Reprinted from the *Soil Science Society of America Journal*
Volume 49, no. 1, January–February 1985
677 South Segoe Rd., Madison, WI 53711 USA

The Effect of Furrow Irrigation Erosion on Crop Productivity

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ABSTRACT

Furrow irrigation erosion redistributes topsoil by eroding upper ends of fields and depositing sediment on downslope portions causing a several fold topsoil depth difference on individual fields. This investigation was conducted to evaluate the effects of this erosion and deposition process on crop yield and to develop crop yield-topsoil depth relationships. Studies were conducted on 14 farmer-operated fields and on field plots with a continuous topsoil depth gradient from 10 to 66 cm. Severe erosion on the upper ends of fields combined with tillage has mixed light-colored subsoil with topsoil and caused these areas to become whitish in color. Crop yields have sharply decreased on these whitish areas compared to areas where the topsoil depth is 38 cm, or the original depth. Yields were increased, but less sharply, where sediment deposition has increased topsoil depth above 38 cm up to a depth of about 66 cm. Yield-topsoil depth relationships followed the equation $Y = a + b \ln X$ with significant correlation coefficients for wheat (*Triticum aestivum* L.), sweet corn (*Zea mays* L.), barley (*Hordeum vulgare* L.), alfalfa (*Medicago sativa* L.), dry beans (*Phaseolus ssp.*) and sugarbeets (*Beta vulgaris* L.). Yield decreases per unit loss of topsoil were greatest for wheat and sweet corn and least for sugarbeets. Yields on whitish soil areas could not be improved more than indicated by these relationships by adding additional fertilizer phosphorus or potassium.

Additional Index Words: **topsoil-loss, sediment deposition, soil conservation.**

Carter, D.L., R.D. Berg, and B.J. Sanders. 1985. The effect of furrow irrigation erosion on crop productivity. Soil Sci. Soc. Am. J. 49:207–211.

FURROW IRRIGATION erosion redistributes topsoil within fields and causes serious topsoil losses into rivers and lakes. Erosion and the resulting soil loss is greatest on the upper portions of fields (Berg and Carter, 1980; Carter and Berg, 1983; Mech and Smith, 1967) where the furrow stream size is largest and the energy to erode is greatest. Both erosion and sediment deposition along irrigation furrows are directly proportional to the energy of the furrow irrigation stream. This stream must be large enough at the application point to provide sufficient water for infiltration over the entire furrow length to meet the purposes of irrigation. Where slopes exceed about 0.7%, the flow velocity combined with this stream size at the upper ends of fields has sufficient energy to erode soil. Infiltration of water into the soil reduces the furrow stream size as the water moves down the furrow. As the stream size decreases so does the energy to erode and transport soil. First, the stream energy reaches a level where it no longer erodes soil. Then, further down slope, it reaches a level where it will no longer carry the accumulated level of sediment. At this point, sedimentation begins and continues downslope. This topsoil redistribution process decreases topsoil depth along the upper one third of fields and increases the depth along the lower two-thirds (Carter and Berg, 1983).

This down-furrow redistribution of topsoil has reduced crop yields on the upper portions of many fields. Power et al., (1981) reported that topsoil depth is an important factor in crop yields. It is reasonable to assume that where topsoil depth is increased, yields may be increased. This paper reports results from a study to quantify the effects of furrow irrigation erosion on crop yield. The soils studied represent large areas of irrigated land.

MATERIALS AND METHODS

The soils in the study area are Portneuf silt loam (Durixerollic Calciorthid) and similar silt loam soils, with a lime and silica cemented hardpan (caliche) that begins 30 to 45 cm below the surface and varies in thickness from 20 to 45 cm. The surface soil, or topsoil, is pale brown (10 YR 6/3) silt loam, the hardpan is white (10YR 8/2) silt loam and the soil below the hardpan is light gray (10 YR 7/2) silt loam. The silt content ranges from 62 to 67% in the topsoil, 65 to 75% in the hardpan and generally above 70% below the hardpan. The upper ends of many fields in the study area are whitish in color because erosion has reduced the topsoil depth sufficiently that plowing has fractured and brought portions of the white caliche layer to the surface, and has subsequently been mixed with the topsoil. We will refer to these areas as whitish soil areas throughout the paper. The term "whitish" is not used in the soil taxonomy sense, but simply to identify a highly calcareous soil material of very light color. A typical field illustrating the color differences is shown in Fig. 1.

Topsoil depth and crop yields were measured on 10 fields operated by cooperating farmers in 1982. Four of these, plus four additional fields, were studied in 1983. Over the two years, data were collected from six wheat (*Triticum aestivum* L.), seven dry bean (*Phaseolus ssp.*), two alfalfa (*Medicago sativa* L.), and one sugarbeet (*Beta vulgaris* L.), dry pea (*Pisum sativum* L.), and Norgold Russet potato (*Solanum tuberosum* L.) fields. All of these fields had been furrow irrigated for 75 to 78 yr, except four which had been furrow irrigated for approximately 60 yr and then converted to sprinkler irrigation. Topsoil depth was measured using soil probes or augers along four transects parallel to the head ditch. These transects were located by measuring the distance that the whitish soil extended downslope from the head ditch to where a transition zone was clearly evident between the whitish soil and normal topsoil. This transition zone represented where the plow depth was the same as the topsoil depth. The first transect was one-half the distance between the head ditch and the transition zone. The second transect was at the transition zone, the third was about one-third the distance between the transition zone and the lower end of the field, and the fourth approximately 30 m from the lower end of the field. The distance from the head ditch to each transect was recorded along with the field length and the distance from the head ditch to the lower end of the whitish soil area. This latter information was used to calculate the portion of the field that exhibited whitish soil.

Depth measurements to the plow depth and to the hardpan were made at three or more locations along each transect. Plow depth was easily detected by an abrupt change in the resistance to the force placed on a soil probe. Hardpan depth was also readily detected by a similar change in resistance, and it was also evidenced by an abrupt color change. Along the upper ends of fields, the plow depth was the only parameter that could be recorded because the hardpan had

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been partially fractured and mixed with soil above by tillage. In some cases, erosion had been so severe over the years that the hardpan had been completely fractured by tillage, and no restriction layer remained.

All crops were harvested along each transect at the usual harvest stage. Three, 1 m-square areas of wheat were hand-clipped, dried in a solar drier, threshed, cleaned, and weighed. Four to six rows of dry beans were cut, windrowed and allowed to dry in the field, and 3.05 m length sections of these windrows were later gathered at each site, threshed, cleaned, and weighted. Three, 1 m-square samples of dry peas were pulled, dried, threshed, cleaned, and weighed. Three 3.05 m sections of potato rows were dug along each transect, and the potatoes graded into five classes according to market standards. These were: no. 1, 113 to 283 g with rounded ends and good skin netting characteristics; no. 1 bakers, >283 g with rounded ends and good skin netting characteristics; no. 2, 113 to 283 g with pointed ends, rough, poor shape, or lack of skin netting; no. 2 baker, > 283 g with pointed ends, rough, poor shape, or lack of skin netting; and culls. Sugarbeets were dug from four 3.05 m sections of rows along each transect, topped, and weighed. The alfalfa was harvested at 10% bloom once during the year of establishment, or three times per year in established stands. The alfalfa was swathed, windrowed, allowed to dry in the field, and then 3.05-m length sections of the windrow were weighed. All measurements were converted to a per hectare basis.

Another experiment was conducted in 1983 in which topsoil depth was controlled. A paddle wheel carryall was used to establish a continuous topsoil gradient from 10 to 66 cm by differentially removing topsoil from part of the experimental area and depositing it on the remaining area. Twenty-four plots, each 6.09 m long were planted to six crops: 'Probran 751' hard red spring wheat; 'Steptoe' barley (*Hordeum vulgare* L.); 'Ranger' alfalfa with an 'Early Frosty' dry pea cover crop; 'Amalgamated AH-14' hybrid monogerm sugarbeets; 'Green Giant' hybrid sweet corn (*Zea mays* L.); and 'Royal Red' kidney beans. A blanket fertilizer application of 112 kg of N, 67 kg of P, and 11 kg of Zn per ha was made in the spring. Additional P and K treatments were randomly applied to selected plots at the rates of 224 kg P and 336 kg K/ha. Wheat, alfalfa, and barley were planted in 3.05 m wide plots with 76 cm between corrugates. Eight rows of sugarbeets and corn were planted with 56 and 76 cm row spacing, respectively. The beans were seeded in 16 rows with 56 cm row spacing. Borders of 1 m or more were left between each crop. The experimental plots were furrow irrigated frequently enough to avoid water stress.

Fig. 1—Whitish soil resulting from furrow erosion and tillage mixing on the upper end (foreground) and topsoil on the lower portion of a typical field.

Several yield parameter measurements were taken on the wheat, barley, and corn before and after harvest. The number of tillers per plant, head length, and plant height of 10 plants per plot were measured on the wheat and barley. The plant height and number of suckers (additional stalks) per corn plant were measured on 10 plants per plot. After harvest, test weights were determined for both barley and wheat from each plot. The ear perimeter at 5 cm above the base of the husked ear was measured on 10 ears per plot and the percent moisture was determined using five ear samples by removing the husks and shanks and weighing the ears before and after all moisture had been removed by drying. Stand counts were made on dry beans, sweet corn and sugarbeets.

All crops were harvested at maturity. The wheat and barley crops were harvested by hand-clipping three, 1 m-square areas per plot, threshing, cleaning, and weighing. The pea stand was poor, so peas were removed without weighing. Alfalfa was swathed without crimping, windrowed, allowed to dry in the field, and 3.05-m length sections of windrow in each plot were then weighed. Four rows of sugarbeets, each 3.05 m long were dug, topped, and weighed. The number of beets per harvested row section was also recorded. Four, 3.05-m length rows of sweet corn were hand-picked and the ears weighed with husks and shanks. Four 3.05-m length rows of beans were harvested by cutting plants at the base with a shovel, placing the plants in burlap bags, drying in a solar drier, threshing, cleaning and weighing. All yields were converted to a per hectare basis.

RESULTS AND DISCUSSION

The average portion of whitish soil was 30% on the 14 farmer-operated fields studied (Table 1). This percentage reflects the degree of erosion over the long term. The average percentage of whitish soils for fields less than 200 m long was 38% and the average for fields over 200 m long was 22%. These results indicate that the furrow stream size has not differed greatly for long and short runs over the long term because the length of the whitish soil area does not seem related to the field length. This finding does not agree with the usually accepted understanding that irrigators use smaller furrow stream sizes on shorter runs. Today, with the awareness of the relationship of stream size to erosion, furrow stream size is sometimes adjusted for run length, but historically it probably was not.

In a separate study underway, we have found that 70% of the furrow irrigated fields in the study area now have whitish soil areas. Those that do not, have slopes less than about 0.7%.

Table 1. Whitish soil, field lengths, and percent whitish soil on fields studied.

Field no.	Distance from head ditch to transition zone	Total field length	Whitish soil
	——— m ———		%
1	78	381	20
2	32	137	23
3	91	190	48
4	46	160	29
5	64	384	17
6	64	238	27
7	78	399	20
8	82	255	32
9	46	198	23
10	46	387	12
11	110	164	67
12	69	174	40
13	110	389	28
14	69	187	37

Table 2. Plow depth and depth to lime-silica cemented hardpan along four transects in farmers' fields studied.

	Transect no. 1†	Transect no. 2		Transect no. 3		Transect no. 4	
field no.	plow depth	Plow depth	Hard-pan	Plow depth	Hard-pan	Plow depth	Hard-pan
	cm						
1	25	36	38	36	38	36	41
2	20	30	30	41	48	41	56
3	25	25	51	25	51	25	61
4	25	30	30	36	36	38	46
5	20	30	30	36	96	30	76
6	30	36	46	36	56	41	61
7	30	36	36	41	48	41	71
8	20	36	41	36	61	38	68
9	30	36	36	38	61	38	68
10	30	30	30	30	36	30	51
11	25	25	33	25	43	25	58
12	25	25	48	25	51	26	76
13	25	28	30	30	71	30	84
14	28	28	37	28	51	28	56

† Hardpan depth was not recorded because it was the same as the plow depth because tillage had fractured part of it and mixed it with top-soil or entire hardpan had been fractured and therefore none existed.

Assuming that the 30% whitish soil area we measured on our study fields is representative of the entire area, then multiplying that value by the 70% of the fields eroded to the extent that whitish soil appears, gives a value of 21% of the area as severely affected by erosion. We found significant yield reductions for all crops on all whitish soil areas studied. Therefore, significant yield losses resulting from furrow irrigation erosion are occurring on 21% of the farmed area after 78 years of irrigation.

The initial topsoil depth in our study area was 30 to 45 cm with most areas having an original depth of 38 cm, according to soil surveys and depth of noncultivated soil in the area. The amount of soil lost from the upper ends of fields cannot be accurately measured because of the yearly mixing by tillage and the absence of reliable reference points. Observations, limited measurements based upon reference points, and soil depth measurements downslope indicate that a loss of 20 to 30 cm over 78 yr of irrigation is common, and in some situations losses are greater.

Table 3. Yield ranges for crops studied.

Crop	Lowest yield	Highest yield
	Mg/ha	
Wheat	1.41	12.04
Barley	3.78	7.02
Sweet Corn	6.50	28.69
Dry beans	0.82	3.70
Dry peas	2.24	4.71
Sugarbeets	52.68	76.22
Potatoes	45.51	61.87
Alfalfa		
establishment yr.	2.46	7.62
1st cutting	6.50	10.76
2nd cutting	3.81	6.28
3rd cutting	3.14	6.28

The depth to the hardpan indicates that significant amounts of sediment have been deposited on the middle and lower thirds of fields where the third and fourth transects were made (Table 2). Depth to hardpan exceeded the average original depth of 38 cm along both of the lower transects except at three sites along the third transect from the head ditch. In some cases, topsoil depth along the lower transects is more than twice the original depth. The depth to the hardpan was deeper than the plow depth along the transition transect in some cases because downslope movement of whitish soil from the upper end of the field had deposited over top of topsoil. We selected the transition transect based upon whitish soil on the surface. Also, the plow depth may be deeper than actual tillage depth.

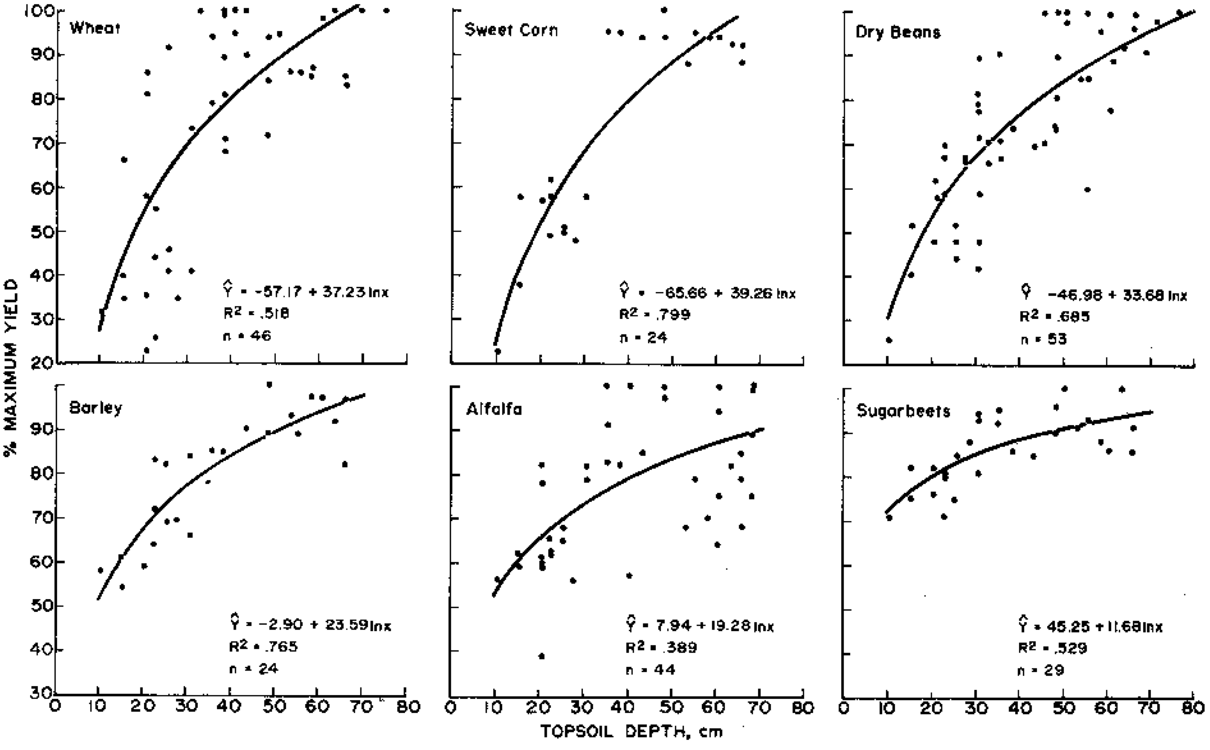

Fig. 2—Percent maximum yield at various topsoil depths for six crops grown on farmers' fields and experimental plots.

because the best defined resistance change to the soil probe may be at the previous plowing depth below the present plow depth because of deposition increasing the topsoil depth.

Yields of the eight crops studied on farmers' fields covered a wide range because of the diversity of cultural practices, cultivar differences and stand age in the case of alfalfa (Table 3). In every case, yields were reduced on whitish soil and generally increased where topsoil depth was increased from deposition. The actual yield relationship for six of these crops was calculated based upon the highest yield in the field or on the plots as maximum and other yields taken as a percentage of the maximum (Fig. 2). Data for the plot study were more precise than those from farmers fields, but the relationships followed identical patterns for each crop, so all data were combined.

The relationships between crop yield and topsoil depth followed reasonably well the equation $Y = a + b \ln X$, where Y is yield and X is topsoil depth. All correlation coefficients were statistically significant at the 0.001 probability level. The equation and the R^2 value are given for each relationship (Fig. 2).

Wheat and sweet corn followed very similar relationships. These two crops exhibited the greatest yield response per unit change in topsoil depth (Fig. 2). Bean yields responded almost as sharply as wheat and sweet corn. Barley and alfalfa exhibited similar responses. These two crops yielded consistently better on shallow topsoils compared to deep topsoils than did beans, sweet corn, and wheat. Sugarbeet yields were least affected by topsoil depth. Data for dry peas are not presented because a poor stand was obtained on the plots. Results from one farmer-operated field indicated about the same yield-topsoil depth relationship curve as for dry beans.

Potato yields were significantly greater at a topsoil depth of 38 cm compared to whitish soil areas, and further increased at a topsoil depth of 56 cm (Table 4). The total percent of no. 1's improved while the percent culls decreased as topsoil depth increased. These potato data were collected from three locations on whitish soil at each of the two topsoil depths indicated. Although our potato data provided insufficient points for a regression analysis like those presented for other crops, results indicate the same effect of the loss of topsoil on potato yields as for other crops.

Results of our investigations clearly show that topsoil depth has a major impact on crop yield in the study area. Results also show that the original 38 cm topsoil depth was not sufficient for maximum yields in the area. Topsoil losses sharply reduce yields of most crops, and topsoil additions increase yield. The yield decrease per unit depth loss of topsoil below the original 38 cm depth was greater than the yield increase per unit depth increase in topsoil above the original. Our findings suggested that the 66 cm maximum topsoil depth in our plot study was near the depth required for maximum yield.

Table 4. Potato yield and grade at different topsoil depth.

Topsoil depth	Yield	% no. 1 grade: Baker >283 g	% no. 1 grade: 113–283 g	Total	No. 2	Cull
cm	Mg/ha	%				
Whitish	45	11	53	64	11	25
38	51†	25	47	72	8	20
56	62†	12	60	72	12	16

† LSD (0.05) = 3.59 Mg/ha.

A careful examination of the relationships and the scatter of data points might suggest that a different equation should be used for wheat that would give a steeper portion of the curve at shallow topsoil depths, and a flatter portion at deeper topsoil depths. Also, the sweet corn relationship, which was from the plot study only, might indicate that the curve should be nearly flat at topsoil depths greater than 40 cm. Admittedly, the relationships for these crops might be improved with some mathematical manipulation, but we used the same general equation for all crops for comparison purposes. Other equations were tried, but the logarithmic equation gave the highest correlation coefficients.

Several yield parameters were measured for wheat, barley, and sweet corn in an attempt to identify those parameters affected by topsoil depth that in turn affected yield (Table 5). The number of tillers per plant and plant height were significantly decreased for wheat and barley by topsoil depth loss as a result of erosion. Sweet corn height was also significantly reduced. Test weights and head length for wheat and barley were significantly reduced on whitish soils on some fields and by shallow topsoil on the experimental plot area, but differences were very small as indicated by the small slopes of the linear relationships (Table 5). The percent ear moisture for sweet corn was significantly greater on the shallow topsoil. Visual observations indicated that sweet corn matured about 10 days later on the shallow topsoil than on the deep topsoil. The number of suckers per corn plant differed significantly with topsoil depth, but the line slope was very small.

The number of tillers per plant for both wheat and barley tended to cluster, with the 36 cm topsoil depth being the point of separation. The number of tillers was significantly greater at the 0.01 probability level on plants growing on topsoil depths greater than 36 cm than on topsoil less than 36 cm. The number of

Table 5. Linear equation, correlation coefficient, and significance level of yield parameters for corn, wheat, and barley (x = topsoil depth in cm).

Yield parameter	Equation	Unit	Correlation coefficient (r)	Significance level (α)
	Corn			
Height	$y = 162.78 + 0.58x$	cm	0.72	0.01
No. suckers	$y = 0.99 + 0.02x$	--	0.60	0.01
% moisture	$y = 76.30 - 0.04x$	--	−0.42	0.05
Avg. perimeter	$y = 15.14 + 0.01x$	cm	0.50	0.05
	Wheat			
Test weight	$y = 737.62 + 0.24x$	kg/m^3	0.48	0.05
Tillers/plant	$y = 0.80 + 0.11x$	--	0.85	0.01
Head length	$y = 6.06 + 0.04x$	cm	0.74	0.01
Plant height	$y = 51.55 + 0.46x$	cm	0.88	0.01
	Barley			
Test weight	$y = 610.86 + 0.02x$	kg/m^3	0.76	0.01
Tillers/plant	$y = -1.91 + 0.09x$	--	0.77	0.01
Head length	$y = 5.17 + 0.02x$	cm	0.63	0.01
Plant height	$y = 73.28 + 0.30x$	cm	0.74	0.01

tillers per plant did not differ significantly on topsoil depths of 10 to 30 cm, nor on depths of 36 to 66 cm.

Stand counts of dry beans, sweet corn, and sugarbeets indicated no significant stand loss on shallow topsoil plots. In fact, both dry beans and sugarbeets had significantly higher stand counts on the shallow topsoil depths. Therefore, plant emergence and subsequent plant stand were not factors reducing crop production of these crops. Individual sugarbeets were significantly larger on the deeper topsoils than on the shallow topsoils.

During the course of our investigations, a question was raised concerning the use of sprinkler irrigation to overcome some of the deleterious effects of erosion on yield. Although we could see no reason for such a different response, we did include four fields the second year that had previously been furrow irrigated and then converted to sprinkler irrigation within the past 10 yr. Results from those fields were identical to those from the other fields in the study. We concluded that water relation differences that may exist with the two irrigation methods did not alter the effects of topsoil depth on crop yield.

Soils in the study area require supplemental nitrogen, phosphorus and zinc, depending upon the crop being produced, for best yields. Subsoils, including the hardpan, are very low in available phosphorus, and we considered the possibility that large phosphorus applications may partially compensate for topsoil loss. However, we found no significant yield increases from such large phosphorus applications, nor from potassium applications. Adequate nitrogen and zinc were applied to the entire plot area to avoid deficiencies of these nutrients.

These investigations have shown that the loss of topsoil from furrow irrigation erosion sharply decreases crop production on irrigated soils of our study area. This yield loss cannot be overcome by any method presently known, except possibly the returning of topsoil to eroded areas. The extent to which these results can be applied to other furrow irrigated areas needs further investigation. The soils we studied represent more than 2 million hectares of irrigated land. Some research is being planned to evaluate the effects of furrow irrigation erosion on crop yields in other areas.

Topsoil is a valuable resource, and we must apply all of our knowledge and technology not only to prevent its loss into rivers and lakes, but to keep it in place on the land.

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