No-till Systems for Corn Following Hay or Pasture

M. A. Smith and P. R. Carter

Research Question

Most producers who plant no-till following perennial forage species apply herbicides to kill perennials in the spring, rather than the fall. Farmers have not made side-by-side on-farm comparisons of corn planted no-till following spring-killed and fall-killed perennials to evaluate relative yields, management challenges, and economics.

The objective of this study was to compare two no-till systems (fall-kill no-till and spring-kill no-till) with farmers' current tillage systems, which included either chisel or moldboard plowing.

Literature Summary

Growers' major concern about planting corn no-till into perennial forages is the application timing and efficacy of herbicides to control perennials. Previous research has indicated that split herbicide treatments, either in the fall or early spring and at planting, were needed to completely control perennial vegetation. No-till systems using fall Roundup (glyphosate) applications have consistently resulted in yields comparable to those with moldboard plowing. Results for corn planted no-till with spring-kill of perennials have been inconsistent, with performance highly dependent on spring rainfall.

Study Description

Farmer-managed comparisons were made on silt loam soils on six Wisconsin farms in 1988 and 1989.

Treatments:

A. Fall-kill no-till
   (Glyphosate applied to kill perennial species in the fall)
B. Spring-kill no-till
   (Glyphosate or atrazine applied to kill perennial species in the spring)
C. Current tillage
   (Fall or spring chisel or moldboard plowing)

Additional weed control, soil fertility, insect control, hybrids, and other cultural practices varied with farms but were similar within sites for the three tillage systems.

Applied Questions

Which no-till system (fall- or spring-kill) resulted in best performance?

No-till corn planted following spring-kill of perennial forage vegetation resulted in greatest residue cover after planting (Table 1), which probably would provide best soil erosion control. But spring-kill no-till resulted in inconsistent weed control, variable plant stands and corn growth, and reduced average yields compared with growers' current tillage systems (Table 1). With fall-kill no-till, weed control was effective and grain yields were always comparable to, or greater than, current tillage systems. Average corn production cost per bushel was lowest for fall-kill no-till, intermediate for current tillage systems, and highest for spring-kill no-till.

Full scientific article from which this summary was written begins on page 46 of this issue.

Given these production advantages, why have few farmers adopted fall-kill no-till for corn following forage perennials?

Fall-kill no-till requires growers to use a fixed crop rotation schedule, with the decision to rotate to corn made the previous fall. Growers prefer to assess forage crop winter survival in the spring as a basis for crop rotation plans. Other constraints, such as the need for fall grazing and labor shortages at corn harvest time, may prevent fall herbicide applications. In addition, crop residue cover from fall-killed vegetation, as low as 30% after planting (Table 1), may not provide adequate soil erosion control on steep slopes.

Table 1. Average residue cover after planting, plant populations at harvest, grain yield, and production cost for corn grown under three tillage systems at six farms.

Tillage system	Residue cover	Harvest population	Grain yield	Production cost
	— % —	plants/acre × 1000	bu/acre	— $/bu —
Current tillage	13 (4-40)†	22 (18-26)	114 (62-163)	2.42 (1.25-3.88)
Fall-kill no-till	53 (30-67)	23 (19-26)	120 (74-162)	2.30 (1.29-3.64)
Spring-kill no-till	72 (57-89)	21 (15-29)	98 (20-176)	4.68 (1.21-11.80)

† Range of values across six farms.

No-Till Systems for Corn following Hay or Pasture

M. A. Smith and P. R. Carter*

No-till (NT) corn (*Zea mays* L.) production following perennial forages can reduce soil loss and machinery and labor requirements; yet few farmers in the northern USA are using this practice. Research has indicated NT corn performs best when planted following fall-killed perennials; yet most farmers who practice NT apply herbicides to perennials in the spring. The objective of this study was to compare two NT systems, fall-kill NT and spring-kill NT, with farmers' current tillage (CT) systems, which included either chisel or moldboard plowing. Farmer-managed comparisons were made in field-sized, replicated strip tests on silt loam soils on six farms in 1988 and 1989. Variables measured were percentage residue cover after planting, harvest plant populations, and grain moisture and yields. Residue cover averaged 13, 53, and 72% for CT, fall-kill NT, and spring-kill NT, respectively. Spring-kill NT, compared with CT and fall-kill NT, resulted in reduced plant populations at three of six farms and 3% higher average grain moisture. Fall-kill NT produced yields equal to, or higher than, CT and spring-kill NT at all farms. Averaged over all farms, production costs per bushel were lowest for fall-kill NT, intermediate for CT, and highest for spring-kill NT. Despite these advantages, use of fall-kill NT may be limited by (i) farmers' preferences for evaluating hay stands in the spring, before deciding where to plant corn; (ii) fall grazing needs; (iii) minimum requirements for crop residue cover after corn planting; and (iv) shortage of labor in the fall.

NO-TILL CORN production following perennial forage species is an effective method of reducing soil loss on sloping soils and of decreasing fuel, machinery, and labor costs (Moomaw and Martin, 1990). Farmers' biggest concern about no-tilling corn into sod is the application timing and efficacy of herbicides to control perennials. Wisconsin research has indicated that split herbicide treatments, either in the fall or early spring and at planting, were needed to completely control sod vegetation (Buhler and Mercurio, 1988; Buhler and Proost, 1990). Best vegetation control was achieved with fall Roundup (glyphosate) applications. Smith et al. (1992) demonstrated that when sod vegetation was killed in the fall and corn planted no-till in late April, yields were comparable to those under conventional (moldboard plow) tillage. But, in 3 of 4 yr, corn planted no-till with spring-kill of perennials yielded 17 to 45 bu/acre less than corn under fall-kill NT.

Although these and other researchers (Barnett, 1990), have demonstrated that corn can be successfully grown with no-till planting into mixed alfalfa (*Medicago sativa* L.)/grass sod that has been chemically killed, adoption of no-till has been slow in the northern USA. And, most farmers who plant corn no-till into sod apply herbicides to kill perennials in the spring, rather than in the fall. Although corn may yield well when perennials are controlled in the spring, farmers have not made side-by-side comparisons of corn planted following spring-killed and fall-killed perennials to evaluate relative yields, management challenges, and economics. Lack of farmer involvement in testing no-till may be one reason for the slow adoption of these technologies. Rzewnicki (1991) found that field-sized, farmer-managed, strip tests have twice the farmer support of demonstrations or experiment station trials.

On-farm research is a means of providing much wider exposure to experiment station research results, both with respect to environment and to potential users; and it can fill a void in the research-extension continuum of information transfer. Types of on-farm research range from researcher-managed trials, in which farms are used mainly for their physical characteristics, such as soil type or geographic location; to farmer-managed trials, in which technologies tested are implemented by farmers and compared to existing practices (Shaner et al., 1982). Important aspects of farmer-managed trials are the opportunities for farmers to modify treatments or technologies to fit their farming system and for researchers to identify bio-

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Abbreviations: CT, current tillage; NT, no-till.

Table 1. Field characteristics and production practices for tillage comparisons at six farms, 1988 and 1989.

	Farm and year					
	1988		1989			
Item	Steinback	Mueller	Speerstra	Mueller	Adrian	Wolfe
County	Grant	Columbia	Trempealeau	Columbia	Grant	Buffalo
Soil type†	Fayette silt loam	Plano silt loam	Port Byron silt loam	Channahon silt loam	Fayette silt loam	Fayette silt loam
Organic matter %	1.9	3.3	2.4	4.5	2.3	2.6
Slope %	8–10	3–6	3	6–12	3	16
Previous crop	Alfalfa‡ hay	Orchardgrass, smooth bromegrass, and alfalfa hay	Quackgrass, foxtail, and orchardgrass set-aside acres	Alfalfa, smooth bromegrass, and orchardgrass pasture	Alfalfa and orchardgrass hay	Alfalfa, orchardgrass, and tall fescue hay
Implement used and time for current tillage system	Chisel plow spring	Chisel plow fall	Moldboard plow spring	Disk-chisel plow fall	Chisel plow spring	Disk-chisel plow fall
Manure applied	Hog and steer, 30 ton/acre (liquid)	None	Dairy, 30 ton/acre (solid)	None	None	Dairy, 20 ton/acre (liquid)
Fertilizer applied (N+P+K)	7+9+6 lb/acre	12+21+40 lb/acre 120 lb/acre N	132+18+100 lb/acre	12+21+40 lb/acre 120 lb/acre N	18+20+50 lb/acre 100 lb/acre N	18+20+50 lb/acre
Insecticide applied§	Terbufos 0.08 lb a.i./1000 ft	None	Fenvalerate 0.05 lb a.i./acre	None	Terbufos 0.08 lb a.i./1000 ft	None
Corn hybrid (Relative maturity)	Pioneer brand 3737 (95 d)	Dekalb brand 524 (100 d)	Pioneer brand 3585 (105 d)	Henry brand H30A (110 d)	Northrup King brand 4590 (100 d)	Pioneer brand 3751 (95 d)
Planter						
Make and model	I.H. 800	New Idea/Kinze	J.D. 7000	New Idea/Kinze	I.H. 800	J.D. 7000
In-row attachments	Row-cleaning disks	Rippled coulter	Fluted coulter	Rippled coulter	--	Rippled coulter
Planting date	11 May	2 May	15 May	4 May	11 May	13 May
Harvest date	14 October	19 October	12 October	11 November	11 October	12 October

† Fayette (fine-silty, mixed, mesic Typic Hapludalfs); Plano (fine-silty, mixed, mesic Typic Argiudolls); Port Byron (fine-silty, mixed, mesic Typic Hapludolls); Channahon (loamy, mixed, mesic Lithic Argiudolls).

‡ Latin names of plants are: alfalfa (*Medicago sativa* L.), orchardgrass (*Dactylis glomerata* L.), smooth bromegrass (*Bromus inermis* Leyss), quackgrass (*Elytrigia repens*), foxtails (*Setaria* spp.), tall fescue (*Festuca arundinacea* Schreb.).

§ Terbufos = Phosphorodithioic acid S-[[(1,1-dimethylethyl)thio]methyl] 0,0-diethyl ester.

logical, economic, or social constraints to changing practices.

Objectives of this study were to (i) compare two NT systems with CT systems for corn following perennial sod in field-sized, replicated, strip tests under farmer management; (ii) evaluate the economics of each system; and (iii) identify constraints to the adoption of NT.

MATERIALS AND METHODS

Treatments were selected for farmer-managed evaluations using results from 3 yr of a researcher-managed, experiment-station-based study comparing tillage systems, times of sod vegetation kill, and planting dates for corn following sod (Smith et al., 1992). Two no-till/perennial vegetation kill systems: fall-kill NT and spring-kill NT were compared to farmers' CT systems for establishing corn following hay or pasture. Current tillage systems included either chisel or moldboard plowing (Table 1). Trials were field-sized, replicated, strip tests conducted on five farms in central and western Wisconsin during 1988 and 1989. One farmer cooperated both years of the study, for a total of six environments over 2 yr.

Cooperating farmers grew corn for their dairy operations and all had experience with NT. All farms had some steep slopes susceptible to erosion.

A randomized complete block design was used on each farm with three or four replicates, depending on available space. Field plots, sized according to machinery and field dimensions, were two to three times the width of the planter and as long as possible within the field. Plot sizes ranged from 0.25 to 1 acre.

Field sites were on silt loam soils ranging from 3 to 16% slopes. Previous crops varied from a nearly pure alfalfa stand to weedy set-aside acres (Table 1). Guidelines were provided to cooperating farmers suggesting herbicides and rates for both fall- and spring-kill NT treatments. Roundup or Ranger (glyphosate) was suggested for fall-kill of perennials and split atrazine applications (early preplant and preemergence) plus paraquat to kill perennials in the spring. Management of current tillage systems was at the discretion of farm cooperators. Farmers adjusted herbicide choices, rates, and the use of row cultivation to fit their specific weed problems and crop rotations. Farmers also were asked to increase their planting rates by 5% for fall-kill NT and 15% for spring-kill NT to compensate for reduced emergence observed for these treatments compared with CT in a related study (Smith et al., 1992). Actual herbicides and rates applied, use of row cultivation, and corn seeding rates varied with treatment, location, and farm cooperator (Tables 2 and 3).

Fertilizers, manure application rates, and insecticides; corn hybrids; and planting and harvest dates were selected by cooperating farmers. Although these factors varied from farm to farm, they were constant for all three tillage systems at each location (Table 1).

Crop residue cover was estimated after planting with the line-intersect method (Laflen et al., 1981). Plant stands were estimated just before harvest from 10 randomly selected 20 ft lengths of harvest rows. The center four or six rows of plots were harvested with commercial combines. Grain yields were measured with weigh wagons and grain moisture percent was determined with

Table 2. Weed control practices for three tillage systems at six farms, 1988 and 1989.

Tillage system and time of herbicide application†	Farm and year					
	1988		1989			
	Steinback	Mueller	Speerstra	Mueller	Adrian	Wolfe
	Weed control program (herbicide a.i. rates/acre)					
Current tillage						
Fall	--	--	--	Glyphosate, 1.5 lb	--	--
EPP	--	Atrazine, 2 lb	--	--	--	--
Pre	Atrazine, 2.6 lb Crop oil 1 qt X-77 spreader, 0.5 pt	Atrazine, 2 lb Paraquat, 0.2 lb	Atrazine, 2 lb Cyanazine, 1.5 lb	Alachlor, 2 lb Cyanazine, 2 lb	Alachlor, 2 lb Cyanazine, 2 lb	Alachlor, 2 lb Cyanazine, 2 lb
Post	--	--	--	2,4-D amine, 1 lb Dicamba, 1 lb	--	--
	Row cultivation	Row cultivation	Row cultivation	--	Row cultivation	Row cultivation
Fall-kill no-till						
Fall	Glyphosate, 1.5 lb	Glyphosate, 1.5 lb	Glyphosate, 0.8 lb	Glyphosate, 1.5 lb	Glyphosate, 1.1 lb	Glyphosate, 1 lb
Pre	Alachlor, 2 lb Cyanazine, 2 lb 2,4-D amine, 0.5 lb	Alachlor, 2 lb Cyanazine, 2 lb	Cyanazine, 2 lb 2,4-D amine, 0.2 lb	Alachlor, 2 lb Cyanazine, 2 lb	Alachlor, 2 lb Cyanazine, 2 lb	Cyanazine, 2 lb
Post	--	--	--	2,4-D amine, 1 lb Dicamba, 1 lb	--	--
	Row cultivation	--	--	--	--	Row cultivation
Spring-kill no-till						
EPP	Atrazine, 2 lb	Atrazine, 2 lb	Glyphosate, 0.8 lb	Atrazine, 2 lb	Atrazine, 2 lb	Glyphosate, 1.1 lb
Pre	Atrazine, 2 lb Metolachlor, 2 lb Crop oil, 1 qt Paraquat, 0.2 lb X-77 spreader, 0.5 pt 2.4-D amine, 0.5 lb	Atrazine, 2 lb Crop oil, 1 qt Paraquat, 0.2 lb X-77 spreader, 0.5 pt	Cyanazine, 2 lb 2,4-D amine, 0.2 lb	Atrazine, 2 lb Glyphosate, 1.5 lb	Atrazine, 1.5 lb Paraquat, 0.2 lb X-77 spreader, 0.5 pt	Cyanazine, 2 lb
Post	--	2,4-D amine, 0.5 lb	--	2,4-D amine, 1 lb Dicamba, 1 lb	--	--
	Row cultivation	Row cultivation, twice	--	--	--	Row cultivation

† Times of herbicide application are: Fall = October prior to growing season; EPP = early preplant (mid-April); Pre = Preemergence (within 1 wk of planting); Post = postemergence (late May/early June).

Table 3. Corn seeding rates for three tillage systems at six farms, 1988 and 1989.

Tillage system	Farm and year					
	1988		1989			
	Steinback	Mueller	Speerstra	Mueller	Adrian	Wolfe
	Corn seeding rates (seeds/acre)					
Current tillage	26 700	31 100	26 100	26 200	25 900	25 600
Fall-kill no-till	29 500	31 100	27 200	27 800	25 900	26 900
Spring-kill no-till	30 300	33 800	30 200	30 700	26 900	29 800

hand-held moisture meters. Grain yields were adjusted to 15.5% moisture. Analyses of variance for agronomic variables were conducted across farm-sites and separately for each farm.

Production costs were calculated using actual seeding, N fertilizer, and pesticide rates and prices. Charges for P and K were based on average crop removal rates and a charge of \$0.57/lb of P and \$0.16/lb of K (L. Bundy, 1988, personal communication). Machinery costs were estimated using the Minnesota Farm Machinery Economic Cost Estimates (Fuller and Maguire, 1988; Fuller et al., 1989). Because cooperators primarily harvested corn for high moisture grain as feed for dairy animals, grain drying costs were not included. Twelve percent annual interest for 6-mo. was charged on variable costs. Land charges were the best estimates from farm cooperators. Variable, fixed, and total production costs were calculated per acre. Cost of production per bushel of corn was calculated by dividing total production costs (\$/acre) by yield (bu/acre).

In the fall of 1990, a year after field trials had been completed, farm cooperators were interviewed to identify problems or constraints associated with the NT systems.

RESULTS AND DISCUSSION

Air temperatures were above average and rainfall far below average near both farms in 1988, with May and June rainfall 2.1 to 3.7 in. below normal (Table 4). High temperatures with low rainfall in 1988 combined to cause one of the worst droughts in history. Conditions improved in 1989, but both temperature and precipitation during the 1989 growing season were still below average for Wisconsin, with rainfall ranging from 19 to 22 in. (Table 4).

Perennial Weed Control

For fall-kill NT, all farmers applied glyphosate to control perennial species (Table 2). But for spring-kill NT, only Speerstra and Wolfe in 1989 used glyphosate.

Table 4. Monthly air temperature and precipitation for six farms in western and south-central Wisconsin in 1988 and 1989.

	Farm and year					
	1988		1989			
Month	Steinback	Mueller	Speerstra	Mueller	Adrian	Wolfe
			Air temperature, °F			
April	48.6 (0.7)†	55.0 (8.1)	--	45.2 (0.7)	47.9 (−0.8)	--
May	63.8 (4.6)	62.6 (4.1)	--	57.6 (−0.9)	59.2 (−1.6)	--
June	72.9 (4.7)	71.6 (4.9)	--	66.3 (−0.8)	68.5 (−1.4)	--
July	76.5 (4.1)	75.0 (3.3)	--	72.8 (0.9)	76.0 (2.0)	--
August	76.5 (6.1)	74.7 (5.3)	--	69.5 (0.1)	71.4 (−0.7)	--
September	65.3 (3.2)	64.4 (3.1)	--	59.4 (−1.8)	61.0 (−2.6)	--
October	45.0 (−6.3)	44.6 (−4.8)	--	51.2 (1.6)	52.9 (−0.1)	--
			Precipitation, in.			
April	2.1 (−1.5)	3.3 (0.2)	2.0	1.4 (−1.6)	3.0 (−0.3)	2.0
May	0.9 (−3.0)	1.0 (−2.1)	4.1	1.8 (−1.2)	3.4 (−0.4)	4.1
June	0.9 (−3.7)	1.5 (−2.1)	1.5	2.0 (−1.6)	2.6 (−1.7)	1.5
July	3.0 (−1.6)	1.6 (−2.0)	3.5	3.8 (0.2)	2.1 (−2.6)	3.5
August	1.9 (−2.2)	2.9 (−1.4)	4.3	4.3 (−0.2)	4.4 (0.7)	4.3
September	4.4 (0.8)	3.9 (−0.2)	1.7	3.8 (−0.3)	3.1 (0.2)	1.7
October	1.4 (−1.3)	2.2 (−0.3)	2.3	2.4 (−0.1)	3.4 (1.2)	2.3
Season total	14.6 (−12.5)	16.3 (−7.9)	19.4	19.5 (−4.5)	22.0 (−2.9)	19.4

† Number in parentheses is the deviation from the 20-yr average, shown when data is available.

Table 5. Perennial weed kill ratings for three tillage systems at six farms, 1988 and 1989.

	Farm and year					
Tillage system and time of weed kill rating	1988		1989			
	Steinback	Mueller	Speerstra	Mueller	Adrian	Wolfe
			Relative level of perennial weed kill†			
Current tillage						
At planting	Excellent/good	Fair (alfalfa, grass)‡	Excellent/good	Excellent/good	Excellent/good	Excellent/good
Before post-emergence weed control§	Poor (orchardgrass)	Poor (quackgrass)	Fair (quackgrass)	Fair (alfalfa, grass)	Good	Good
60 d after corn emergence	Good	Fair (quackgrass)	Fair (quackgrass)	Good	Excellent/good	Excellent/good
Fall-kill no-till						
At planting	Excellent/good	Excellent/good	Excellent/good	Excellent/good	Excellent/good	Good
Before post-emergence weed control	Good	NA¶	NA	Good	NA	Good
60 d after corn emergence	Good	Excellent/good	Good	Good	Excellent/good	Excellent/good
Spring-kill no-till						
At planting	Poor (alfalfa, orchardgrass)	Fair (alfalfa, quackgrass)	Fair (grass)	Poor (alfalfa, grass)	Excellent/good	Excellent/good
Before post-emergence weed control	Poor (alfalfa, orchardgrass)	Poor (alfalfa, quackgrass)	NA	Fair (alfalfa, grass)	NA	Good
60 d after corn emergence	Fair (orchardgrass)	Fair (quackgrass)	Good	Good	Excellent/good	Excellent/good

† Excellent, good, fair, and poor ratings based on relative amount of visual kill of above-ground perennial weed tissue.
‡ Weed species not controlled are indicated in parentheses. Alfalfa (*Medicago sativa* L.), orchardgrass (*Dactylis glomerata* L.), quackgrass (*Elytrigia repens* L.).
¶ NA = Not applicable.

For spring-kill NT, we suggested atrazine/paraquat use (rather than glyphosate) for perennial grass control based on university extension recommendations which were current when the study was initiated (Doersch and Buhler, 1989). These guidelines suggested relatively high spring-applied atrazine rates (which are no longer labelled by the manufacturer), along with paraquat to hasten burndown of living above-ground perennial weed tissue at planting. Glyphosate was not recommended for spring-kill NT, unless the grower planned to rotate from corn to alfalfa the succeeding year (in which case carryover residues from atrazine use would preclude this crop rotation choice). Previous research and experience in Wisconsin had indicated that spring-applied glyphosate was relatively less effective than atrazine in controlling perennial weed species (Doersch and Buhler, 1989; Buhler and Mercurio, 1988). Spring glyphosate use also causes planting delays and soil moisture depletion (Smith et al., 1992) while weed species grow to the 8 to 12 in. height required before herbicide application. In the current study, the two farmers (Speerstra and Wolfe in 1989) who used glyphosate rather than atrazine for spring-kill NT had the latest corn planting dates (Table 1).

Table 6. Residue percent cover after planting, plant populations at harvest, and harvest grain moisture percent for corn grown under three tillage systems at six farms.

	Residue cover					Harvest population					Grain moisture				
Farm and year	CT†	FK NT	SK NT	LSD (0.05)	CV %	CT	FK NT	SK NT	LSD (0.05)	CV %	CT	FK NT	SK NT	LSD (0.05)	CV %
	%					plants/acre × 1000					%				
Steinback 1988	11	47	69	19	19.9	24.3	22.0	15.5	NS	19.6	17.9	18.5	26.8	NS	19.7
Mueller 1988	40	30	78	7	8.4	25.5	26.1	24.3	0.9	2.1	19.7	19.6	21.8	0.9	2.2
Speerstra 1989	6	81	89	12	8.8	20.8	25.9	21.1	4.2	8.2	34.8	31.1	35.8	4.0	5.2
Mueller 1989	13	40	60	14	21.0	17.7	18.5	14.5	3.0	10.3	18.7	20.2	24.1	0.9	2.5
Adrian 1989	4	67	82	7	5.9	24.0	24.5	24.1	NS	3.6	23.7	23.6	23.4	NS	4.0
Wolfe 1989	7	51	57	17	19.2	22.0	22.5	28.9	NS	19.2	21.5	22.7	21.4	NS	2.7

† CT = Current tillage system; FK NT = Fall-kill no-till; SK NT = Spring-kill no-till.

Use of row cultivation to control weeds in NT systems was also left to the discretion of cooperating farmers. Growers applied herbicides at the suggested rates and times, and then cultivated if they had appropriate equipment and perceived that it was necessary to control weeds. Row cultivation was used on two of six farms for fall-kill NT and on three of six farms for spring-kill NT (Table 2). Corn height at row cultivation ranged from 14 to 20 in.

Perennial weed kill was always good-to-excellent for fall-kill NT (Table 5). Among the three tillage systems, perennial weed kill was most inconsistent for spring-kill NT, with control generally related to spring rainfall. Good-to-excellent perennial weed control from planting to early corn growth stages occurred only at Adrian's and Wolfe's in 1989 (Table 5). Perennial weed control was particularly difficult at Steinback's and Mueller's in 1988, when dry April/May conditions (Table 4) limited herbicide effectiveness and crop competitive ability. In on-farm studies in New York, Cox et al. (1992) also found unsatisfactory perennial weed control with spring-applied glyphosate or atrazine for NT corn following alfala-grass sod.

At all sites, only perennial weeds presented control difficulties. Annual weeds were controlled effectively with preplant and pre-emergence herbicides.

Residue Cover Percentages

Spring-till NT systems always had more residue remaining after planting than did fall-kill NT (Table 6). Spring-kill NT left from 60 to 90% ground cover, while fall-kill NT left 30 to 80% ground gover, depending on the location. This was consistent with residue cover from similar treatments in a related researcher-managed small-plot study (Smith et al., 1992). In 1988, CT at Mueller's had more residue cover after planting than did fall-kill NT due to a heavy infestation and poor control of quackgrass (*Elytrigia repens*). Higher percentages of grass vs. alfalfa in a hay or pasture mix generally resulted in more residue cover after planting (Tables 1 and 6).

Plant Population

Even with overplanting NT treatments (Table 3), harvest plant populations were lower in spring-kill NT than fall-kill NT at three of six farms (Table 6). Stand counts taken shortly after corn emergence (data not shown) were similar to those at harvest (Table 6). Therefore, reduced corn stands for spring-kill NT were due primarily to reduced seedling emergence or early post-emergence mortality.

In 1988, for spring-kill NT at Steinback's and Mueller's, surviving alfalfa and grasses (Table 5) depleted seed-zone soil moisture, which made it difficult to place seed in moist soil. The 1988 drought resulted in reduced stands for spring-kill NT and contributed to great variability in plant populations, especially at Steinback's. Corn populations with spring-kill NT at Steinback's were 9 000, 15 000, and 22 000 plants/acre for individual replicates. Although rainfall in 1989 was more favorable than in 1988 (Table 4), spring kill of perennials at Speerstra's and Mueller's was slow that spring (Table 5), which caused dry seed-zone soil and contributed to stand reductions in spring-kill NT (Table 6).

Cox et al. (1992) in New York reported substantial post-emergence seedling corn mortality due to slug feeding under spring-kill NT following alfalfa-grass. In our on-farm studies, stand losses for spring-kill NT were usually not attributable to slugs, insects or rodents. Some farmer cooperators did mention that they observed 13-striped ground squirrels (*Spermophilus tricemlineatus*) eating seed embryos in NT corn fields. Speerstra's sprayed fenvalerate (4-Chloro-α-(1-methylethyl)benzene-acetic acid cyano(3-phenoxyphenyl)methyl ester) over the entire trial to control common stalk borer (*Papaipema nebris* Guenee) in 1989 (Table 1), and stalk borer reduced plant populations in all treatments at Mueller's in 1989 (Table 6).

Plant populations were not different at harvest-time for fall-kill NT and CT at five farms (Table 5). Only at Speerstra's was plant population lower under CT than fall-kill NT (Table 6). At that site, seeding depth was shallow (1 in.) and soils were especially dry for CT due to competition from quackgrass. An overly aggressive late cultivation also depleted stands in CT at Speerstra's (Tables 2 and 6).

Grain Moisture

Grain from spring-kill NT treatments contained the most moisture at three of six farms (Table 6). Corn germination and subsequent season-long growth often are delayed when NT planting follows spring-killed sod vegetation (Smith et al., 1992). Delayed early development usually results in delayed silking and maturity. Smith et al. (1992) and Cox et al. (1992) also found that corn planted under NT with spring vegetation-kill had delayed plant development and wetter harvest grain moisture than corn

Table 7. Costs of production for corn following hay or pasture for three tillage systems on six farms, 1988 and 1989.

	Farm and year																	
	1988						1989											
	Steinback			Mueller			Speerstra			Mueller			Adrian			Wolfe		
Production Inputs	CT†	FK NT	SK NT	CT	FK NT	SK NT	CT	FK NT	SK NT	CT†	FK NT	SK NT	CT	FK NT	SK NT	CT	FK NT	SK NT
	$/acre																	
Variable Inputs																		
Seed	28	31	32	25	25	27	25	26	28	20	22	24	20	21	21	23	25	27
Nitrogen fertilizer	2	2	2	17	17	17	34	34	34	16	16	16	29	29	29	3	3	3
Phosphorus and potassium‡	9	11	4	9	11	3	17	20	17	18	17	13	23	24	24	24	23	26
Pesticides	15	60	38	28	50	29	13	33	33	55	55	45	30	53	24	21	28	33
Estimated equipment§ operating costs and labor	31	28	28	27	21	25	37	25	25	30	24	25	32	22	22	35	31	31
Interest (6% of var. costs)	5	8	6	6	7	6	8	8	8	8	8	7	8	9	7	6	7	7
Total variable costs	90	140	110	112	131	107	134	146	145	147	142	130	142	158	127	112	117	127
Fixed Inputs																		
Estimated equipment overhead	33	29	29	33	26	29	38	25	25	35	27	27	28	21	21	37	31	31
Land	100	100	100	100	100	100	30	30	130	100	100	00	95	95	95	55	55	55
Total fixed costs	133	129	129	133	126	129	68	55	55	135	127	127	123	116	116	92	86	86
Total costs/acre ($)	223	269	239	245	257	236	202	201	200	282	269	257	265	274	243	204	203	213
Grain yield (bu/acre)	62	74	27	63	75	20	112	137	114	124	117	87	157	162	164	163	157	176
Cost/bushel ($)	3.60	3.64	8.85	3.88	3.42	11.80	1.80	1.47	1.76	2.27	2.30	2.95	1.69	1.69	1.48	1.25	1.29	1.21

† CT = Current tilage system; FK NT = Fall-kill no-till; SK NT = Spring-kill no-till.
‡ Costs based on 0.19 lb P removed/bu corn × $0.57/lb and 0.24 lb K removed/bu corn × $0.16/lb.
§ Costs calculated based on values for equipment used; from Fuller and Maguire, 1988 and Fuller et al., 1989.

planted following fall vegetation-kill. Delayed crop development, as indicated by grain moisture, may be a more negative factor for cash grain producers who dry corn than for dairy producers who often harvest high moisture corn. Higher grain moistures, however, would delay harvesting for both producers.

Grain moistures for corn from fall-kill NT and CT were similar at four farms, but fall-kill NT produced drier corn at Speerstra's and wetter corn at Mueller's in 1989 than did CT.

Grain Yields

Due to drought in 1988, yields were less than half those in 1989 (Table 4, Fig. 1). Fall-kill NT had equal or greater grain yields than CT and spring-kill NT both years at all farms (Fig. 1). For spring-kill NT, grain yields relative to the two other tillage systems were inconsistent, and response appeared related to both spring rainfall and level of perennial weed kill. In 1988 at Steinback's and Mueller's, yields for spring-kill NT were only 25 to 35% of those for fall-kill NT (Fig. 1). May and June rainfall combined for these farms was only about 2 in. (Table 4) and perennial weed kill for spring-kill NT was poor to fair (Table 5). In contrast, at Adrian's and Wolfe's in 1989, spring-kill NT yields were similar to those for fall-kill NT (Fig. 1), with about 6 in. of May-June rainfall (Table 4) and good-to-excellent perennial weed kill (Table 5). Relative spring-kill NT vs. fall-kill NT yields at Speerstra's and Mueller's in 1989 were intermediate (Fig. 1), as was May-June rainfall at Mueller's (Table 4) and level of perennial weed kill for spring-kill NT at both sites (Table 5).

Yield losses for spring-kill NT vs. fall-kill NT were par-

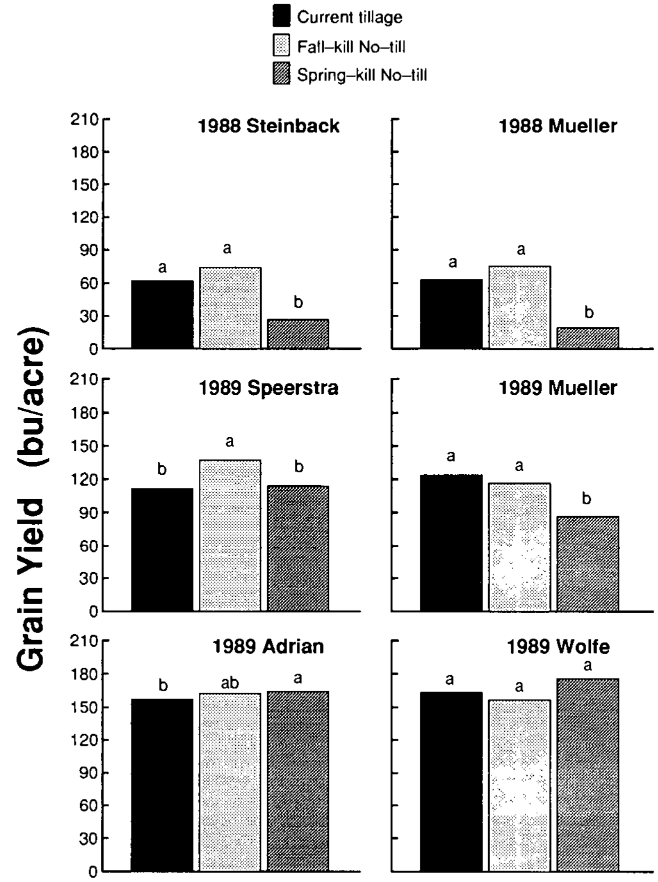

Fig. 1. Corn grain yield response to three tillage/weed control systems (current tillage system, fall-kill no-till, and spring-kill no-till) for six farms. Tillage means are different at each farm if different letters appear above bars.

tially due to the reduced corn stands for spring-kill NT (Table 6). At the four farms where yield losses for this tillage system occurred, however, the percentage yield reduction for spring-kill NT was always greater than that expected based only on reduced plant populations (Table 6, Fig. 1). For example, at Mueller's in 1988, stands for spring-kill NT were reduced about 7% compared with those for fall-kill NT (Table 6). This level of stand loss alone would reduce yields by only about 2%, based on long-term plant population studies at this site (Carter, 1986). But 1988 yields for spring-kill NT at Mueller's were reduced by about 75% compared with those for fall-kill NT (Fig. 1). Unsatisfactory perennial weed kill for spring-kill NT at Steinback's and Mueller's in 1988 and at Speerstra's and Mueller's in 1989 (Table 5) resulted in depleted soil moisture reserves, which not only reduced corn stands but also increased visible plant water stress and decreased corn yields during these relatively low rainfall years (Table 4). With increased rainfall (particularly in May and June) relative performance of spring-kill NT vs. fall-kill NT probably would be improved, both due to enhanced perennial weed kill and to less negative effect of uncontrolled weeds on corn growth. In researcher-managed trials, Smith et al. (1992) also reported more consistent corn performance with fall-kill NT vs. spring-kill NT.

Production Costs

Total production costs per acre ranged from $200 to $282 (Table 7). Variable costs were usually higher for NT due to increased herbicide costs and increased seeding rates. Fixed costs were usually higher for CT because of tillage equipment costs (Table 7). Land charges per acre were the same for all three tillage systems at each location and ranged from $30 to $100, depending on the farm.

Total production costs varied little among treatments at each farm (Table 7), therefore yield was the primary factor contributing to differences in production costs per bushel. Because of extremely low yields in 1988, production costs per bushel were very high (Table 7). Averaged over two farms that year, costs of production were $3.74/bu for CT, $3.53/bu for fall-kill NT and $10.33/for spring-kill NT (Table 7). In 1989, costs per bushel averaged over four farms were $1.75 for CT, $1.69 for fall-kill NT, and $1.85 for spring-kill NT (Table 7). Of the three tillage systems, spring-kill NT was most variable with the lowest cost per bushel at two farms and the highest cost per bushel at three farms. Fall-kill NT had the lowest production cost per bushel at three farms and had production costs of not more than $0.04/bu over CT at all farms. Fall-kill NT had lower production costs per bushel than did spring-kill NT at four of the six farms.

Farmer Perceptions

Although the number of farmers involved in these studies is too small to constitute a statistically valid survey sample, their operations and experiences are typical and their opinions probably reflect those of many dairy producers in northern regions. Constraints both to the general use of NT following hay or pasture and to fall-kill NT were identified.

Factors that may limit the general adoption of NT for corn planted into perennial sod include: (i) the cost of a NT planter, and (ii) the need to incorporate large amounts of manure. Constraints to NT systems that include killing perennial forage species in the fall, include: (i) the need for forage in the fall for grazing, (ii) the percent residue cover following corn planting may not provide adequate erosion control (although erosion control probably will be better than many CT systems), (iii) labor may not be available during harvest for spraying sod vegetation, and (iv) the preference for waiting until spring to evaluate winter survival of hay stands before deciding where to plant corn.

Farmers also discovered several advantages for fall-kill NT including: (i) atrazine, a herbicide with lengthy residual in soil, was no longer needed to control quackgrass and other perennials; (ii) fall treatment of quackgrass and other perennial species with glyphosate gave more effective control than spring application; (iii) herbicide rates may be reduced; and (iv) with the extended period between killing perennials and spring planting, fall-kill NT provided the option of growing corn or seeding another alfalfa crop without alfalfa autotoxicity problems.

REFERENCES

Barnett, K.H. 1990. No-tillage corn production in an alfalfa-grass sod. J. Prod. Agric. 3—71-75.

Buhler, D.D., and J.C. Mercurio. 1988. Vegetation management and corn growth and yield in untilled mixed-species sod. Agron J. 80:454-462.

Buhler, D.D., and R.T. Proost. 1990. Sequential herbicide treatments for corn (*Zea mays*) planted into mixed-species perennial sod. Weed Technol. 4:781-786.

Carter, P.R. 1986. Corn replanting or late-planting decisions. Univ. of Wisconsin Coop. Ext. Bull. A3353.

Cox, W.J., D.J. Otis, H.M. van Es, F.B. Gaffrey, D.P. Snyder, K.R. Reynolds, and M. van der Grinten. 1992. Feasibility of no-tillage and ridge tillage systems in the northeastern USA. J. Prod. Agric. 5:111-117.

Doersch, R.E., and D.D. Buhler. 1989. Controlling weeds in conservation tillage corn production. Univ. of Wisconsin Coop. Ext. Serv. Bull. A3425.

Fuller, E., B. Lazarus, and D. Nordquist. 1989. Minnesota farm machinery economic cost estimates for 1989. Minnesota Ext. Serv. no. AG-FO-2308.

Fuller, E.I., and M.F. Maguire. 1988. Minnesota farm machinery cost estimates for 1988. Minnesota Ext. Serv. no. AG-FO-2308.

Laflen, J.M., M. Amemiya, and E.A. Hintz. 1981. Measuring crop residue cover. J. Soil Water Conserv. 36:341-343.

Moomaw, R.S., and A.R. Martin. 1990. No-till corn in alfalfa sod. Univ. of Neb. Ext. NebGuide G74-131.

Rzewnicki, P. 1991. Farmers' perceptions of experiment station research, demonstration, and on-farm research in agronomy. J. Agron. Educ. 20:31-36.

Shaner, W.W., P.F. Philipp, and W.R. Schmehl. 1982. On-farm research and analysis. p. 111-145. *In* Farming systems research and development: Guidelines for developing countries. Westview Press, Boulder, CO.

Smith, M.A., P.R. Carter, and A.A. Imholte. 1992. Conventional vs. no-till corn following alfalfa/grass: Timing of vegetation kill. Agron. J. 84:780-786.