Crop sequences and conservation tillage to control irrigation furrow erosion and increase farmer income

By D. L. Carter and R. D. Berg

ABSTRACT: Five years of research show that there are many benefits to conservation tillage on furrow-irrigated land. Benefits are enhanced when cropping sequences are altered to accommodate the fewest number of tillage operations over the entire cropping sequence. Results showed that soil erosion can be reduced 47 to 100 percent, crop yields can be sustained, and farmer net income can be increased an average of more than \$125 ha^{-1} each year over a 5-year cropping sequence.

FARMERS who furrow irrigate generally regard crop residue on the soil surface as a serious deterrent to successful irrigation. This perception has prolonged the practice of moldboard plowing to bury crop residues on furrow-irrigated soils.

Recent erosion control research results (2) have led to consideration of alternative tillage practices that maintain some crop residue on the soil surface. For example, Miller and Aarstad (*5*) determined that small amounts of straw placed in irrigation furrows almost eliminated furrow erosion and sediment loss. They also showed that planting directly into fields with corn residue on the surface provided excellent erosion control. Berg (*1*) applied small quantities of straw to furrows on steep, sloping sections of a corn field and achieved erosion control and improved water infiltration. Furthermore, this treatment significantly increased corn yield. Brown (*3*) and Brown and Kemper (*4*) also reported extensive studies demonstrating the benefits of straw in irrigation furrows for both erosion and irrigation uniformity.

These results prompted us to study conservation tillage on furrow-irrigated land. Our objectives were to determine (a) what is meant by conservation tillage on furrow-irrigated land; (b) whether conservation tillage systems can be developed and used successfully on furrow-irrigated land; (c) how effectively conservation tillage controls furrow erosion and sediment loss; (d) whether crop yields can be maintained by applying conservation tillage to furrow-irrigated land; and (e) what the overall effect on farmer income is when applying conservation tillage to furrow-irrigated land.

For the first objective, we defined conservation tillage as reducing tillage operations to only those required to produce the crops grown while minimizing soil erosion. In most instances this does not require any new tilling or seeding equipment for furrow-irrigated land. For instance, deep-seeding drills to place seed where germinating moisture is present, as required on nonirrigated land, are not needed on irrigated land because water can be applied by irrigation to wet the soil and seed.

When the above definition of conservation tillage is applied to a given crop, the previous crop is a factor. For example, the minimum number of tillage operations required to seed dry edible beans following wheat, with four tons of residue per acre, is higher than the number of options required to seed beans following beans, with only a few hundred pounds of residue per acre. Therefore, when developing conservation tillage systems for furrow-irrigated land, the entire cropping sequence should be considered.

We chose not to use the common definition of conservation tillage—any system that leaves 30% residue cover on the soil surface after planting—because residue for furrow-irrigated land is not as important as residue for nonirrigated land.

This report includes results of several years of field research conducted to answer the objectives listed above—based on our definition of conservation tillage. Results include only one representative cropping sequence for objective “e,” and they represent only a small portion of the total data collected over the past 5 years of research.

Study methods

Our approach to developing and evaluating conservation tillage systems on furrow-irrigated land had two major components. The first was aimed at objectives “b,” “c,” and “d,’—to determine if conservation tillage systems could be successfully irrigated, if these systems effectively controlled furrow erosion and sediment loss, and if crop yields were as high from conservation-tilled plots as from traditionally tilled plots. Some of the studies were conducted on cooperating farmers' land and others on land where we controlled all operations. More than 70 separate field studies were completed from 1985 through 1989, all with the same general results.

Plots. Plots for all studies were established so each plot included the full irrigation run length. The statistical design was, therefore, random strips of traditional and conservation tillage over the entire field length. At least three replicates were included in all studies, and four were used where conditions permitted. Statistical significance was determined by applying the t-test to sediment loss values and crop yields. The conservation tillage treatments applied were generally selected in conformance with our definition given earlier. In some instances, however, where farmer cooperators were involved, more tillage operations were used because we included the judgment of the farmer in the process. The number of tillage operations farmers felt were necessary was usually higher than the number we suggested.

Tillage operations. The tillage operations used in these studies, a symbol for each, and

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Reprinted from the *Journal of Soil and Water Conservation*
March-April 1991, Volume 46, Number 2
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the per hectare cost based upon 1989 figures are presented in table 1 (*6*), along with unit volume costs for herbicides. These symbols and costs will be used where applicable throughout this report. The combination of tillage operations along with herbicide applications for a number of comparisons, are presented in table 2, along with the sediment yield data.

Table 1. Costs of agricultural operations, based on custom rates in the study area, and fertilizer and herbicide cost per unit.

Operation	*Cost Per Unit*
Crowning alfalfa (Cr)	\$29.65 ha^{-1}
Moldboard plowing-alfalfa ground (MP)	44.48 ha^{-1}
Moldboard plowing-open ground (MP)	39.54 ha^{-1}
Disking (D)	22.24 ha^{-1}
Roller harrowing (RH)	19.77 ha^{-1}
Furrowing (F)	19.77 ha^{-1}
Furrows cleaned (FC)	19.77 ha^{-1}
Cultivating (C)	24.71 ha^{-1}
Chiseling (Ch)	29.65 ha^{-1}
Seeding cereal, corn or beans (S)	22.24 ha^{-1}
Combining cereal (H)	61.78 ha^{-1}
Corn silage cutting and hauling (H)	12.97 ha^{-1}
Bean cutting and windrowing (H)	30.89 ha^{-1}
Bean combining-commercial (H)	27.56 Mg^{-1}
Applying herbicide with spray rig (Sp)	12.36 ha^{-1}
Fertilizer application-dry broadcast (Fe)	11.12 ha^{-1}
Fertilizer application-injecting, sidedressing (Fe)	17.30 ha^{-1}
Herbicide Costs	
Roundup	15.85 L^{-1}
2, 4-D	3.17 L^{-1}
Preemergence herbicides for beans-average	23.72 ha^{-1}

Table 2. Tillage operations, herbicides application, sediment loss, and crop yield for traditional and conservation tillage systems.

*Operations**	*Traditional Tillage*	*Conservation Tillage*	*Significance*
(A) Dry beans following wheat, slope = 1.3%			
Fall	D	D	
Spring and summer	Fe, D, MP, RH, Sp, RH, S, F, C	D, Sp, RH, S, F, C	
Sediment loss, Mg ha^{-1}	114	29.4	1%
Yield, Mg ha^{-1}	1.98	2.16	NS
(B) Dry beans following wheat, slope = 2.4%			
Fall	D, Ch	D, Ch	
Spring and summer	D, MP, RH, Sp, RH, S, F, C	D, Sp, RH, S, F, C	
Sediment loss, Mg ha^{-1}	14.1	7.4	1%
Yield, Mg ha^{-1}	1.78	1.98	5%
(C) Dry Beans following wheat = 3.3%			
Fall	D, Ch, D	D, D	
Spring and summer	MP, RH, RH, Sp, RH, S, F, C	Sp, RH, S, F, C	
Sediment loss, Mg ha^{-1}	11.0	2.7	1%
Yield, Mg ha^{-1}	2.12	2.86	1%
(D) Dry beans following wheat, slope = 0.6%			
Spring and summer	MP, RH, Sp, RH, S, F	D, D, Sp, RH, S, F	
Sediment loss, Mg ha^{-1}	30.3	14.1	1%
Yield, Mg ha^{-1}	2.24	2.24	NS
(E) Sweet corn following alfalfa, slope = 1.1%			
Spring	Sp, D, MP, RH, RH, S-F	Sp, S-F	
Sediment loss, Mg ha^{-1}	11.0	5.8	1%
Yield, Mg ha^{-1}	15.4	15.9	NS
(F) Silage corn following wheat, slope = 0.6%			
Fall	D, MP	None	
Spring and summer	RH, RH, S-F	S-F	
Sediment loss, Mg ha^{-1}	12.6	0.4	1%
Yield, Mg ha^{-1}	89.6	100.8	5%
(G) Silage corn following corn, slope = 1.4%			
Fall	D		
Spring and summer	MP, RH, RH, S-F, C	D, RH, RH, S-F, C	
Sediment loss, Mg ha^{-1}	12.1	1.8	1%
Yield, Mg ha^{-1}	49.5	49.7	NS

*MP, moldboard plowing; D, disking; RH, roller harrowing; F, furrowing; C, cultivating; S, seeding cereal, corn or beans; Sp, applying herbicide with spray rig; Fe, fertilizer application.

Water flow. Water inflows and outflows were measured in individual furrows using small flumes. Times when the water was started, when it reached the lower end of the furrow, when irrigation was terminated, and when runoff ceased were recorded for each irrigation. Flume readings were made several times during each irrigaiton to verify inflows and to determine changes in outflows. Total inflows were calculated on the basis of the inflow rate over the irrigation duration, which was usually 12 or 24 hours. Surface runoff was calculated on the basis of outflow rates and the time each outflow rate represented and summing the results for each irrigation. This was accomplished using a computer program designed for this purpose. The program uses a particular flume reading from a specific time and the previous one to the time midway between that particular reading and the subsequent reading, then sums results over the entire irrigation. Infiltrated water is the difference between inflows and outflows for each irrigation. Seasonal totals were obtained by adding results for all irrigations.

Sediment outflow. Net sediment outflows were based on water inflows and outflows and the sediment concentration in these flows. Sediment concentrations were measured in 1-liter samples collected each time flume readings were taken. The previously described computer program was then used to calculate total sediment inflows and outflows for each irrigation and the total for the season. Net sediment outflow was used to represent erosion.

Cropping sequence. The second major component of the research was to select a traditional cropping sequence and change it to accommodate the application of conservation tillage over the entire sequence. We then compared the new sequence with the traditional one from the standpoint of operational costs and net farmer income. The main goal was to answer objective "e." The traditional cropping sequence included the following sequence of crops: alfalfa, alfalfa, dry edible beans, dry edible beans, winter wheat, silage corn, and spring wheat-alfalfa. Based on the results of our earlier studies, we concluded that the minimum number of tillage operations required could be achieved if the cropping sequence were changed to alfalfa, alfalfa, silage corn, winter wheat, dry edible beans, dry edible beas, and spring wheat-alfalfa. Tillage practices, other operations and materials, and costs are shown in table 3 for both cropping sequences.

In addition to the data shown in table 3, other comparisons were made during the study. Every year, at each experimental site, there was a comparison set of plots of the same crop grown with both traditional and conservation tillage systems. For example, the second year when dry beans were grown with traditional tillage there were also comparison plots of dry beans grown with conservation tillage. There were also simultaneous comparison plots of winter wheat grown with traditional tillage and no-tillage winter wheat plots. These plots compared yields, erosion, and costs on a yearly basis. The only exception was the lack of conservation tillage plots in dry beans the first year following alfalfa.

Seeding rates. Seeding rates for all crops were those recommended and used in the area. These rates were the same for both traditional and conservation-tilled plots: 112 kg ha^{-1} for winter wheat, 78 kg ha^{-1} for spring wheat with alfalfa, 16 kg ha^{-1} for silage corn, 13 kg ha^{-1} for sweet corn, 90 kg ha^{-1} for dry edible beans, and 11 kg ha^{-1} for alfalfa with the spring wheat. Seed costs included seed treatment to prevent infection by fungi and other organisms.

Fertilizer application. Fertilizers were applied based on soil test values, including consideration of the previous crop, and were surface broadcast in most cases. Side dressing was used for some corn crops. Crops were irrigated according to soil water depletion measurements. Herbicides were applied as needed with traditional ground spraying equipment. Seed, fertilizer, and herbicide costs are shown in table 3. The application costs for fertilizer and herbicides were recorded as part of the other operational costs. An average value was used for preemergence herbicides for dry edible beans because several different materials were used and costs varied a small amount. Preemergence herbicides used included Sonalan, Eptam, and Treflan. Harvesting was by traditional methods. Wheat was combined. Corn was cut and chopped for silage. Dry edible bean plants were cut, accummulated into windrows, and threshed with a combine equipped with a pick-up for swathed or windrowed crops. Alfalfa was swathed and baled.

Yield analysis. Crop yields were obtained as follows: Wheat yields were obtained by combining 2.44-m-wide strips, 50 to 150 m long, depending on plot length, placing the wheat in a truck and weighing it on a commercial scale. Corn yields were measured by hand-harvesting four adjacent rows, 3 m in length, from each plot. Corn silage yields were corrected to 65% water content. Dry edible bean yields were measured by two methods. Where plots were wide enough, windrows comprised of six or eight rows were threshed over lengths varying from 50 to 150 m; the beans were then placed in a truck and weighed on a commercial scale. Where plots or conditions did not allow this approach, windrow lengths of 3 m were placed in burlap bags, then dried and threshed with a small, stationary bean thresher. No records were kept for the 2 years the fields were in established alfalfa because there were no differences in tillage operations.

Table 3. A comparison of traditional and conservation tillage cropping sequences following alfalfa showing tillage and other operations, their costs, crop yields, and net returns. Total operational and net income values were rounded to the nearest dollar.

Year	*Traditional Tillage*	*Conservation Tillage*
First year		
Crop	Dry beans	No tillage corn silage
Tillage and seeding operations*	D, Cr, Cr, D, MP, RH, RH, F, S, F, C	S-FC
Cost, (\$ ha^{-1})	274.27	22.24
Other operations	Sp, Fe, H	Sp, H
Cost, (\$ ha^{-1})	153.20	343.23
Seed, fertilizer/herbicide cost (\$ ha^{-1})	128.49	170.50
Yield, (Mg ha^{-1})	3.59	57.53
Price (\$ unit^{-1})	286.60	20.94
Net income (nearest \$ ha^{-1})	473.00	668.00
Second year		
Crop	Dry beans	No tillage winter wheat
Tillage and seeding operations	D, MP, RH, RH, F, S, C	S, FC
Cost, (\$ ha^{-1})	163.10	42.01
Other operations	Fe, Sp, H	Fe, Sp, H
Cost (\$ ha^{-1})	153.20	82.25
Seed, fertilizer/herbicide cost (\$ ha^{-1})	128.49	92.66
Yield, (Mg ha^{-1})	3.70	8.41
Price (\$ unit^{-1})	286.60	76.06
Net income, (nearest \$ ha^{-1})	615.00	423.00
Third year		
Crop	Winter wheat	Dry beans
Tillage and seeding operations	D, MP, RH, RH, S, F	D, RH, S-F, C
Cost, (\$ ha^{-1})	143.32	84.01
Other operations	Fe, Sp, H	Sp, H
Cost (\$ ha^{-1})	85.25	111.20
Seed, fertilizer/herbicide cost (\$ ha^{-1})	122.32	118.61
Yield (Mg ha^{-1})	8.47	3.59
Price (\$ unit^{-1})	76.06	286.60
Net income, (nearest \$ ha^{-1})	293.00	915.00
Fourth year		
Crop	Silage Corn	Dry beans
Tillage and seeding operations	D, MP, RH, RH, S-F, C	D, RH, SF, C
Cost (\$ ha^{-1})	148.26	88.96
Other operations	Fe, Sp, H	Sp, H
Cost (\$ ha^{-1})	353.36	11.29
Seed, fertilizer/herbicide cost (\$ ha^{-1})	156.91	114.90
Yield (Mg ha^{-1})	57.53	3.70
Price (\$ unit^{-1})	21.22	286.60
Net income, (nearest \$ ha^{-1})	560.00	742.00
Fifth year		
Crop	Spring wheat-alfalfa	Spring wheat-alfalfa
Tillage and seeding operations	D, MP, RH, RH, S, F	RH, S, F
Cost (\$ ha^{-1})	143.32	81.54
Other operations	Fe, H	Fe, H
Cost (\$ ha^{-1})	72.90	72.89
Seed, fertilizer/herbicide cost (\$ ha^{-1})	112.43	112.43
Yield (Mg ha^{-1})	5.38	5.04
Price (\$ unit^{-1})	122.36	122.36
Net income, (nearest \$ ha^{-1})	329.00	347.00
Totals, 5-year sequence		
Tillage and seeding operations		
Costs (\$ ha^{-1})	872.00	319.00
Net income, (nearest \$ ha^{-1})	2,270.00	2,896.00

*Mp, moldboard plowing; D, disking; RH, roller harrowing; F, furrowing; FC, furrows cleaned; C, cultivating; S, seeding cereal, corn, or beans; H, combining cereal; Sp, applying herbicide with spray rig; Fe, fertilizer application.

Results and discussion

More than 70 comparisons of traditional tillage and conservation tillage systems demonstrated that conservation-tilled, furrowed land can be successfully irrigated. Minor problems occurred only on two conservation-tilled fields; they resulted because wheat straw was cut into short pieces by excessive disking. The small pieces of straw tended to move with the water and "clump" at a resistance point in the furrow, blocking water flow. In contrast, problems were often encountered getting the water through the entire run length during the first irrigation on traditionally tilled land. This problem was usually solved by allowing the furrows to dry for a day or two and then applying water a second time. As a result, more water was generally needed to produce crops on soils traditionally tilled than on those conservation-tilled. From these results, we concluded that conservation tillage systems can be successfully furrow irrigated.

Data in table 2 addresses objective "c"

concerning the effectiveness of conservation tillage practices for controlling furrow erosion and sediment loss. Results from the seven studies selected for this report show that sediment loss was significantly less from conservation-tilled plots than from traditionally tilled plots. The reduction in sediment loss ranged from 47% to 96%. The data represent a range of field slopes from 0.6% to 3.3%, a range that includes nearly all of the furrow-irrigated land in the study area. Data are reported on two row crops normally associated with high erosion rates, dry beans and corn. Results are typical of those for the many other comparisons we made. We did conduct some comparisons where crops were seeded without tillage that showed no measurable sediment loss. Generally, the correlation was high between the number of tillage operations and sediment loss.

Crop yields generally did not differ when grown with conservation tillage as compared to traditional tillage (Table 2). There were three cases where conservation-tilled crops produced significantly greater yields than the same crops grown with traditional tillage. In 76 comparisons, we found six instances where conservation-tilled crops yielded significantly more. There were no significant yield differences in the other 64 comparisons, based upon the t-test at the 5% probability level. In some cases, where differences were found, they could be explained as resulting from irrigation problems or insufficient fertilizer applications. In some cases, however, such explanations were not satisfactory. For example, the lower dry bean yield following wheat under traditional tillage (Table 2C) resulted from drought. Straw residue mixed in the soil surface increased water-holding capacity in the root zone of beans grown with conservation tillage when compared to straw buried by moldboard plowing in the traditional tillage regime. The interval between irrigations was too long for the traditionally tilled beans, and water deficiency occurred for a day or two before each irrigation. The extra water held in the soil in which residues were mixed prevented drought under the conservation tillage treatment.

A similar explanation seems plausible, although not as clear, for the data in table 2B. We could not identify a particular cause for the yield difference shown in table 2F. It is possible that nitrogen was leached below the root zone temporarily because of the greater amount of water that was required to irrigate the entire field length of the traditional tillage plots the first couple of irrigations. This was not visibly evident, and our data did not indicate any nitrogen deficiency as the crop grew and matured.

The conclusion regarding objective "d" is that generally crops yield the same on furrow-irrigated land, regardless of the tillage systems used, so long as other cultural requirements are not limiting. The most probable causes for yield differences are drought and nitrogen deficiency on the traditionally tilled lands and nitrogen deficiency on the conservation-tilled lands. Nitrogen deficiency is generally caused by survival of previous-season alfalfa, which can extract nitrogen much more efficiently than can wheat. We encountered this problem in one comparison. Nitrogen deficiency can also reduce the yield of a crop following alfalfa if sufficient time with adequate soil water and temperature are not permitted for the decomposition of alfalfa roots and nodules and subsequent nitrification to occur. Attempts to kill alfalfa in the spring and then grow spring cereal is a high-risk situation for nitrogen deficiency. We demonstrated this by growing spring barley, with and without added nitrogen, following the killing of alfalfa in the spring. Barley receiving nitrogen produced higher yields than that without.

The final objective of the study was to determine the overall effect on farmer income of applying conservation tillage to furrow-irrigated land. Results presented have shown that crop yields are consistent under both tillage regimes and that fewer tillage operations are required for conservation tillage. Therefore, farmers can produce the same yield at less cost, thereby increasing net profit.

These results can be enhanced when the entire cropping sequence is considered. By doing so, farmers can often alter the number of tillage operations required for the entire sequence. And by changing the order of crops grown in some traditional sequences, there is potential for greater utilization of symbiotically fixed nitrogen and subsequent lower nitrogen fertilizer requirements during the cropping sequence. This is demonstrated in table 3.

Results of the study show that net farmer income increased \$125 ha^{-1} each year with the application of conservation tillage and changing the cropping sequence. These data represent one example of several such comparisons we made. For instance, some farmers grew sugarbeets and others grew corn for several years in sequence. Some produced potatoes or onions. Nevertheless, the principles we applied can be applied to all cropping sequences with success.

The traditional cropping and tillage system included at least 31 tillage operations, not counting seeding, compared to only 11 for the conservation tillage sequence (Table 3). Most of the increased net income with the conservation tillage cropping sequence resulted from savings realized for less tillage. Savings from reducing the number of tillage operations was \$553 ha^{-1} over the five years, or an average of \$111 ha^{-1} each year. The remaining increase in net income resulted from corn needing no nitrogen fertilizer because the nitrogen available from alfalfa was adequate. The alfalfa supplied part of the nitrogen required by wheat the second year.

Both corn and small grains can be seeded without tillage into killed alfalfa stubble, and both crops can be seeded into the residue of the other without tillage. These small grain crops also require relatively high amounts of nitrogen and can efficiently extract nitrogen from the soil. Such crops should be grown following alfalfa the first two seasons. The largest number of tillage operations used in the traditional cropping sequence was to prepare a seedbed for dry bean production following alfalfa. Growing corn or wheat instead of beans after alfalfa saves these operations.

Comparing net farmer income annually reveals some interesting results relative to farmer preceptions. Our discussions with farmers indicated that about half believe their best income results from dry beans following alfalfa. This is true for gross income. Because of high tillage costs, however, net income is less than that for corn silage grown with conservation tillage. In the second year after alfalfa, dry beans with traditional tillage did provide greater net return than did no-till winter wheat. In the third and fourth years after alfalfa, dry beans grown with conservation tillage produced yields equal to those grown the first and second years with traditional tillage, but with greater net returns.

The conservation tillage cropping sequence presented in table 3 and others we have tried can be further refined. There remain many unanswered questions about the best application of conservation tillage to furrow-irrigated land.

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