Integrated Cropping System for Corn-Sugar Beet-Dry Bean Rotation: The Experience of the Innovative Farmers of Michigan
Michigan State University
Michigan State University Extension
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Issued March 2001
36 pages

Extension Bulletin E-2738, New, March 2001

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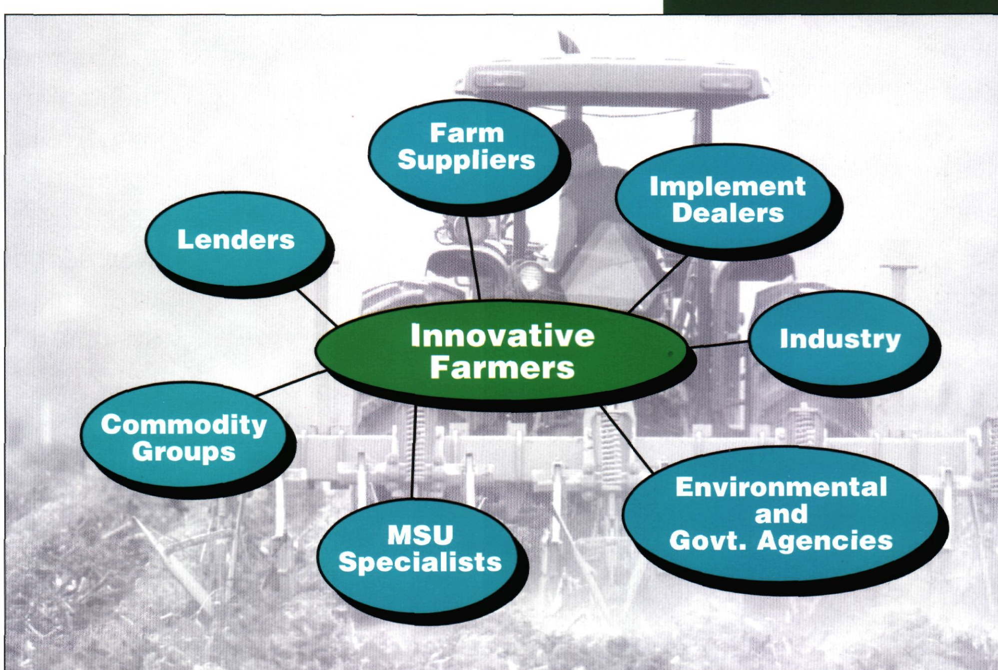
Who are the Innovative Farmers?

The Innovative Farmers of Michigan is an agricultural organization initially formed by farmers in Huron County. The group organized to promote research that would make the area's agricultural industry more efficient and economically and environmentally sound, aid in the development and expansion of new technology to neighboring farms, increase awareness and educate the public on current agricultural issues and trends, and provide a forum for discussion of agricultural and environmental issues.

The Innovative Farmers members believe that involvement of all segments of the agricultural industry is the key to success. The farmers' efforts and patience and the support of lending institutions, agribusinesses and agencies created a remarkable synergism.



What Were the Concerns and How Were They Addressed?

During the late 1980s, water quality issues came to the forefront in Michigan's Thumb area with concerns about potential sediment, pesticide and nutrient loading of the area's surface water. With more than 90 miles of Lake Huron shoreline, Huron County producers were well aware of these concerns. The Huron County Innovative Farmers was organized in 1993 to establish large, on-farm plots to evaluate the effectiveness of soil nitrate testing, reduced pesticide application, manure application techniques and narrow-row production. In addition, 14 producers collected more than 120 water samples from their tile outlets to determine nitrate levels in the drainage water. Samples were collected and analyzed, and an economic analysis was completed to determine the value of nitrogen lost through the drainage systems. Some farmers were losing as much as 70 pounds of nitrogen worth $14 an acre.

MSU Extension agent Jim LeCureux speaking at a Washington, D.C. press conference organized by the Coastal Alliance to publicize Innovative Farmers' work.

As a result of those preliminary efforts, the negative impacts of conventional agricultural practices on the environment were identified. Farmers met to discuss alternative farming systems that could reduce nutrient, pesticide and sediment loading of the area's surface water. The key issue was the risk involved in switching to conservation tillage practices to reduce soil loss with a high value crop rotation that included sugar

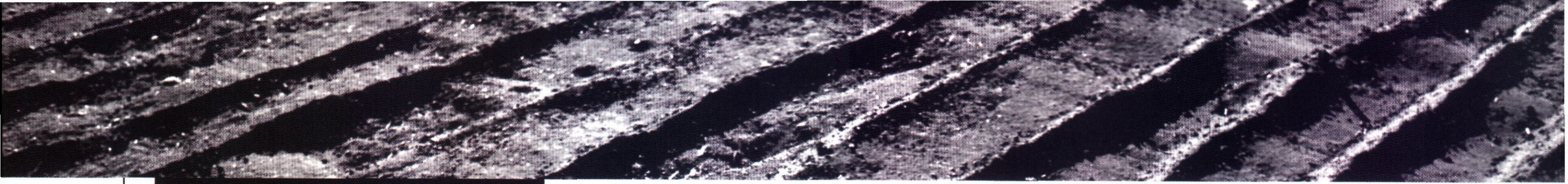
Equipment developer Ray Rawsen speaking at an Innovative Farmer field day.

beets, corn and dry beans. **The goal was to produce major crops with equal or increased net returns while significantly reducing environmental impacts.** Research specialists were invited to share their experience in implementing conservation tillage systems. They addressed not only the benefits and possible inconveniences but also the process of change and its difficulties. The Innovative Farmers put together a program to develop a system to fit their already established crop rotation while reducing tillage and remaining economically competitive.

In 1993, two farm sites were identified and tillage experiments initiated. The experiments were unique in design because they examined the entire cropping systems using a multi-disciplinary approach. In addition to the farmers, the study involved specialists in many fields, including agronomists, agricultural engineers, soil scientists, weed scientists, micro-biologists, agricultural economists and Extension agents.

The experiments generated interest across and beyond Michigan. More than 20 plot tours for the general public, agribusiness representatives and policy leaders attracted more than 1,500 people during six years. Innovative Farmers' annual reports detailing soil quality changes, crop performance, weed control, erosion control, etc., were in high demand.

1994 Innovative Farmer field day.



Lessons Learned and Conclusions

After six years of farmer experiences and research data, the Innovative Farmers and their partners are confident that a reduced tillage system works well. Soil erosion potential was reduced in the first year and in each year after by more than 50 percent—from 5.4 tons per acre per year to 2.3 tons—by using zone-till rather than plowing.

Soil quality changed more gradually as organic matter and soil nutrients began to accumulate in the upper 4 inches of soil with reduced tillage. Soils at two sites showed increased water infiltration rates, with greater improvement on the finer textured soil. Zone-tillage on the Voelker farm increased infiltration by 58 percent over plowing, resulting in a higher infiltration rate compared with moldboard plowing on the Shaw farm's sandier soil. Water-holding capacity increased slightly on the Shaw farm, but not on Voelker's finer-textured soil. The nitrogen-supplying capacity of the soil increased by 38 percent on the Shaw farm and by 37 percent on the Voelker farm with trans-till compared with plowing.

Crop yields with reduced tillage were slightly higher than yields with moldboard plowing on sandy soils. Yields on the finer textured soil were similar regardless of tillage system.

The Voelker site averaged a 5 to 7 percent increase in net returns for both zone-till and chisel compared with moldboard plowing. The Shaw site showed a more dramatic increase in net returns, with 30 to 47 percent increase for conservation tillage compared with moldboard plowing. Chisel plow performed better on the sandier soil.

"The innovative farmers have come together in a true participant research spirit, supported by agricultural business and by the local communities," said Richard Harwood, MSU Crop and Soil Sciences Department. "The scientific results have been well documented over several years, with replication and statistical analysis appropriate to farmer-managed, large-scale plots. Improvements in soil quality have more than offset the few disadvantages of reduced tillage. Farmers in the area should be well pleased with these results. They have made the systems work!"

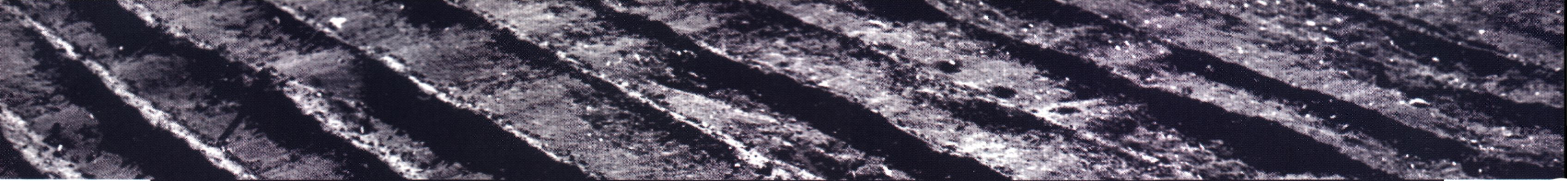
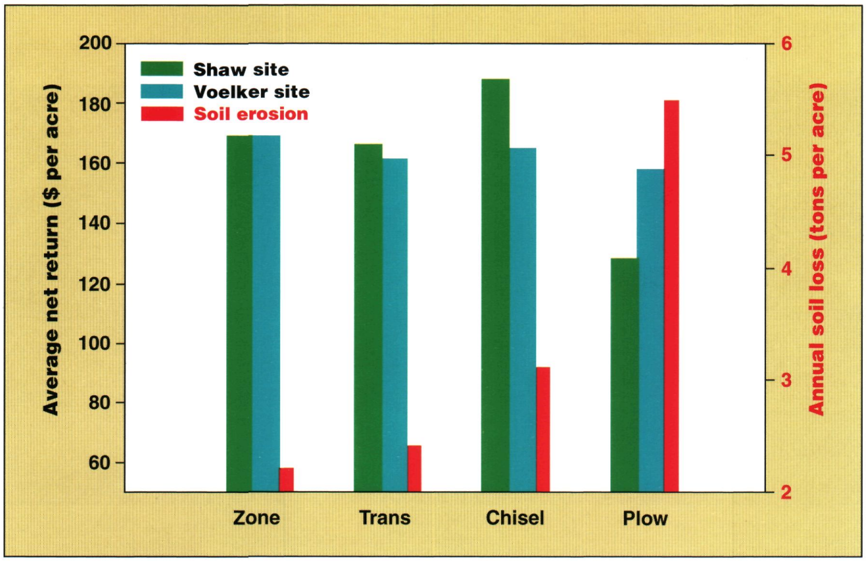


Figure 1. Reducing tillage cuts soil loss and saves money.*



*These figures are averaged over the corn, sugar beets and dry beans of the rotation, assuming the farms would have equal acreage of each (1994-1998 averages).

Site Description

Two 40-acre research farms differing in soil texture were established because success with conservation tillage depends on soil type, drainage, climate and management practices.

	Shaw site	Voelker site
Location	**Near Bad Axe**	**Near Pigeon**
Climate	Cold, moist winters and warm, humid summers	
Average precipitation	31 inches per year	
Soil type	Mixture of Kilmanagh and Shebeon loams	
Water holding ability	Moderate	
Slope	1-2%	0-1%
Organic matter	1.6-2.3%	2.5-4.0%
Texture	Sandy loam: 57-70% sand	Loam: 51-55% sand
	18-25% silt	28-30% silt
	13-16% clay	17-19% clay
Plot size	40 acres	40 acres
Rotation	Sugar beet-corn-dry bean-wheat	Sugar beet-corn-dry bean

Site Description

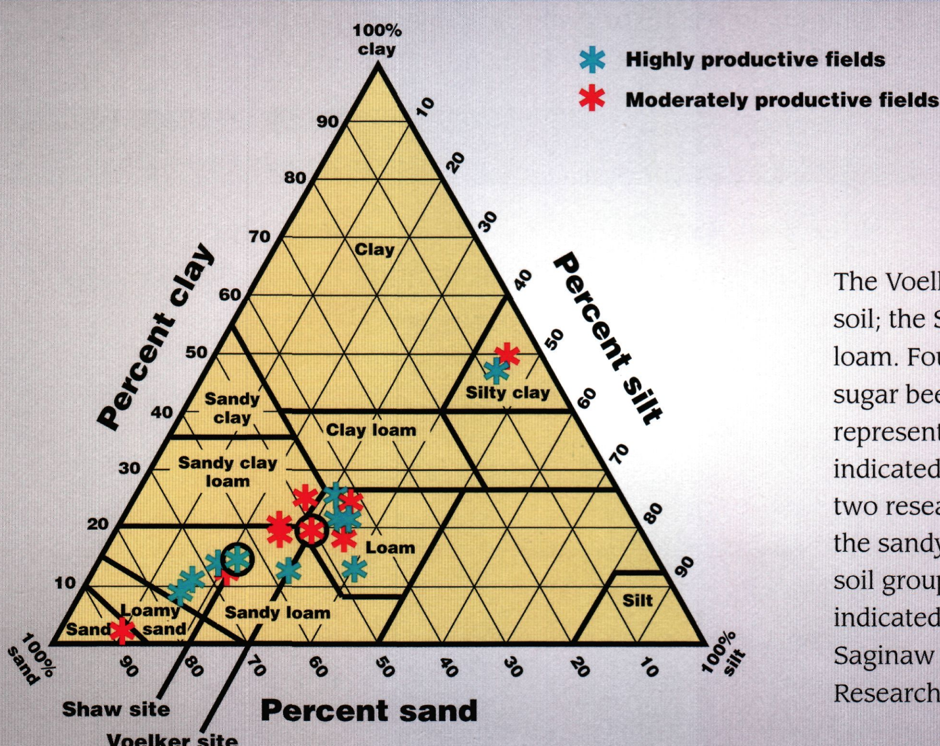
Replicated plots were established to evaluate four tillage systems: fall moldboard plowing, fall chisel plowing, trans-till planting and zone-till planting.

The Shaw site

The Voelker site

The two sites represent much of Michigan's sugar beet acreage in soil texture, as shown by a sampling of sugar beet farms in 2000.

Figure 2. Representativeness of the two sites in soil texture.



The Voelker farm has a loam soil; the Shaw site has a sandy loam. Fourteen farms growing sugar beets, chosen for their representativeness, are indicated by the asterisks. The two research farms represent the sandy loam and the loam soil groups. The silty clay soils indicated are found at the Saginaw Valley Bean and Beet Research Station.

Tillage Systems and Equipment

Moldboard plow.

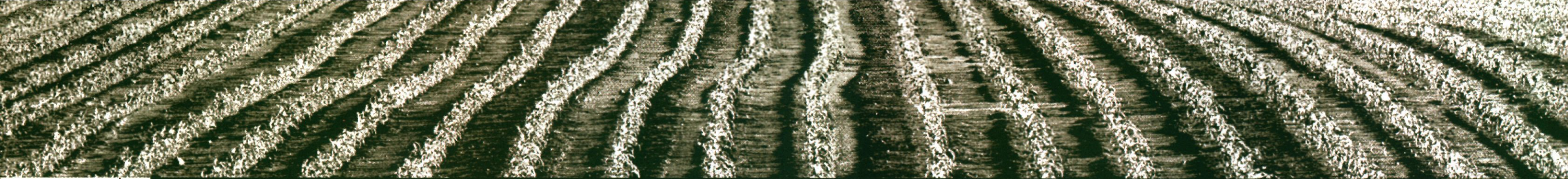
Tillage objectives vary from farm to farm. Tillage prepares the soil for planting; manages crop residue; alleviates soil compaction; incorporates lime, fertilizer, pesticides and other soil amendments; and controls weeds, insects and disease. Tillage can be an effective way to loosen the soil, increase pore space, and improve infiltration and drainage. Four tillage systems were compared at the Innovative Farmer sites: fall moldboard plowing with spring seedbed tillage, fall chisel plowing with spring seedbed tillage, spring zone-tillage using planter-mounted coulters and spring preplant strip tillage with a trans-till implement.

The moldboard plow buries crop residue and inverts the soil. Moldboard plowing costs $10 to $14 per acre and requires a lot of horsepower — 10 to 20 horsepower per foot of plow width. Many Michigan farmers prefer this system because fall-plowed ground tends to be warmer and drier at planting time than untilled, residue-covered soil.

Chisel plows lift and shatter the soil. A chisel plow is faster and requires less horsepower per foot of width than a moldboard plow, creates no back or dead furrows, and leaves considerable crop residue on the soil surface.

Farmers can match seedbed tillage tools to a wide range of soil and residue conditions. Options include disks or coulter gangs to cut heavy residue; sweeps, chisels or goosefoot points on S-tine or C-shaped cultivator shanks; chopper reels, rolling baskets or rolling harrows to break up soil clods, incorporate

Chisel plow.

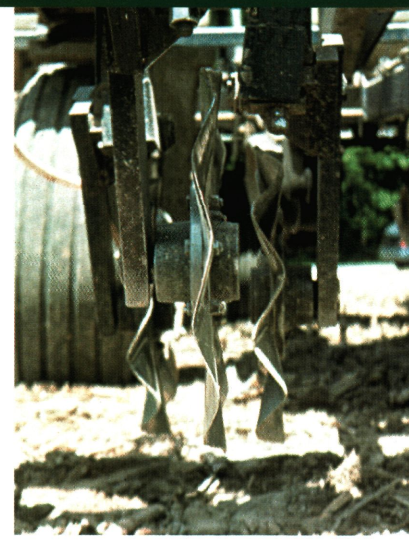


Tillage Systems and Equipment

pesticides and firm the seedbed; and leveling harrows to prepare a fine seedbed for small-seeded crops. Such tillage tools can be used in both moldboard and chisel plowed ground to create a level, uniform surface for planting.

Zone-tillage tools generally use a combination of coulters and row cleaners to cut and sweep residue from the soil and till a narrow band of soil. Removing or incorporating residue from the soil surface allows faster soil warm-up and precise placement of fertilizer. When two or three coulters per row are run side by side on a planter, a zone of soil 6 to 10 inches wide is tilled, loosened and cleared of most surface residue. Row cleaners sweep the residue to the side, exposing a bare strip of soil 10 to 12 inches wide in front of the planter units.

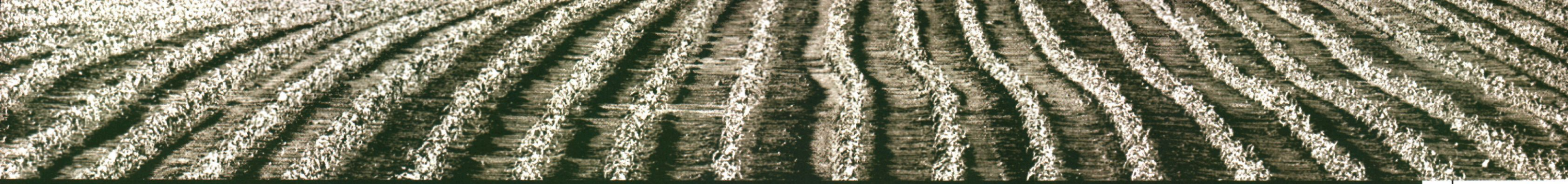
The trans-till is a zone-tillage tool designed and built by Dave, Paul and Vince Roggenbuck in Sanilac County, Michigan, to take advantage of the time and cost advantages of no-till planting on a fine-textured silty loam soil that is slow to warm up in the spring. The trans-till implement uses a narrow chisel point running 6 to 8 inches deep between two fluted coulters to cut and

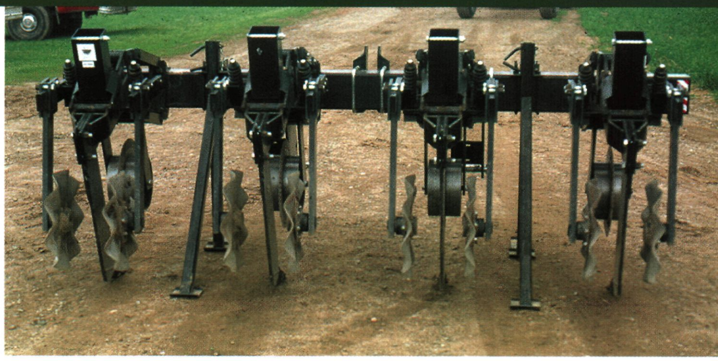


Close up of 3-coulter zone-till system.

Zone-till equipment with specialized vegetable planter.

22-inch zone-till equipment with corn planter.





Trans-till implement.

Close-up showing shank and two coulters.

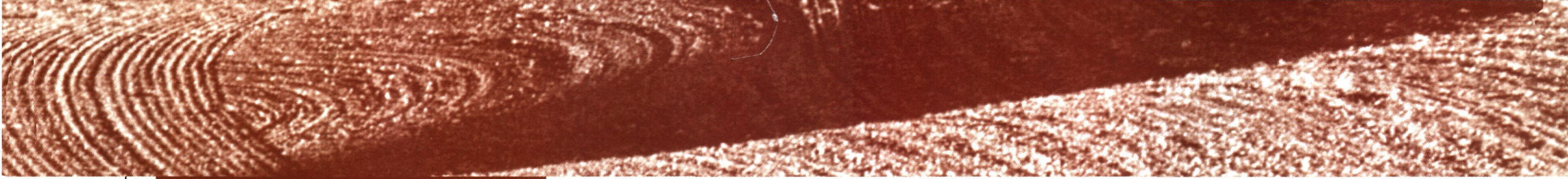
incorporate crop residue. It was designed to lead the planter by a few hours to a few days and prepare a tilled planting zone.

Zone-till, trans-till and chisel plowing are considered reduced or conservation tillage systems because they keep more crop residue on the surface than does moldboard plowing.

"We thought that because we are so far north, we needed plowing to help warm the soil in the spring," said Ross Voelker, host for one of the Innovative Farmer plots. "We learned that there are other ways we can manage the system to achieve the same results. The majority of farmers in this area have changed. There is much less fall plowing, and farmers are confident that they are not losing yield. The moldboard plow is no longer a major feature of farming here."

Innovative Farmer Pat Sheridan was already zone-tilling when he joined the Innovative Farmers. "I haven't used a moldboard plow in years," he said. "Even though I had a gut feeling that zone-till was the way to go, I'm still surprised at how many other farmers have joined me and are now zone-tilling or using reduced tillage. I didn't think it would grow so fast. Also, I'm getting calls from my neighbors asking me how to make the system work. Now, with high fuel costs and low crop prices, folks are seeing that zone-tillage or reduced tillage makes sense."

Zone-till in wheat and cornstalks.

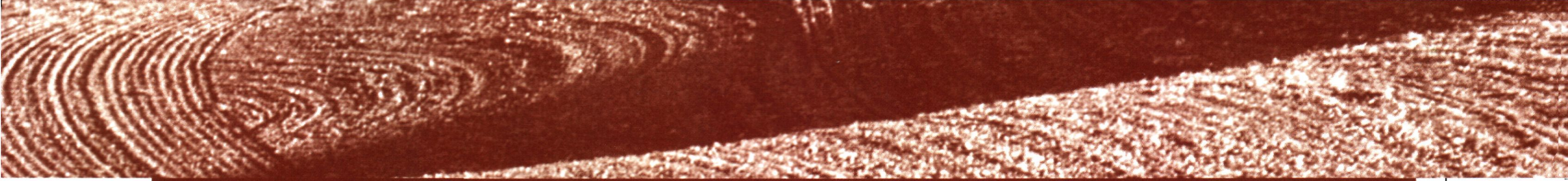


Crop Management

Except for tillage, similar crops in each site generally received similar agronomic treatment in any given growing season. Fertilizer was applied by different equipment at different times because of tillage differences, but the total amounts were close to the same. Where fungicides or insecticides were used, all tillage plots on a given farm were treated the same. Herbicide use changed with tillage. To ensure maximum environmental benefit, the best management practices suggested by previous research and field experience were used throughout the study.

Sugar beets

A sugar beet variety was selected each year for each site according to industry recommendations. The preferred varieties were Beta 5823 and Hilleshog E-17. The latter was planted at the Voelker site in 1998 and at the Shaw site in 1999. Only the Shaw site received phosphorus and/or potassium fertilizer, applied preplant or at planting in amounts suggested by a soil test prior to planting. Starter nitrogen was usually applied at planting. Sidedress nitrogen was determined following a presidedress nitrate test. All plots normally received Pyramin (2.8 pt/A) at planting and Betamix (1 pt/A) for postemergent weed control. When needed, the zone- and trans-till plots were treated preplant with Roundup (glyphosate, 1qt/A) to eliminate any postwinter plant cover. Secondary cultivation was used for all plots following sidedress nitrogen additions. Intensive scouting monitored changes in insect populations. No insecticide application was needed because insects did not exceed the threshold limits. In 1999, an application of Benlate and Pencozeb was needed for disease control.



Corn

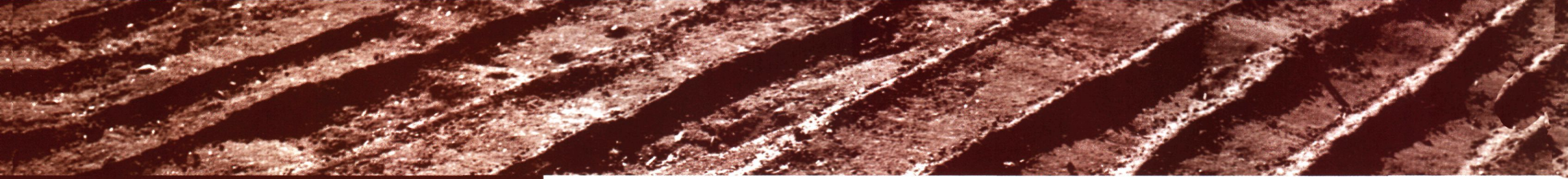
The selection of a season's corn hybrid for each site followed technical recommendations. Pioneer 3752 (31,000 plants per acre) and Pioneer 37R71 Bt (34,000 plants per acre) were planted at both sites in 1997 and 1998, respectively. Phosphorus and/or potassium fertilizer was applied prior to or at planting as determined by a soil test prior to planting. In only a few occasions were phosphorus or potassium used at the Voelker site, and in very small amounts. Nitrogen fertilizer was applied at planting and at sidedress following the presidedress nitrate test. All plots received Dual (1 qt/A) at planting. Clarity (1 pt/A) was used for postemergence weed control. When needed, the zone- and trans-till plots were treated preplant with Roundup (1 qt/A) to eliminate any existing winter plant cover. All plots were cultivated following sidedress nitrogen applications. Intensive scouting monitored changes in insect populations. No insecticide was needed because insects did not exceed the threshold limits.

Dry beans

The dry bean varieties Vista, Mayflower and Blackjack were used based on MSU variety trial data or industry suggestions. The latter was planted at both sites in 1999. Phosphorus and/or potassium fertilizers were applied preplant or at planting as determined by a soil test prior to planting. Nitrogen fertilizer was applied only at planting. Plots under chisel and plow tillage systems generally received an application of Eptam (1¼ qt/A) plus Treflan (1 pt/A) prior to planting followed as needed with a post-emerge application of Basagran (1 pt/A). The zone- and trans-till plots were treated preplant with Roundup (1 qt/A) to eliminate any existing plant cover. During planting, Eptam (⅓ qt/A treated) plus Treflan (⅓ pt/A treated) was banded in a 10-inch band over the row. Several secondary cultivations were generally performed until canopy closure. Intensive scouting monitored changes in insect populations. In 1994, 1996 and 1997, dimethoate (⅓ pt/A) was applied to control potato leafhopper populations.

Wheat

On the Shaw farm, wheat followed beans and preceeded sugar beets in the rotation. The wheat was no-till drilled into bean stubble in October across all tillage types. The herbicide 2-4-D was applied in the spring along with nitrogen application.



Environmental Impact

Wind erosion in Huron County.

Ditch bank blow-out.

Lack of residue cover causes important soil losses through wind and runoff erosion.

Soil erosion has both on-farm and off-farm impacts. It reduces soil depth, which can substantially limit productivity because of nutrient removal, lowered soil organic matter, and diminished snow-catching and water-storing capacity.

Nutrient-carrying sediment can degrade streams, lakes and estuaries. In nutrient-rich water bodies, excessive algae and aquatic plant growth may detract from aesthetics and water quality. Fish kills following algae blooms are a related problem.

Erosion control

Under conservation tillage systems, especially zone- and trans-till, the soil is not plowed and crop residues accumulate on the soil surface as a mulch. These residues reduce soil erosion and its related impacts.

"The spring winds we had this year (2000) let us see that the changes we've made really do help the environment," said Innovative Farmer T.L. Bushey.

Crop residue

Six years of data collected from the Shaw and Voelker sites (Table 1) show how conservation tillage can substantially increase crop residue cover.

"Black snow" from winter wind erosion.

Algae in ditch; high phosphorus and phosphate levels.

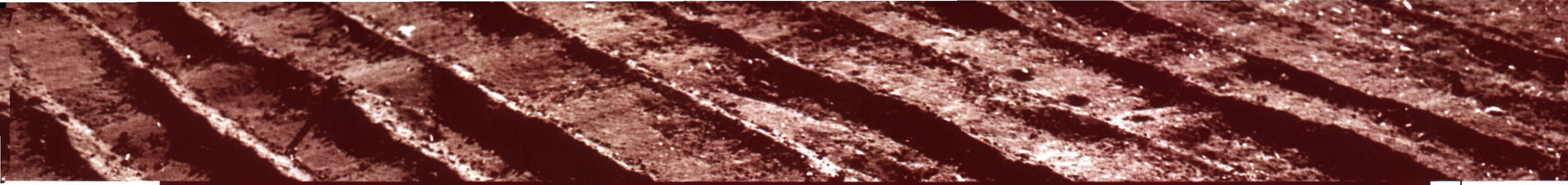


Table 1. Crop residue cover as affected by tillage.

	% surface covered by residue		
Tillage	**After sugar beet***	**After corn***	**After wheat****
Zone-till	6	46	39
Trans-till	5	38	30
Chisel	5	29	19
Plow	less than 1	5	2

* Shaw and Voelker sites
** Shaw site

"Before the IF plots, my farm was 100 percent plowed behind wheat and corn and I had no cover crops," Bushey said. "Now I very rarely leave a field without cover crops, and I fall plow only before sugar beets. I leave more trash on top of the soil."

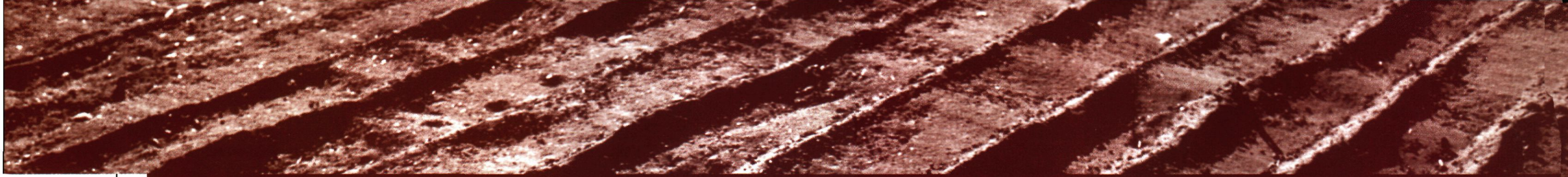
Potential soil loss

The percentage of crop residue left on the soil surface after tillage was used to determine the potential soil loss by erosion using Natural Resources Conservation Service estimates. Potential soil erosion on the Innovative Farmer plots was reduced up to 60 percent (averaged across all crops) with zone-till compared to fall plowing (Table 2).

Table 2. Potential soil erosion loss as affected by tillage.

	After sugar beet*			After corn*			After wheat**		
Tillage	**Wind**	**Runoff**	**Total**	**Wind**	**Runoff**	**Total**	**Wind**	**Runoff**	**Total**
	tons per acre								
Zone-till	3.0	0.6	3.6	0.6	0.4	1.0	1.6	0.8	2.4
Trans-till	3.2	0.8	4.0	0.5	0.6	1.1	1.6	0.9	2.5
Chisel	3.3	1.1	4.4	0.8	0.8	1.6	2.5	1.3	3.8
Plow	3.7	1.6	5.3	3.3	2.2	5.5	3.7	1.8	5.5

* Shaw and Voelker sites
** Shaw site



Measuring crop residue cover.

Melted snow core samples from ditch along zone-till, chiseled and moldboard plowed fields (from left to right).

Soil Quality

Different degrees of soil disturbance and residue placement led to significant changes in soil physical, biological and chemical properties. After six years, the soils under conservation tillage have shown significant improvement in soil quality.

Physical conditions

Bulk density and soil resistance to penetration

Bulk density is the weight per unit volume of oven-dry soil. It measures soil compaction. Soils with excessively high bulk densities can restrict root growth and inhibit productivity. Throughout the experiment, no differences in bulk density were observed among the four tillage systems. After six years (Table 3), the bulk density remained uniform across tillage systems. No differences were detected when resistance to soil penetration was measured. It is possible that conservation tillage would exert a positive impact on these soil quality parameters over a longer time.

Farmers, however, have noticed changes on their farms. "Our plot work has shown that we don't have to go on exhausting our soil," said Innovative Farmer Jim Sattelberg. "I've seen the soil structure change over time. In places where we used to use a tractor, it had gotten so that

Table 3. Soil bulk density after six years under four tillage systems.

Tillage	Shaw site	Voelker site
	g/cm^{-3}	
Zone-till	1.43	1.30
Trans-till	1.40	1.29
Chisel	1.41	1.29
Plow	1.44	1.28

Measuring bulk density and water infiltration.

we needed a 200 horsepower tractor to work the soil. We were seeing compaction and emergence problems. So the IF plots confirmed my decision 20 years ago to minimize tilling. And now I'm expanding my no-till acres. This was my first big no-till year, and I'm continuing to test this more and more on my own."

T.L Bushey shares one of his experiences with changes in bulk density. "We had planted fall rye in one of our fields. In the spring, it grew to 10 inches or so before we burned it down. My brother planted beans in that field. When he finished, he asked me what I had done to work up that field and make the soil so mellow. He couldn't believe that it was just the rye cover crop! Now he wants to plant all our beans after a rye cover crop."

Water-holding capacity is the water content of the soil at field capacity after gravity drainage. It indicates the soil's ability to hold and provide water needed for plant growth. Water-holding capacity is influenced by both the soil's texture and the amount of organic matter present. At the Shaw site, the ability of the soil to retain water was greater under conservation tillage. No significant differences were observed at the Voelker site (Table 4).

Table 4. Soil water-holding capacity as influenced by tillage.

Tillage	Shaw site	Voelker site
	%	
Zone-till	41	43
Trans-till	40	42
Chisel	40	42
Plow	37	42

Water infiltration

Infiltration refers to how fast standing water goes into the soil. In the last two years of the project, water infiltration capacity was consistently higher under zone-till than plow (Figure 3). Water can percolate into conservation tilled soils faster. During rain events (shown in the photo on page 17), more water percolates into the soil, thus reducing the amount of soil and water lost through surface runoff.

Figure 3. Water infiltration rate (1999).

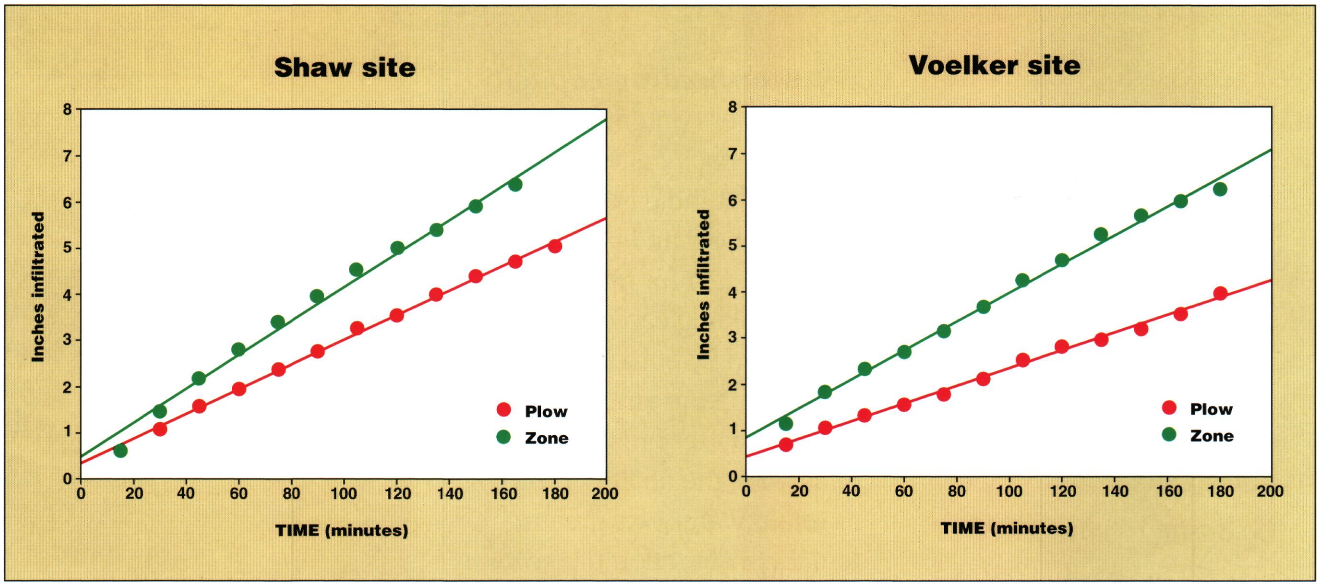
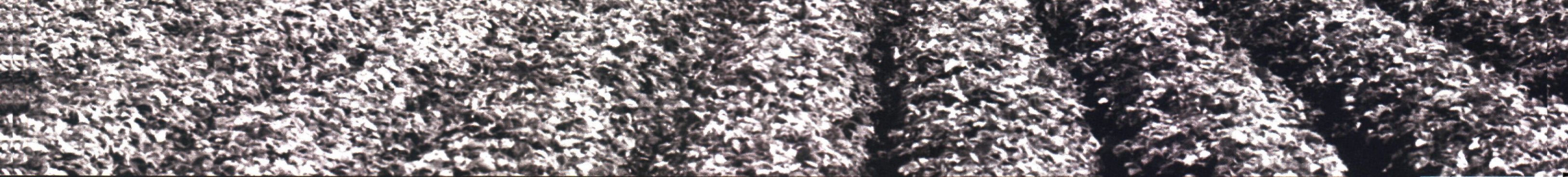


Table 5. Water infiltration.		
	Inches of water that could infiltrate in one hour	
	Shaw	**Voelker**
Plow	1.7	1.3
Zone	2.3	2.1
% increase	35%	58%

The Shaw site, having more sand and less silt and clay, already had a relatively high infiltration rate. This rate increased by 35 percent over time with zone-till. Infiltration at the heavier Voelker site increased 58 percent with zone-till, to 2.1 inches in three hours, a figure higher than that of moldboard plowed sandy soil (Table 5).



Zone-tilled and plowed soils immediately after rain in adjacent fields of same farm.

Carbon and nitrogen cycling

Pat Sheridan has seen benefits with nutrients.

"Over the past 15 to 20 years, I never used a lot of fertilizer," he said. "But even from that base, I've been able to substantially reduce my inputs. I've found that I can get by with less; I'm doing a better job with less fertilizer. When Jim LeCureux first started talking to me about sidedress nitrogen tests, I thought it was 'voodoo' science. But I'm very much a believer now! Using the test has saved me between $10,000 and $20,000 on my farm this year. And I'm seeing something happen with potassium, too. Something different is going on in the soil, and it's increasing fertility."

Total carbon and nitrogen

Conservation tillage reduces soil erosion and is a major step to conserve soil carbon. Carbon, in the form of soil organic matter, is a major source of plant nutrients and the major food source for most soil organisms. Table 8 (page 21) shows that total carbon and nitrogen accumulates in the top 4 inches of the soil in reduced tillage systems. The upper 4 inches is the critical area for most soil microbial and beneficial insect activity. It is inportant for crop establishment and early seedling growth.

Mineralizable carbon and nitrogen

Reduced tillage increased not only the total carbon and nitrogen in the top 4 inches, but also their mineralizable forms. As tillage intensity decreased (from moldboard plow to zone-till), the amounts of mineralizable carbon and nitrogen increased (Figure 4 and Table 6). Therefore, the soil's capacity to supply nitrogen to a growing crop increases with reduced tillage.

Figure 4. Carbon and nitrogen mineralization potential as affected by tillage intensity.

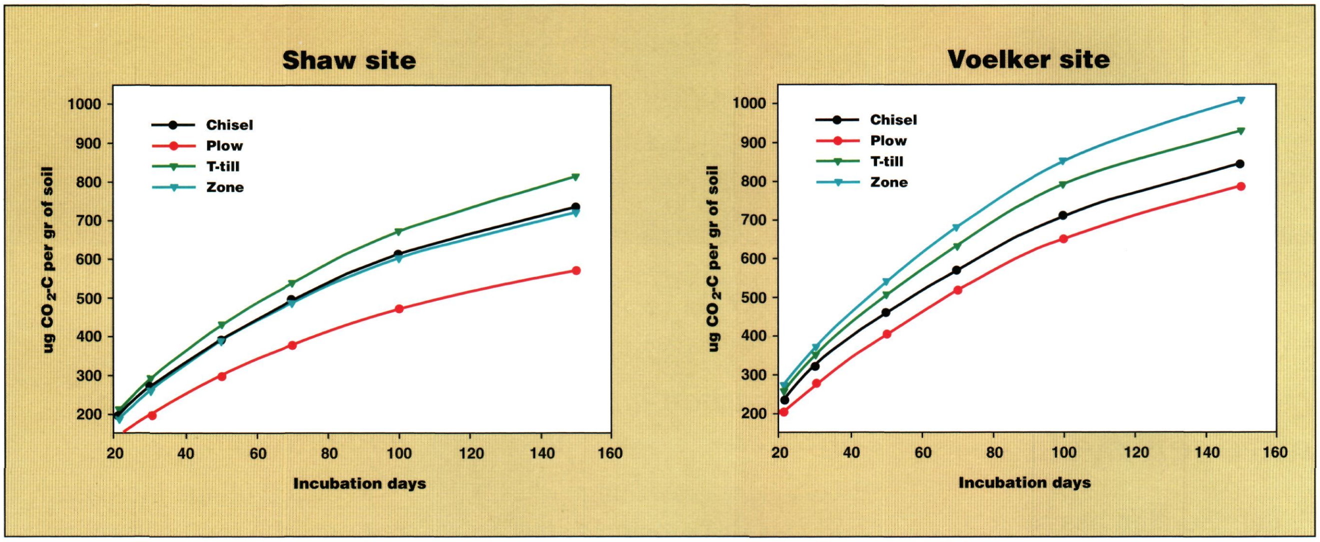


Table 6. Carbon and nitrogen mineralization potential as affected by the intensity of tillage at 70 and 150 days of laboratory incubation. Samples were taken in November 1999 at a 10-cm depth. Analysis was done across all crops/fields.

Tillage	Shaw				Voelker			
	70 days							
	C[2]	*% increase*[1]	*N*[2]	*% increase*[1]	C	*% increase*[1]	N	*% increase*[1]
Zone	485a[3]	29	43a	33	681a	31	46a	31
T-till	539a	44	44a	38	633a	22	48a	37
Chisel	494a	32	44a	38	570b	10	43a	21
Plow	375b	—	32b	—	518b	—	35b	—
	150 days							
	C		*N*		C		N	
Zone	718b	27	70b	29	1008a	29	79a	25
T-till	812a	43	80a	48	927a	19	82a	28
Chisel	731b	29	75ab	38	840b	8	71b	12
Plow	566c	—	54c	—	781b	—	64c	—

[1]Percentage increase over plowed soil.
[2]Expressed in mg kg^{-1}.
[3]Numbers within a column followed by a different lowercase letter differ at the 0.05 probability level.

Microbial community structure

The numbers of fungi and protozoa were significantly higher under reduced tillage when sampled in November 1999 (Table 7). The numbers of bacteria and nematodes, however, were not reduced. The number of bacteria may increase during the most intense periods of residue decomposition, but their population is kept somewhat constant by the protozoan grazers.

Table 7. Microbial community structure as influenced by tillage.

Microbial community structure	Zone	Chisel	Plow
Bacterial biomass[1]	122	120	117
Fungal biomass[1]	31	27	22
Total nematodes[2]	9	7	12
Total protozoa[3]	62,747	58,576	42,477

[1]Expressed as µg g-1.
[2]Nematodes per g of dry soil.
[3]Protozoa per g of dry soil.

Other nutrient availability

Increased soil organic matter in conservation tillage soils increases water retention. Nutrient retention would also be expected to increase due to reduced leaching. Soil organic matter has a net negative charge that attracts positively charged nutrients such as potassium, calcium and magnesium and keeps them from leaching. Furthermore, with broadcast fertilizer applications, nutrients concentrate on or near the surface because reduced tillage causes little or no inversion of soil. Nutrients remain where they are available to growing plants.

Phosphorus

In Shaw's sandy soils, zone-till maintained the phosphorus level in the top 4 inches. With moldboard plowing there was a significant reduction in phosphorus. In Voelker's loamy soils, zone-till and plow both maintained phosphorus levels throughout the tillage layers (Figure 5). A similar pattern was observed for the last sampling in November 1999 (Table 8). Plant roots and crop growth "pump" phosphorus upward to accumulate in the top layer. Because the phosphorus is insoluble, it is not carried downward by water movement.

Potassium

At both sites, the potassium level in the top 4 inches of soil was higher under zone-tillage than under moldboard plowing. There was a strong stratification in potassium concentration between the top 4 inches and the 4- to 10-inch soil depths (Figure 6). At the end of the experiment, the potassium concentration pattern remained for the Shaw site, but no differences were observed at the Voelker site (Table 8).

Figure 5. Phosphorus levels as affected by tillage.

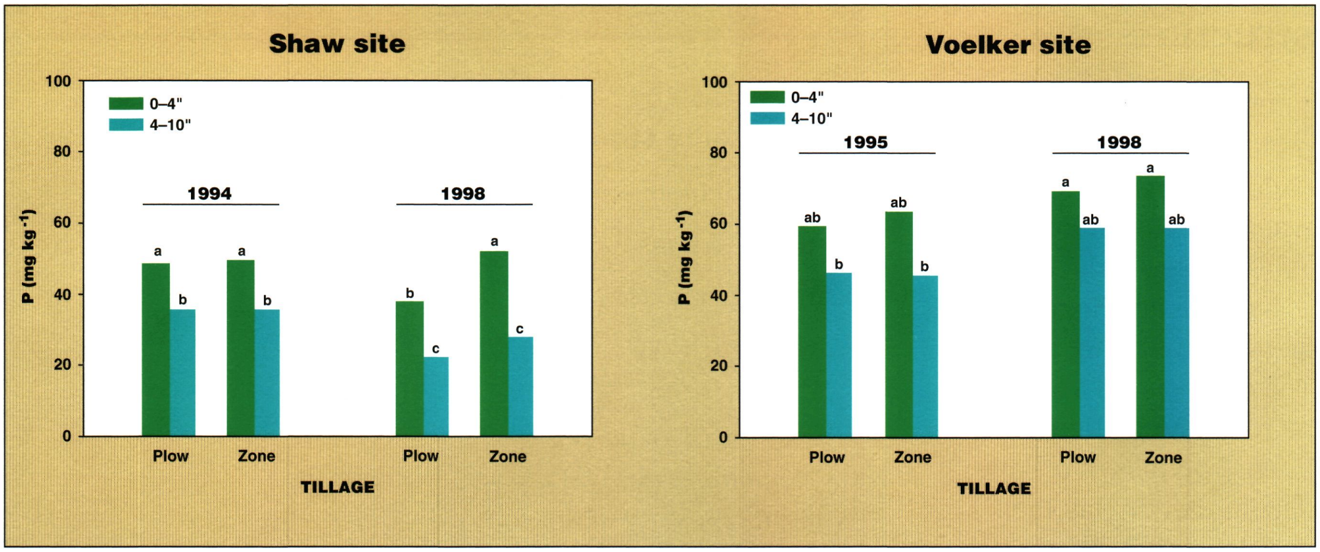
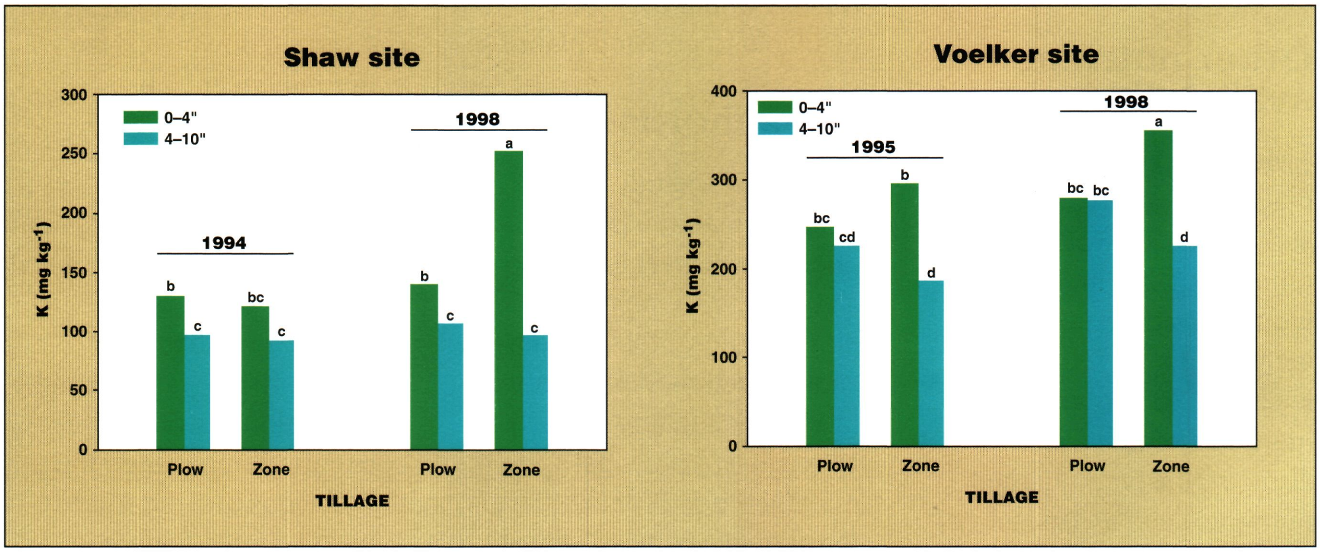


Figure 6. Potassium levels as affected by tillage.



Calcium

The calcium concentration increased over time, but no differences were observed between zone-till and plow (Figure 7). At the end of the experiment (Table 8), the calcium concentration remained constant across all tillage systems.

Note on bar graphs:

Different lower-case letters on graph bars indicate that the value of the bars differ at the 0.05 probability level.

Figure 7. Calcium levels as affected by tillage.

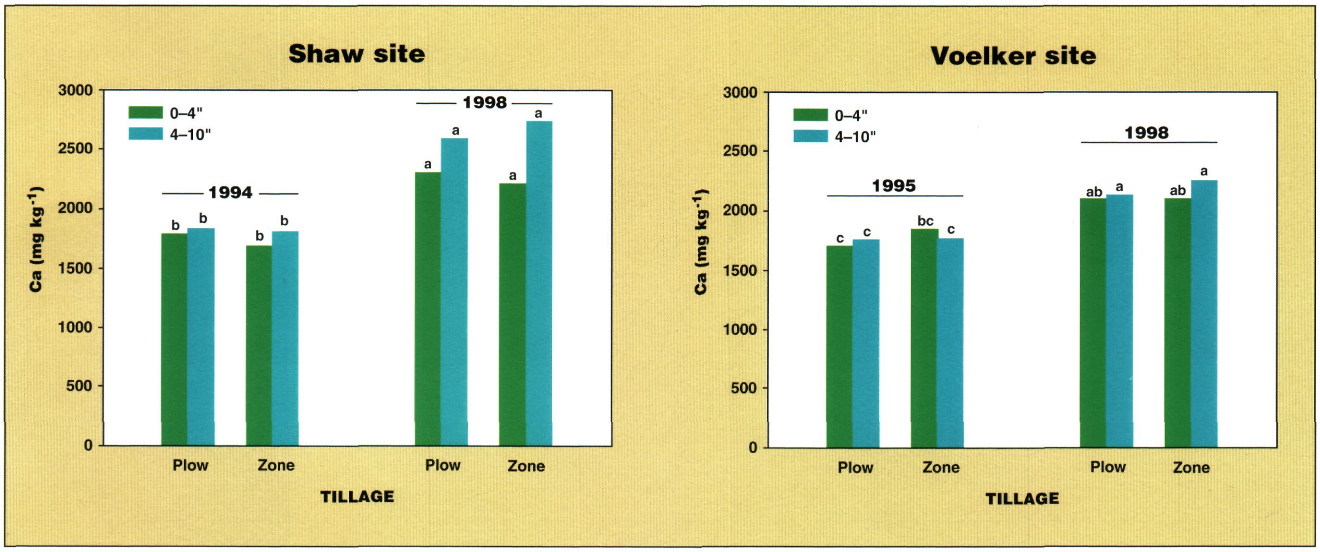


Table 8. Nutrient concentration as affected by tillage. Samples taken at the end of the experiment in November 1999.

	Total C		Total N		P		K		Ca		Mg	
	0-4[1]	4-10[1]	0-4	4-10	0-4	4-10	0-4	4-10	0-4	4-10	0-4	4-10
	mg kg-1											
Shaw												
Zone	144	131	11	9	65	43	237	104	1,752	1,857	278	227
Trans	143	121	11	9	60	43	252	93	1,735	1,695	283	221
Chisel	143	122	11	9	55	43	233	106	1,838	1,827	276	237
Plow	129	130	9	9	53	41	175	139	1,940	1,961	270	219
Voelker												
Zone	183	148	17	16	194	163	253	223	1,874	2,082	330	335
Trans	173	156	17	17	197	171	397	247	1,841	2,037	342	340
Chisel	171	154	16	16	190	175	339	271	1,847	2,047	342	347
Plow	163	165	16	17	205	165	293	300	2,068	1,841	334	339

[1]Soil depth in inches.

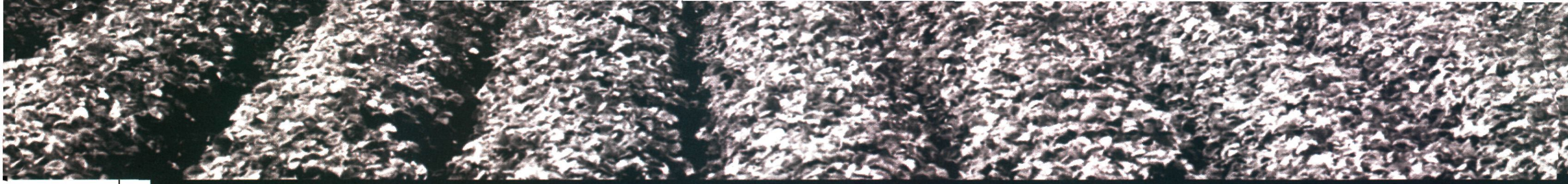
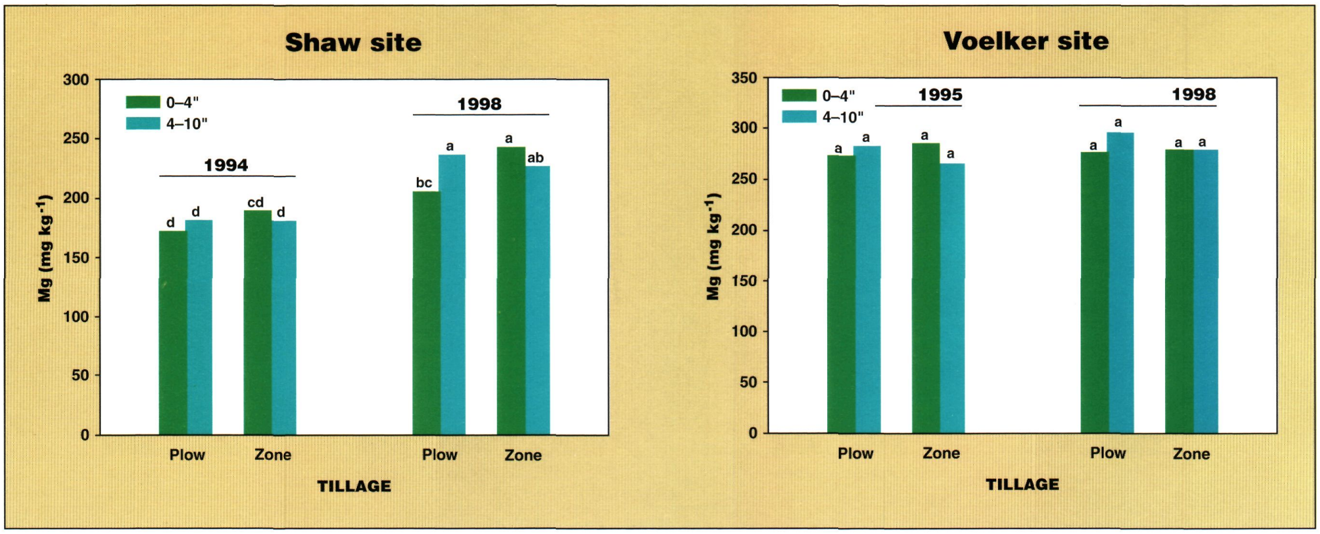
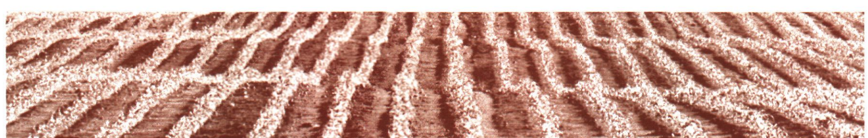


Figure 8. Magnesium levels as affected by tillage.



Magnesium

At the Shaw site, the magnesium concentration increased (Figure 8). A different stratification pattern was observed between zone-till and plow. While zone-till accumulated magnesium in the top 4 inches, plow accumulated magnesium in the lower 4 to10 inches. At the end of the experiment, the magnesium concentration remained constant across tillage systems (Table 8).



Crop Performance

Plant population

Though each tillage system was seeded at the same planting rate, differences in final plant populations were observed among tillage systems at both sites until 1999. In 1999, plant populations were the same in all tillage systems.

Sugar beet populations at the Shaw site were consistently lower under reduced tillage than plow; comparable populations across tillage systems were noted at the Voelker site (Figure 9).

Corn populations in zone-till were marginally lower than in chisel, trans-till and plowing which were similar to each other (Figure 10).

In dry beans, seed was planted at an equal depth in each tillage system, although seeding depth may not have been as uniform in the

Figure 9. Sugar beet plant populations.

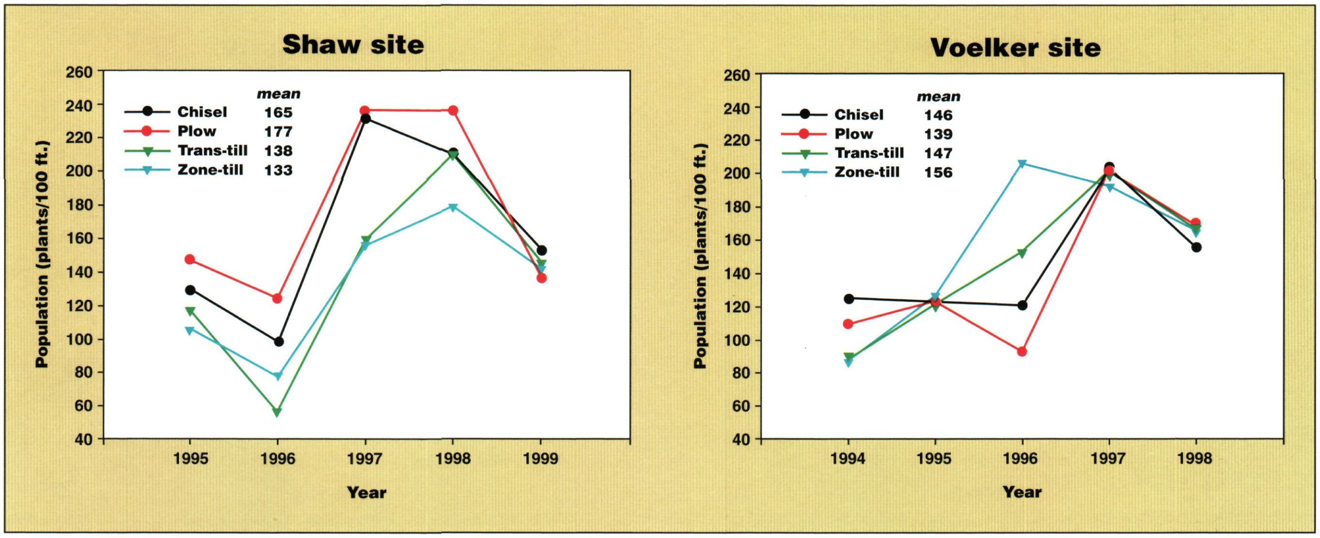
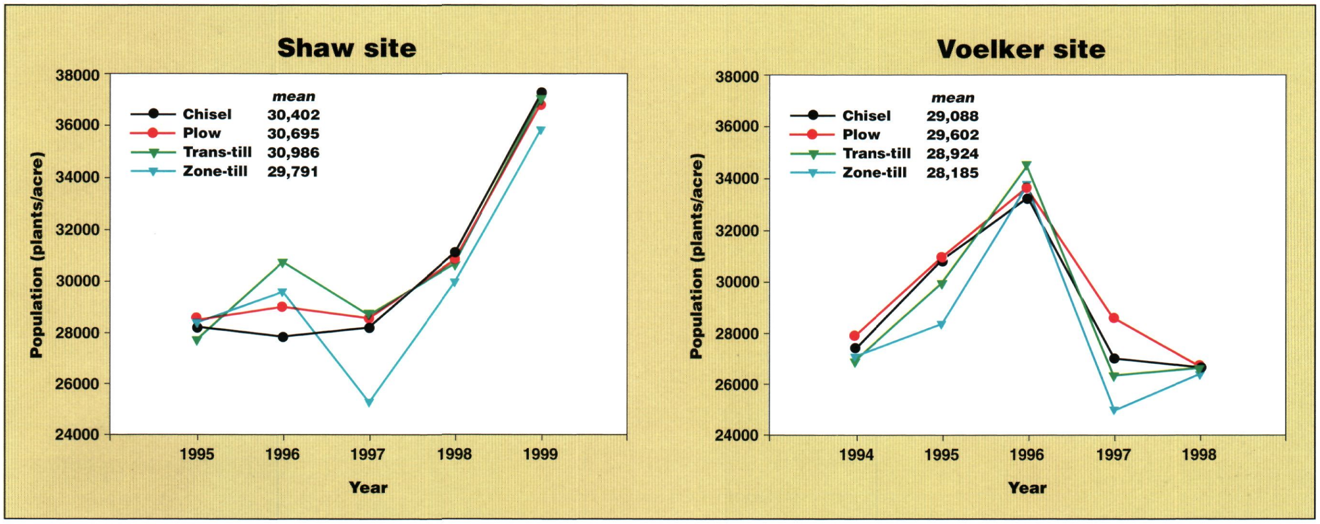
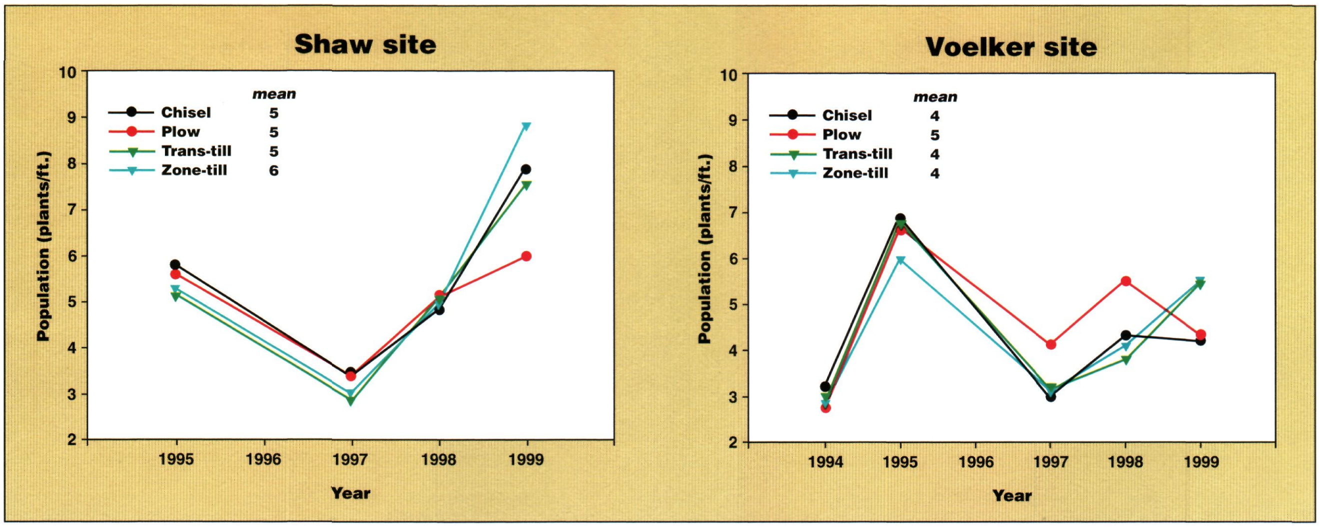


Figure 10. Corn plant populations.



reduced tillage system because of the rougher soil surface. Despite this, overall dry bean populations were somewhat similar across tillage systems (Figure 11). In 1999, the plowed plots had reduced dry bean populations at the Shaw site. At the Voelker site, a similar pattern was observed in the early years. In 1997 and 1998, bean populations in the plowed soils were consistently higher than in those plots under conservation tillage; however, in 1999, plant populations in zone- and trans-till were significantly higher.

Figure 11. Dry bean plant populations.



Weed suppression

The key to successful conservation tillage crop productivity is management, especially weed control. Treatments applied to control weeds before planting usually include non-selective herbicides, such as paraquat or Roundup, followed by additional herbicide(s) to provide residual control. The density of annual broadleaf weeds may decrease in conservation tillage systems while annual grasses and perennial broadleaf weeds may increase. The use of Roundup can significantly lower weed density when it's applied at or shortly after planting. (Roundup must not be applied after the crop has emerged.) This allows more weeds to emerge prior to treatment. In sugar beets, moldboard plowed treatments had higher weed densities at time of first cultivation than any other tillage system (Table 9). This may be the result of tillage stimulating weed seed germination and/or the lack of a winter cover to shade the ground and suppress weed germination and growth.

In corn, other researchers have reported that cover crops and/or existing vegetation must be killed before or at the time of corn planting for satisfactory corn production under reduced tillage systems. Stand reductions may occur as a result of planting into live vegetation.

In dry beans, Roundup controlled winter vegetation and emerged summer annual weeds, and planting was done into a weed-free seedbed in all tillage systems. Redroot pigweed control in zone-till was greater than control in the chisel and plow systems 23 and 64 days after post-emergence herbicide application (Table 10). Common lambsquarter control 23 days after postemergence herbicide application was greater in conservation tillage than in plow (Table 10). When cultivation alone was used, weed control was lower in plow and chisel than in zone-till (Table 11).

Table 9. Weed density in sugar beets as affected by tillage and winter vegetation control.

Tillage	Weed control	Weeds at first cultivation		Weeds at second cultivation	
		1995	1996	1995	1996
		plants/m^{-2}			
Zone-till	Glyphosate-7DBP[1]	—	138	—	142
Zone-till	Glyphosate-PRE[2]	37	179	43	158
Zone-till	Glyphosate-DAP[3]	—	101	—	150
Zone-till	Sethoxydim-Post[4]	—	211	—	96
Zone-till	Clethodim-Post[4]	71	119	35	102
Zone-till	Cultivation only[5]	85	221	31	104
Plow		127	318	45	128
LSD (0.05)[6]					

Source: Knoerr farm, 1997.

[1]Seven days before planting.
[2]Day of planting.
[3]Five to eight days after planting.
[4]Applied when wheat cover crop reached 20 cm in height.
[5]No herbicides were applied to manage winter cover crop, only tillage.
[6]Statistical analysis was taken from a more complete data set.

Insect and disease control

Researchers have reported that cooler soil temperatures, increased soil moisture and reduced tillage applications can enhance pathogen and insect problems, especially in highly susceptible plants such as sugar beets. Many diseases that infect sugar beet seedlings (*Pythium, Fusarium and Rhizoctonia*) thrive under cool, moist soil conditions such as those found with reduced tillage. Reduced tillage also allows for higher levels of insects to survive in the soil, especially armyworms and cutworms. These species are drawn to stubble fields and winter wheat fields to lay their eggs for overwintering. Over the six years of this study, however, no increase in disease or insects was observed in any of the tillage systems.

Other studies have reported that plowing consistently reduces populations of *Rhizoctonia*. Although the

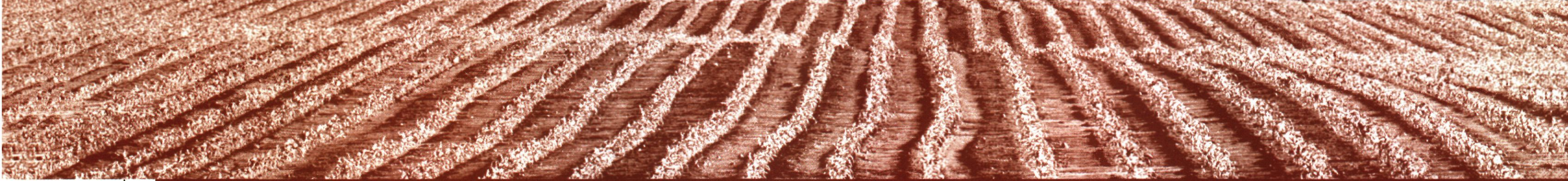


Table 10. Weed control in navy beans 23 and 64 days after postemergence application (1995).

Tillage	Redroot pigweed		Common lambsquarter
	23 DAPO[1]	64 DAPO	23 DAPO
	%		
Zone-till	96	91	99
Chisel	78	74	85
Plow	81	78	68
LSD (0.05)[2]	15	11	8

Source: Powell and Renner, 1999.

[1] Days after postemergence application.
[2] Statistical analysis was taken from a more complete data set.

Table 11. Weed control in navy beans 14 days after postemergence application in the cultivation-only weed management treatment (1996).

Tillage	Redroot pigweed	Common lambsquarter
	%	
Zone-till	63	59
Chisel	0	10
Plow	0	0
LSD (0.05)[1]	19	18

Source: Powell and Renner, 1999.

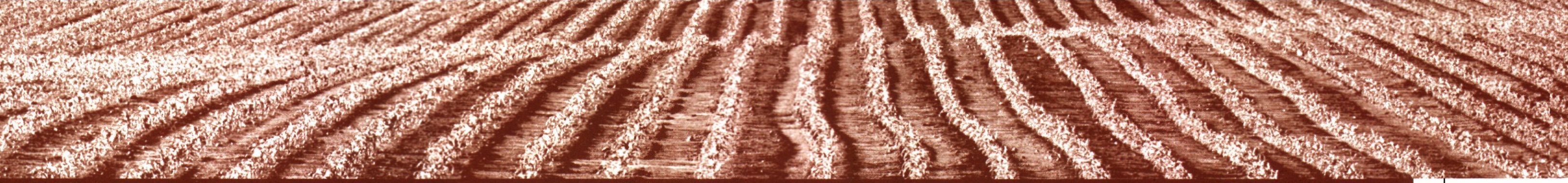
[1] Statistical analysis was taken from a more complete data set.

population of total fungi in soil was lower with plowing than with conservation tillage (Table 7), it is likely that tillage has less influence on populations of *Pythium, Fusarium* and other saprophytic fungi. *Rhizoctonia* survives in surface soil in colonized plant debris and does not survive well in the subsoil below 6 to 8 inches because of low oxygen. Plowing buries surface debris and propagules and brings soil to the surface with low populations of *Rhizoctonia*. In contrast, *Pythium* and *Fusarium* survive many months as dormant propagules in soil to a 12-inch depth, and tillage practices have less influence on the distribution of these fungi in the root zone.

Crop yields and economics

The Innovative Farmers found that yields and economics from reduced tillage systems can match or surpass those of moldboard plowed systems.

"The changes we've made have kept more income on the farm," said Jim Sattelberg. "What I did this spring (2000) saved between $25,000 and $50,000 with today's energy prices."



"One surprise was that all of the tillage systems can produce about the same yield," Ross Voelker said. "That told us that we needed to choose a system and then put our heart and soul into making it work. When we changed tillage, we kept the same yields, so income wasn't reduced. At the same time, we gained in several areas. Water filtration improved, organic matter is increasing and wind erosion is reduced. In 10 to 20 years, I think the increased organic matter will result in better crops."

"We had a mindset that every field needed fall plowing," said T.L. Bushey. "It was a surprise to see that other systems could work just as well. I find that I have to be more timely and a better manager with these systems. There are economic benefits. Last year I had two sugar beet fields side by side. The yield from the field that had not been fall plowed was 1½ tons higher."

Sugar beets

Sugar beet yields with conservation tillage equal or exceed those with plowing (Table 12 a and b). This slight increase in yields resulted in higher net returns because total costs were similar across all tillage systems. The highest net returns in sugar beets at the Shaw site were obtained under chisel and zone-till. At the Voelker site, sugar beets grown in zone- and trans-till systems gave the highest net returns. Shifting from conventional plowing to reduced tillage may cause a yield reduction during a transition period, as was observed in 1994 at the Voelker site (Figure 12). After this period, yields tend to be comparable across tillage systems in normal years and be significantly higher under zone- and trans-till during a dry year such as 1998.

Corn

At the Shaw site, corn yields in the zone-till and chisel tillage systems were significantly greater than those under trans-till and plow (Table 12a). No differences among tillage systems were observed at the Voelker site (Table 12b). The highest net return at both sites was under chisel. A yield reduction may also be expected in the initial period of transition, especially on a heavier soil, as at the Voelker site (Figure 13). Yields in a year with moisture stress, such as 1998, were higher under both zone- and trans-till.

Dry beans

No significant differences were observed in dry bean yields among tillage systems at either site (Table 12 a and b). Net returns at the Shaw site were higher under conservation tillage than those from plowing. This was due to a marginal increase in yields and lower total costs. At the Voelker site, plow and chisel systems generated the highest net returns.

Wheat

The wheat planted on the Shaw farm was treated only as a rotation crop. It was no-till drilled into each tillage system following dry beans. No data were collected concerning the wheat.

Table 12 (a and b). Average (1995-98) net return ($/acre) for sugar beets, corn and dry beans under four tillage systems at the Shaw and Voelker sites (analysis performed using the MAX Economic Analysis Program [Purdue University]). The four-year average prices were used for calculations.

(a) **Shaw site**

	Sugar beets				Corn				Dry beans			
	Zone-till	Trans-till	Chisel	Plow	Zone-till	Trans-till	Chisel	Plow	Zone-till	Trans-till	Chisel	Plow
Yield [1]	20	19	20	18	152	149	154	145	18	19	19	17
Revenue[a]	810	777	809	710	375	367	378	357	363	381	388	340
Total cost[b]	472	476	467	471	306	309	307	305	240	249	251	261
Seed	32	32	32	32	32	32	32	32	26	26	26	26
Fertilizer	35	31	34	31	35	34	35	33	10	12	10	12
Pesticides	69	72	51	60	26	26	19	19	24	24	16	16
Field operations [2]	108	116	123	123	62	64	71	71	58	64	75	79
Indirect cost [3]	206	202	209	206	139	139	141	141	113	113	114	119
Other cost [4]	22	22	19	19	10	13	9	9	9	9	9	9
Cost per unit	24.4	25.3	23.9	25.9	2.0	2.1	2.0	2.1	13.8	13.3	13.4	15.7
Net return (a-b)	**340**	**305**	**344**	**240**	**72**	**58**	**77**	**58**	**126**	**136**	**144**	**88**

(b) **Voelker site**

	Sugar beets				Corn				Dry beans			
	Zone-till	Trans-till	Chisel	Plow	Zone-till	Trans-till	Chisel	Plow	Zone-till	Trans-till	Chisel	Plow
Yield [1]	21	21	20	20	150	152	152	153	18	18	19	19
Revenue[a]	822	808	791	770	369	380	379	380	345	354	373	385
Total cost[b]	456	468	469	469	317	319	314	320	272	280	270	280
Seed	33	33	33	32	32	32	32	32	26	26	26	26
Fertilizer	26	27	25	26	37	31	29	31	9	9	10	10
Pesticides	47	47	44	44	38	38	28	28	29	29	19	19
Field operations [2]	101	110	118	119	52	56	65	66	58	66	77	79
Indirect cost [3]	230	232	231	230	156	156	156	160	128	128	129	136
Other cost [4]	20	20	18	18	2	6	2	2	21	21	10	10
Cost per unit	22.7	23.0	23.7	23.6	2.1	2.1	2.1	2.1	15.9	16.0	14.8	14.8
Net return (a-b)	**366**	**341**	**323**	**302**	**61**	**62**	**67**	**62**	**85**	**81**	**105**	**111**

[1] Yields are expressed: sugar beets as tons per acre, corn as bushels per acre, and dry beans as cwt per acre.
[2] Field operations: primary and/or secondary tillage, planting, fertilizer and pesticides application, and harvest.
[3] Indirect cost: land cash rent value, soil loss charge, harvest hauling charge, grain drying and interest.
[4] Other cost: other operations, other pest control, cover crop, etc.

Figure 12. Sugar beet yield affected by tillage.

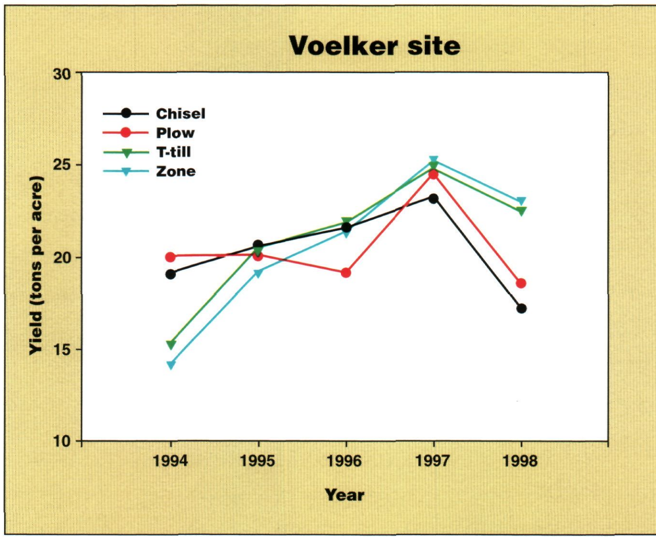


Figure 13. Corn yield affected by tillage.

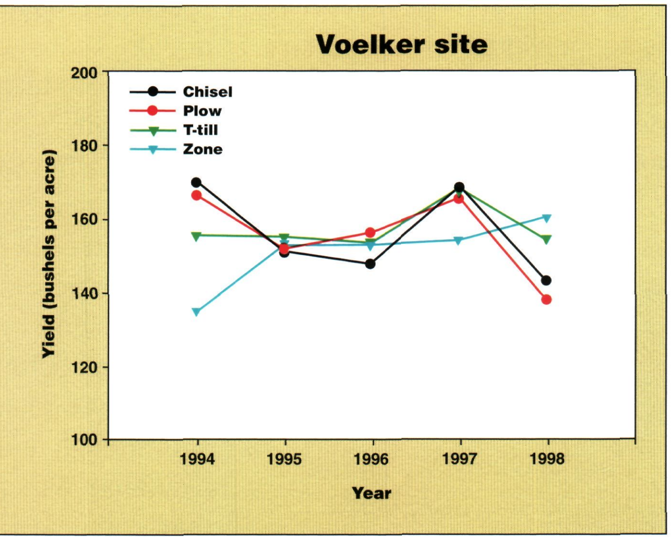


Table 13. Cropping system average returns (beets, corn and dry beans combined).

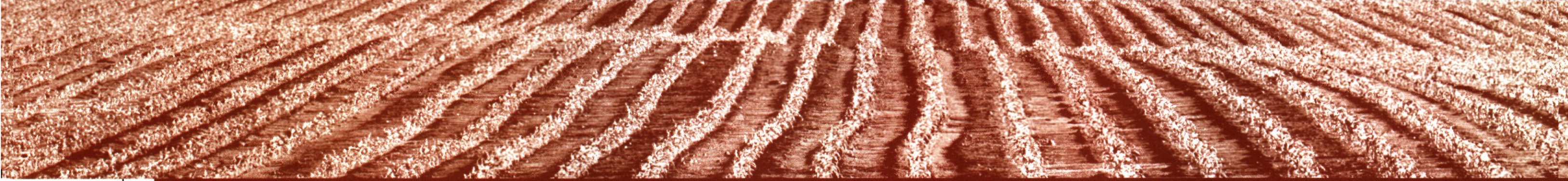
Shaw[1]	$ return per acre (% increase over plow)
Zone	179 (+40)
Trans	166 (+30)
Chisel	188 (+47)
Plow	128
Voelker	
Zone	164 (+8)
Trans	158 (+2)
Chisel	164 (+4)
Plow	155

[1]Calculations do not include the wheat contribution.

Putting the Pieces Together

The data from six years of Innovative Farmer plot work is impressive. But what do the farmers think?

Pat Sheridan: "Beyond the financial gains, an even bigger benefit of being part of Innovative Farmers has been the opportunities it provides for me to talk with like-minded individuals. I can call people I didn't know before to ask them questions, and I get calls from folks throughout the Thumb. The information age is great, but I can't digest it all. If a group is willing to share its failures as well as its



successes, then it can really help. Innovative Farmers (IF) took a lot of the risk away from individual farmers. If I try something on 50 acres and it doesn't work, then I have an expensive problem."

Jim Sattelberg: "Groups like IF may come up with some radical ideas. If you're willing to think outside the box, to be willing to change, this group is out in front!"

Ross Voelker: "We started IF to improve environmental quality without damaging family farm income. We wanted to look at limited tillage and no-till with our specialty crops — sugar beets and dry beans. We knew that others were using reduced tillage with corn and soybeans, but we needed to try it out here, with our important cash crops. Also, because farmers were making the decisions, once we were 95 percent certain about the system, we could decide that was enough and then move in a different direction rather than continue on to 99 percent certainty. The biggest benefit from IF is that it gave us confidence to try new tillage systems and buy the necessary equipment with fewer financial risks. We proved that the new systems work."

T.L. Bushey: "People should realize that not participating is a decision, too. We don't really have the option to sit on the side and just keep doing things the way we always have. We will have to make changes, including some that we may not like. But joining IF lets people become part of the decision process for change."

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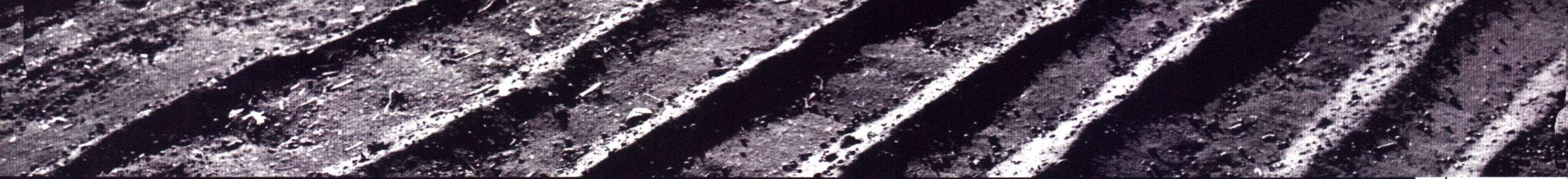

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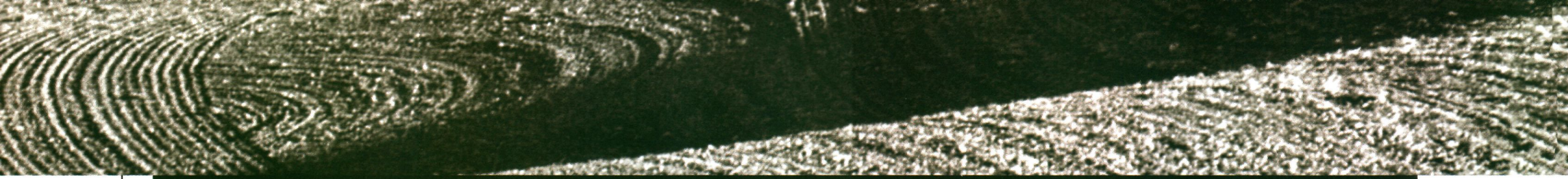

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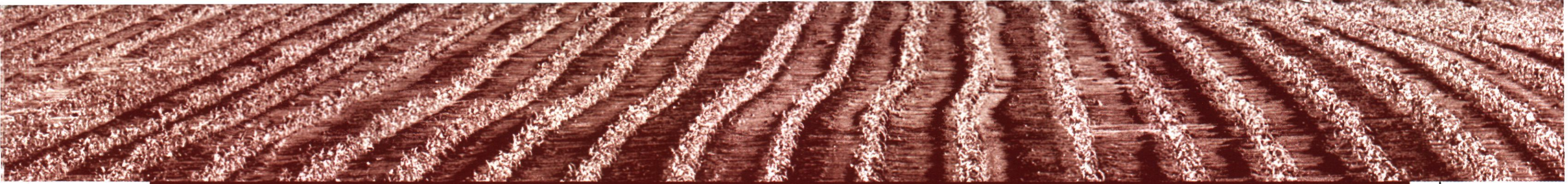
Coastal Alliance
Cooperative Elevator (Pigeon & Sebewaing)
Dosatron International, Inc.
Dry Bean Research Advisory Board
East Central Michigan Farm Credit Services
Farm Credit Services
Farmers Co-op Grain Company (Kinde)
First of America Bank
Gettel Implement
Great Lakes Sugar Beet Growers
Grower Services (Fairgrove & Owendale)
Helena Farm Supply
Henderson Sales & Service
Hilleshog Mono-Hy Seeds
Hiniker Equipment
Huron County Board of Commissioners
Huron County Soil Conservation District
Ike's Welding & Mfg., Inc.
Independent Bank
Kongsklide Equipment
Laethem Equipment
LGM Seeds
MAX (sponsored by CTIC, Successful Farmers, Bayer, Monsanto & IH Case)
Michigan Agricultural Stewardship Association
Michigan Corn Marketing Program
Michigan Crop Improvement Association
Michigan Groundwater Stewardship Program
Michigan Department of Environmental Quality
Michigan Department of Natural Resources
Michigan Integrated Food & Farming Systems
Michigan Sugar Company
Midwest BioAg
Monsanto
MSU Michigan Agricultural Experiment Station
MSU Extension
Natural Resource Conservation Service
Nietzke & Faupel, P.C., C.P.A.
North Central Region Sustainable Agriculture Research and Education Program
Northrup King (Paul Smaglinski)
Novartis Seeds
Osentoski Equipment, Inc.
Pioneer Hi-Bred International, Inc. (Jeff Leipprandt, Paul Ruthko)
Producers Natural Products
Row-Tech, Inc.
Ruth Farmers Elevator
Ruth State Bank
Saginaw Bay RC&D
Saginaw Bay USDA Water Quality Project
Sandusky New Holland
Signature Bank
Sugar Beet Advancement
Terra International, Inc. (Bad Axe, Elkton, Fairgrove/ Gera, Kinde & Owendale)
Thumb Farm Service, Inc.
Thumb National Bank
Triangle M Equipment
Tri-State Equipment
Unverferth
World Wildlife Fund
Wruble Elevator
Yetter Manufacturing
Zeneca Ag Products



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Correct Citation:

Sanchez, J., R. Harwood, J. LeCureux, J. Shaw, M. Shaw, S. Smalley, J. Smeenk, and R. Voelker. 2001. Integrated Cropping Systems for Corn-Sugar Beet-Dry Bean Rotation: The Experience of the Innovative Farmers of Michigan. Michigan State University Extension Bulletin E-2738, 32 pp.

Improved soil quality leads to better root development.