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Effects of Erosion on Soil Productivity

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Abstract: Research efforts across the United States have shown that soil erosion decreases soil productivity. Erosion-caused crop production decreases up to 50% have been measured with decreases of 15 to 30% commonly reported. Furrow erosion on irrigated land redistributes topsoil, decreasing topsoil depth on the upslope 33% and increases topsoil depth on lower 50 to 55% of fields. Crop yields are decreased where topsoil depths are decreased, but yields are not increased where topsoil depths are increased above the original depth of 38 cm in a large study area representative of several million hectares of furrow irrigated land. Crops vary in their sensitivity to decreases in topsoil depth. Soil productivity of the entire study area was decreased at least 25% by furrow erosion over 80 irrigation seasons. Technology is not available to restore crop production to the potential level that would have existed without erosion. Research and technology application are needed to reduce or eliminate topsoil loss and redistribution by furrow irrigation to preserve our soil resources in furrow irrigated areas. Application of conservation tillage to furrow irrigated land is suggested as the best known practice to reduce furrow erosion.

Introduction

Soil erosion has challenged mankind for centuries. Some historians believe that soil erosion reduced the abilities of some early civilizations to produce food, and therefore these civilizations declined until they were conquered or relocated (Wolman, 1985). Perhaps these claims are speculative, but considering recent reports of 40% fertility loss from erosion of some USSR soils, 25 to 50% yield loss from erosion of some United States soils, 30% less production on eroded than on noneroded Haiti soils, and 50% yield decline from erosion of 5 cm of surface soil from some Nigeria soils (Wolman, 1985), such claims are not without indirect support. There is no question that erosion is a serious problem, and we are only recently beginning to understand its impact on soil productivity and crop yield potential.

Most reports of the detrimental impact of soil erosion on crop production have been published in the last five years, and they represent all regions of the United States, as well as some other countries. White, et al. (1985) reported that crop yields on severely eroded soils in the Southern Piedmont were only 50% as great as those on non-eroded soil. They found that with severe erosion, surface horizons were thinner, had higher clay contents, were redder in color, less fertile, more acid, and had lower infiltration rates. McDaniel and Hajek (1985) reported that crop yields were reduced on moderately eroded sites in 65% of the fields studied in Alabama, and the average yield decrease was 22%. Erosion reduced corn yields 12% on Maury soil and 21% on Cridder soil in Kentucky. Yields of winter crops on eroded Maury soil ranged from

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17 to 36% (Frye, et al., 1982). Papendick, et al. (1985) reviewed research results for the Northwestern United States and reported both linear and curvilinear relationships between wheat yield and the thickness of the topsoil. Krauss and Allmaras (1982) reported that the loss of 13 cm of topsoil over a 90 year period at a site in Whitman County, Washington, decreased wheat yields 50%.

The soil properties that are most commonly changed in the surface soil by soil erosion and that are also most commonly associated with crop yield decreases are decreased organic matter, increased clay content, increased bulk density, decreased infiltration rate, and decreased available water holding capacity (Frye, et al., 1985; Nawak, et al., 1985). Fertilization can restore yields on eroded soils in some cases, but not in others.

Recent reports indicate that furrow erosion reduces crop yields on furrow irrigated land (Carter, 1985; Carter, et al., 1985). The purpose of this paper is to present available information on the effects of erosion caused by irrigation on soil productivity and potential crop production, and to suggest management alternatives to prevent or at least slow the rate of further deleterious impacts. Furrow erosion impacts will be the primary topic. Erosion occurs under sprinkler irrigation, but a properly designed system can eliminate most of that erosion. Generally, fields suitable for border and basin irrigation are not subject to serious erosion.

The effects of furrow erosion on topsoil depth

The irrigation furrow has two purposes. First it is the infiltrating surface for water to enter the soil to replenish the supply to meet evapotranspiration requirements. Secondly, it is the conveyance channel to supply water for infiltration over the entire furrow length. Meeting the requirements of the second purpose gives rise to erosion because the furrow stream size at the upper end of the furrow often exceeds the minimum erosive stream size. Hence, the furrow stream erodes soil along the upper ends of furrows and transports it downslope. As the stream size diminishes from infiltration, there is a point along the furrow where the stream size becomes smaller than the erosive size and erosion ceases. Further down slope, the stream size becomes still smaller and no longer has sufficient energy to carry the sediment load accumulated from upstream erosion. At that point, sedimentation begins and continues until all of the sediment has settled, or until the lower end of the furrow is reached and some soil is carried from the field in tailwater. The end result is removal of surface soil from the upper ends of fields, deposition of part it on downslope portions, and loss of the remaining portion. The topsoil depth decreases near the head ditch and downslope for a distance depending upon the slope and irrigation practice which includes the stream size. Topsoil depth is increased along a portion of the field where deposition occurs, and significant quantities of soil are lost from fields by furrow erosion. (Berg and Carter, 1980).

A detailed study of fields in a large irrigated tract has shown that furrow erosion has caused extensive redistribution of topsoil (Carter, et al., 1985). The study area was first farmed and irrigated in 1905, and has therefore been irrigated for about 80 irrigation seasons. The topsoil depth averaged approximately 38 cm when irrigation began. The subsoil is nearly white, high in lime, and much less fertile than the topsoil. Where subsoils have been exposed by erosion and tillage, the field surface becomes whitish in contrast to the gray topsoil color. A survey indicated that 75% of the fields now have whitish upper ends.

Individual field surveys were made to determine topsoil depth over the fields. Soil augers were used to bore holes and measure topsoil depth at points on a grid that would show patterns on each field. Several conclusions were drawn from these surveys. Some fields had lost 75 cm of soil from near the head ditch, and most fields had lost more than 20 cm. Topsoil depths up to 150 cm were found on the downslope portions of a few fields with depths of 60 cm occurring frequently. Buried topsoil zones were evident in some fields. This resulted from eroding mixed topsoil and subsoil from upper ends of furrows and depositing it over topsoil, and subsequent mixing. The 75% of the fields with whitish upper ends exhibited the following average patterns: 33% of the surface was whitish, an additional 10% or more of the field area had less than the original 38 cm of topsoil, and the remainder had 38 cm or more of topsoil. The typical pattern found on many fields is illustrated in Figure 1.

Relationships between topsoil depth and crop yield

Crop yields were measured at locations in 14 fields where topsoil depths had been measured, representing a range of topsoil depths from near 0 to 150 cm. Replicated measurements were made at each site by harvesting m^2 yield areas for grain crops or row length segments for row and alfalfa crops. In addition to these fields, plots having a

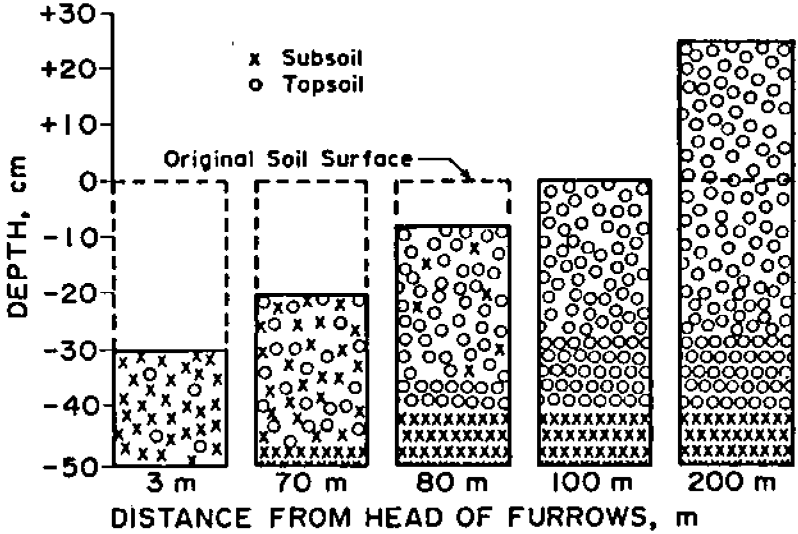

Figure 1. Erosion and deposition pattern on many fields after 80 years of furrow irrigation.

topsoil depth range of 10 to 66 cm were studied for three growing seasons. The crops studied for yield effects were alfalfa, barley, wheat, dry beans, sweet corn, and sugarbeets. Data from both fields and plots were combined and relationships between crop yields and topsoil depth were developed. To enable including all yield data in the same relationship, the highest yielding plot or location in the field was rated 100% yield, and yields on all other plots or positions on the field were expressed as a percentage of that yield.

Curvilinear relationships based upon the equation $y = a + b \ln x$ and linear relationships for two depth ranges have been reported (Carter, 1985; Carter, et al., 1985). The third approach reported herein is with the general asymptotic equation $y = a + b(1 - e^{-cx})$, where y is yield, and x is topsoil depth. This type of equation is often used to express crop production in relation to the availability of a yield controlling factor, and has become as the Mitscherlich-Spillman relationship. The relationships for six crops are illustrated in Figure 2.

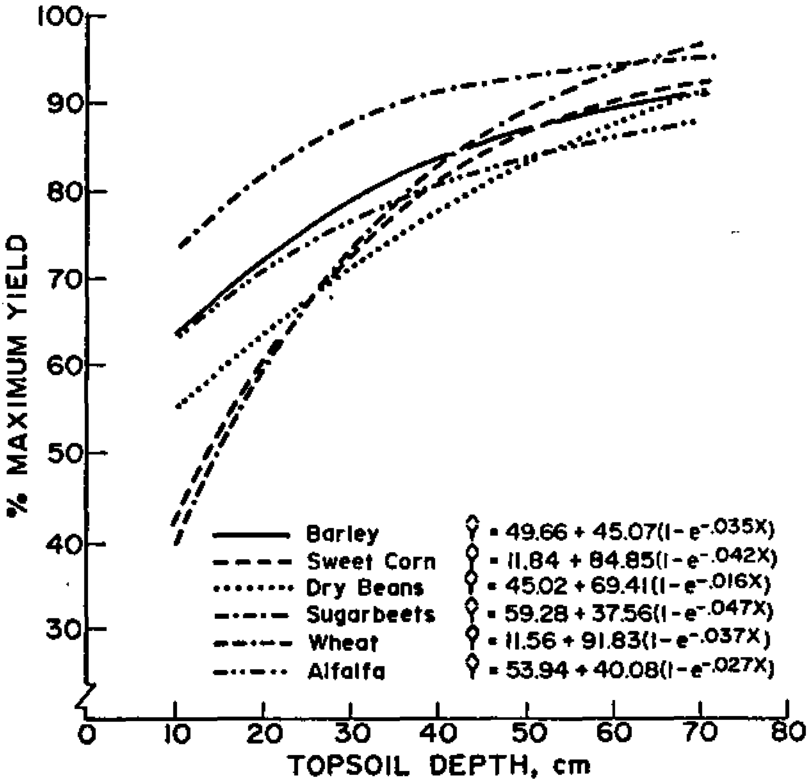

Figure 2. Crop yields as related to topsoil depth

One problem with the asymptotic relationships is that it is difficult to ascertain the point on the relationship above which topsoil depth has no significant impact on yield. We had previously used linear regression for two portions of the data representing yield on topsoils less than and greater than the original topsoil depth, and concluded that adding topsoil to give depths greater than the original would be of no benefit. Our division was made arbitrarily at the original depth. Applying asymptotic relationships may lead to a slightly different conclusion suggesting a small benefit of a little added topsoil depth, depending upon the crop.

Some authors have suggested that an "S" shaped Mitscherlich-Spillman relationship (Christensen and McElyea, 1985) more accurately fits the data for yields of some crops in relation to topsoil depth. However, in most cases the part of the relationship giving the lower tail of the "S" near the y-axis represents such low yields that they are below levels of economic production, and therefore not important.

Some crops are less sensitive than others to changes in topsoil depth (Figure 2). Knowing the relative sensitivity of crops is important in making management decisions. For example, a farmer who produces sugarbeets, wheat, and dry beans and has lost topsoil from erosion could expect greater relative production from growing sugarbeets more frequently on the severely eroded fields, and wheat and dry beans more frequently on the less eroded fields. Another example is that a farmer producing wheat and dry beans as cash crops on severely eroded soil may enhance his economic success by changing to producing barley and sugarbeets as his cash crops, depending upon relative crop prices.

Erosion effects on crop production potential

Applying the relationships in Figure 2 to the fields in our study area where 75% of the fields exhibit whitish upper ends and using the average 33% of the field areas as whitish and the 10% of the area with topsoil depth less than the original 38 cm but not yet exhibiting whitish color, indicates an overall potential yield decrease of approximately 25% resulting from 80 seasons of irrigation furrow erosion. These estimates indicated that as a result of furrow erosion over the past 80 years on the entire study area, crop production is only 75% of what it could have been had there been no erosion. This is a conservative estimate for several reasons. The first is that fields not yet exhibiting whitish areas likely have shallower topsoils near the head ditch where crop yields are reduced. We did not measure topsoil depth and production on those areas. The 10% of the field area where whitish soils are not yet evident but where considerable topsoil has been lost is a conservative estimate, and we assumed a 25 cm topsoil depth on that 10% of the area.

Over the past 80 years technology has increased crop production. Our estimates assume that improved technology has increased crop yield equally on both eroded and non-eroded soils. This assumption is probably not entirely correct. Technology has likely increased crop production more on non-eroded than on eroded soils.

Factors changed by erosion that reduce crop yield

Earlier in this paper factors most commonly changed by soil erosion that are associated with crop yield decreases were listed. These will be discussed in relation to our results. The organic matter content of topsoils in the study area is low, ranging between 1.0 and 1.3%. The subsoils contain 0.3 to 0.9%. Such a small difference in soils so low in organic matter probably would not have much impact on crop yields. Soils in the study area are silt loams. The topsoil generally is 62 to 65% silt, about 16 to 18% clay and 16 to 18% sand. Subsoils differ only slightly by ranging from 65 to 68% silt and about 16 to 18% clay, and 15 to 19% sand. These small differences would not likely affect yield. The bulk density of topsoil does not differ from that of the topsoil-subsoil mixture in whitish areas. The infiltration rate is slightly lower where subsoils have been exposed, but adequate water was added in our studies as is generally the case on farmers' fields. Soil tests in the whitish areas indicated adequate available nutrients, and a screening program of foliar application of nutrients has given no indication of crop response. We also tried soil applications of manure, a commercial tree bark amendment, unusually high rates of nitrogen, phosphorus, and potassium without positive response towards restoring yields on whitish areas. There is a possibility that subsoils contain a toxic substance that reduces crop yield, that we have been unable to identify.

All of the information we have gathered indicates that furrow erosion caused yield reductions are permanent in the study area. Subsoils simply are not as productive as topsoils, and we do not have available technology to restore productivity on eroded areas. Some research is underway to evaluate the yield and economic benefits of hauling topsoil from deposition areas of fields to the eroded upper portions. Preliminary results indicate a significant yield benefit.

Applicability of results to other furrow irrigated areas

Earlier in this paper results of research on nonirrigated land was reviewed indicating that erosion reduced crop yields on most nonirrigated soils. In some instances, application of technology restored crop yields on eroded areas, but in most cases it did not. Similar results should be expected from area to area for furrow irrigated soils. The seriousness of furrow erosion caused yield reductions depends upon the relative productivity of the topsoil and subsoil. If the subsoil is nearly as productive as the topsoil, negative impacts of furrow erosion may not be serious. In contrast, if subsoil productivity is much lower than topsoil productivity, the negative impact of furrow erosion may render farming seriously eroded areas unprofitable.

Furrow erosion effects become serious more rapidly where soil erosivity is high. In our study area of highly erosive soils, crop production potential has been reduced to 75% or less of what it would have been without erosion. There are many areas in the Western United States where furrow erosion has been practiced for less time on erosive soils. We must direct our efforts towards controlling furrow erosion in these areas before negative impacts become serious. For example, the productive Columbia Basin in Washington has been under irrigation about 40 to 50 years. No data are available on the effects of topsoil loss on crop production there, but several scientists have stated, based on observations, that furrow erosion is reducing crop yields. We need to be conscious of the potential that furrow erosion may cause serious reductions in soil productivity wherever furrow erosion is practiced.

Controlling furrow erosion

Furrow erosion has been recognized as a serious problem since the 1940's (Gardner and Lauritzen, 1946), but little attention was given to warnings of early researchers to control this problem. Water-quality acts in the past two decades have focused attention on sediment in irrigation return flows as a pollutant (Carter, 1976), and control technology has been developed to reduce sediment loss from furrow irrigated land (Berg and Carter, 1980; Carter and Berg, 1985). Development of sediment loss control technology directed attention to the source of the sediment and the dynamic erosion and sedimentation process in irrigation furrows. We now know that this process has had disastrous effects upon crop production, and we must stop its further detrimental impacts.

At present, the most promising practices for controlling furrow erosion and sedimentation processes is the application of no-tillage and minimum tillage to furrow irrigated land. Furrow irrigation farmers have been reluctant to consider these techniques because of fear that they could not effectively irrigate in the presence of surface residues. Research is underway with promising results that no-tillage and minimum tillage can greatly reduce furrow erosion, and at the same time, significantly reduce production costs without reducing crop yields.

Changing to sprinkler irrigation is another option, but costs of equipment and energy must be evaluated in relation to the crop production potential of the land. In some situations this is the best option.

Our topsoil is a precious resource for us and future generations. We must act now to preserve it in place where it is most productive.

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