatment. Corn was planted at a seeding rate of 69 500 seeds per hectare at a cost of $96 per 80,000 kernel bag, resulting in a total cost of $83.40 per hectare. Soybean seed was applied at a rate of 112.5 kilograms per hectare. The seed cost $14 per 25 kilogram bag which results in a seed cost of $63 per hectare. Prices for seed were obtained from local seed merchants and were average prices for the 1990 crop year.

Corn fertilizer was a split application with a 6-24-10 NPK corn starter applied at a rate of 150 kilograms per hectare at planting for a cost of $38 per hectare. A second application was injected as anhydrous ammonia several weeks after planting at a rate of 135 kilograms of nitrogen per hectare and cost $49.90 per hectare. Soybean fertilizer was applied in a single application at planting as a 8-32-16 NPK starter at a rate of 200 kilograms per hectare and cost $54.50 per hectare. Fertilizer costs were also obtained from local agricultural suppliers.

Custom operators were assumed to be employed to apply all fertilizer, harvest on the 80 hectare farm sizes and haul the harvested crops. All of the custom costs have been taken from the Ontario Ministry of Agriculture and Food, Report 89-14, (1989). It was assumed that corn was the only crop which required drying and the average cost was $80 per hectare. It was also assumed that half the crop was sold at harvest with the rest being gradually sold over the next ten months. The custom storage was therefore based on half the crop being stored for five months. The cost was an average of $25 per hectare for corn and $10 per hectare for soybeans (OMAF Report 89-14, 1989).

Some other variable costs include cost for crop insurance and interest charges on the operating capital. The crop insurance charge was quoted from the Crop Insurance Commission at a price of

$12.50 per hectare for both the corn and soybean crops. The interest on the operating capital required to finance each crop was based from the time the expenditure was made until crop sales generated income. Operating capital includes the cost of fuel, repairs, materials and other cash items. The interest rate applied to the operating capital in this case was based on the 1990 estimated average prime rate of 14.5 percent plus one, for a rate of 15.5 percent.

Fixed Costs

Machinery Fixed Costs

The machinery fixed costs consist of an annual depreciation value, an interest payment on the investment and a value for insurance and housing. Depreciable life was assumed to be ten years for tractors, sprayers and planters, fifteen years for field cultivation equipment and five years for all other machinery. Annual depreciation was calculated on a declining balance method, with a 20 percent declining rate to combines, a 15 percent rate for tractors and a 10 percent rate to non-powered machines. Interest on machinery investment was calculated based on the assumption that the equity portion was 70 percent and the debt portion 30 percent of the total depreciated value (OMAF Report 89-05,1989). Interest on equity was 9.5 percent which was an average rate paid by chartered banks on savings accounts while the interest on the debt portion was based on the estimated 1990 average prime rate of 14.5 percent plus one, for a total of 15.5 percent. This produced a calculated interest rate of 11.3 percent. The interest charge was calculated based on the five year depreciated value of the equipment. Machinery insurance and housing was assumed to be based on 1.5 percent of the purchase price of the machine (OMAF Report 89-05,1989).

Other Fixed Costs

Other fixed costs include the annual cost for ownership of the farmland which was calculated using an interest rate based on the opportunity cost of capital weighted by estimated values for expected growth and appreciation and noneconomic benefit. A 14.5% cost of capital was adjusted by 4% for inflation, 3% for land appreciation (FCC, 1990), and an estimated 1% for noneconomic benefit. This results in a 6.5% interest charge (14.5-4-3-1 = 6.5), being calculated on a bare land value of $2892 per hectare (FCC, 1990) for an annual land ownership charge of $188 per hectare† (This land ownership cost is equivalent to rental values of between $162-225 ha^{-1} for corn-soybean land in Southern Ontario, as quoted by several OMAF county officials.) Overhead costs for miscellaneous items such as farm utilities, accounting and administration costs, and general farm maintenance were estimated from OMAF Report 89-05, (1989).

COMPARISON OF COSTS

Total Costs

The total production costs for each tillage system based on the optimum machinery complement and optimal corn and soybean pre-emergent herbicide applications are summarized in Table 85. Although the no-till and ridge-till systems had higher variable costs per hectare than the moldboard plough and chisel plough systems, the higher fixed costs per hectare for the two fall tillage systems, across all of the farm scenarios, resulted in higher total farm costs per hectare for the moldboard and chisel plough tillage systems. There was little difference in total costs per hectare between different soil types, due to the effect of machinery "lumpiness" and timeliness restrictions, which will be discussed later in this section.

Herbicide Costs

The lower variable costs for the two fall tillage systems were due to the difference in herbicide costs. Weed control cost data was based on the optimal pre-emergent herbicide applications for each tillage system. The total herbicide cost for no-till and ridge-till, which includes the $30 per hectare burn down spray, was higher at $118, and $82 per hectare respectively, when compared with moldboard plough, 52 per hectare, and chisel plough, $48 per hectare. The no-till and ridge-till systems do include a pre-plant burndown spray, and therefore it was unlikely that the chemical costs for these systems would be the lowest of the systems analyzed.

Machinery Costs

The differences in herbicide costs between the tillage systems were more than offset by variations in machinery costs. Variable machinery costs were approximately $25 per hectare and fixed machinery costs approximately $150 per hectare higher for the two fall tillage systems in comparison to no-till and ridge-till. These differences decreased slightly with farm size. The machinery costs for ridge-till are slightly higher than no-till for all case farm scenarios due to a summer inter-row cultivation.

Table 86 illustrates total machinery costs as a percentage of total costs where the machinery charge includes operator labour costs, machinery fuel, lubrication, repair and maintenance, and the machinery investment costs of depreciation, interest, insurance and housing. Machinery costs for moldboard plough and chisel plough tillage systems which include both fall and spring cultivation operations range from 29% to 39% of total farm costs. This was considerably higher than the no-till and ridge-till systems which have no pre-plant cultivation operations and resulted in machinery costs which range from 12% to 26% of total farm costs illustrating the advantages of the smaller machinery complement sizes required for no-till and ridge-till systems.

The difference in machinery costs between farm sizes was greatest between the 80 hectare farm size (12-30% of total costs), and the 160 hectare farm size (24-39% of total costs), with the 240 hectare machinery costs being only slightly lower than the 160 hectare farm size. This difference could be caused by the two larger farm sizes purchasing a combine harvester instead of the custom harvesting operation undertaken by the 80 hectare farm size. This was indeed evident from the resulting small difference in total farm costs between farm sizes illustrated in Table 85 where the custom charges were included in the total farm cost calculations.

Labour Costs

Table 87 illustrates the percentage reduction in labour use for the three conservation tillage systems relative to conventional moldboard plough tillage over the entire crop season for all farm scenarios. Almost all of the conservation tillage system farm scenarios required less labour than the moldboard plough tillage system with the exception of the chisel plough systems on the 160 hectare sandy soil and the 240 hectare clay loam soil type farms. Significant savings in labour were made with the no-till and ridge-till systems, where the omission of pre-plant cultivation operations can reduce labour requirements by up to 61 percent. This large saving in labour for the ridge-till and no-till systems was associated with a significantly lower level of capital investment in machinery (Table 85), which results in advantages to the producer in terms of both input investment and operating costs.

It must be noted that these results give equal weight to unused summer labour, where the no-till has no inter-row cultivation operations, and in spring where optimal sowing times can have critical effects on final crop yields. The effect of timeliness restrictions at the critical spring period on labour requirements is illustrated in Table 87 where only the spring operating time for each tillage system and farm scenario were considered. The chisel plough tillage system had the highest spring labour requirement due to the initial heavy duty field cultivation operation. The no-till and ridge-till systems had significantly lower labour requirements during this critical time period, with no-till requiring 26 percent less labour than the moldboard plough tillage system on the 160 hectare clay loam soil type farm scenario. The no-till and ridge-till 240 hectare sandy soil type farms had 9 percent higher labour requirements because they were able to use a smaller, less expensive 10 meter sprayer, rather than the 20 meter sprayer which was required by similar 240 hectare clay loam soil type farms.

The effect of fall tillage operations on labour requirements between tillage operations is also given in Table 87 where the spring and fall labour requirements were combined. The no-till and ridge-till systems again have significantly lower labour requirements, up to 54 percent, as would have been expected, due to the lack of fall field cultivations with these systems. There was little difference between the moldboard plough and chisel plough systems, except at the 160 hectare farm size where the effect of "lumpiness" of machinery sizing affects the timeliness restrictions. This lumpiness effect of machinery complement selection means that similar machinery complement sizes were chosen for both soil types even though the time constraint was less critical on the lighter sandy soils than on the heavier clay loam soil types. This is evident from Table 85 where there was little difference in machinery costs for either of the two tillage systems or soil types.

The effect of soil type on the timeliness restriction of the farmer is illustrated in Table 88 which gives the total unused labour for each farm scenario for the spring season calculated by subtracting the calculated operating time for each machinery complement and farm scenario from the total available time identified from the available work days and assumed working hours per day. It was decided to consider only the spring period because the spring field cultivations and planting were the most critical period in the crop year. The inclusion of summer and fall timeliness restrictions might have a misleading weighting effect on some tillage systems.

Table 88 illustrates that the sandy soil farm types have the potential to grow larger crop hectarage, due to the extra time available, when compared to the clay loam soil type farms. At each farm size the sandy soil type farms have between two to ten times as much unused labour, with the no-till and ridge-till systems generally having the highest levels. The benefit of this potential labour was shown in monetary terms in Table 88 as an opportunity cost of unused labour and management skills, with a conservative value of $8 per hour charged for each unused hour of available time. The value of this extra time was difficult to quantify because good management decisions at the start of the crop season could amplify to large changes in net farm returns at harvest time. It was useful therefore only to consider the relative values when comparing the tillage systems for each farm scenario.

The opportunity cost of unused labour was greater for the sandy soil when compared with the clay loam soils for all of the farm scenarios. The relative differences in the values of the opportunity cost between soil types was as much as ten times in favour of the sandy soil type indicating the potential for increased production possible on farms with the lighter sandy soils. This potential could be exploited by the farmer by either increasing his cropping hectarage or diversifying his management skills into other enterprises.

SUMMARY

This study has developed and compared the costs of four different tillage systems under a range of different farm scenarios which were representative of cash cropping farm situations in Southern Ontario. Minimum costs were estimated for each scenario by determining the optimal machinery complement which will just permit the producer to complete planting without a yield loss and by finding the optimal pre-emergent herbicide application. Other input costs were based on actual levels of use and current market prices.

Total farm costs per hectare were higher in all farms scenarios for the moldboard plough and chisel plough tillage systems in comparison to no-till and ridge-till due to their larger machinery complement sizes. Machinery costs for the two fall tillage systems ranged from 29% to 39% of total farm costs while no-till and ridge-till machinery costs were lower, ranging from 12% to 26% of total farm costs. Variable costs per hectare for the no-till and ridge-till systems were higher than the fall tillage systems for each farm scenario. This was partly due to the pre-plant herbicide treatment, but the calculated optimal pre-emergent herbicide treatment costs were also higher for the two reduced tillage systems. The variability in net returns among the alternative herbicide No-till systems produced the largest yield and net return variability for both corn and soybean crops with minimal crop management input. This emphasises the importance of a good weed control management strategy for reduced tillage systems, to ensure that the variability of crop yield was minimised.

The reductions in labour associated with the reduced tillage systems indicates that labour costs could be reduced by up to 61% annually, when compared with a conventional tillage system. A more correct labour saving value of 26% was possible when only the critical spring time period was considered. This saving in labour was illustrated as an opportunity cost with reduced tillage systems on sandy soil farm types having greatest potential for expansion of the cropping hectarage or diversification into other enterprises.

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