THE INFLUENCE OF SIMULATED EROSION ON CROP GROWTH AND THE VALUE OF TOPSOIL IN SOIL PRODUCTIVITY

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ABSTRACT

Wind erosion is a major soil degradation phenomenon on the Canadian prairies but its effects on soil productivity are not well quantified. In the spring of 1990, incremental depths of soil (0, 5, 10, 15 and 20 cm) were removed with an excavator, to simulate wind erosion at four sites (three dryland and one irrigated) in southern Alberta. Highly significant non-linear relationships were found between the depth of desurfacing and subsequent spring wheat grain yields showing that simulated erosion drastically reduced soil productivity. Treatment effects at the irrigated site followed the same trend as the dryland site illustrating that topsoil loss cannot be compensated by adequate soil moisture. The 0-1 cm increment of topsoil was worth more (in terms of magnitude of yield loss when it was removed) on the irrigated site followed by the Black, Dark Brown and Brown dryland soils.

INTRODUCTION

The impact of wind erosion on soil quality leads to a reduction in soil productivity and hence crop yield. However, its effects on soil productivity are difficult to quantify. Topsoil depth is recognized as a major parameter in determining soil quality and productivity. Characterizing erosion-topsoil depth-soil productivity relationships is a vital step in assessing the true on-farm costs and benefits of conservation tillage and erosion control programs. If we could adequately assess the effect of loss of topsoil depth (i.e. erosion) on soil productivity we could move part of the way towards providing meaningful costs of soil erosion as well as assessing the economic benefits of switching from conventional to conservation tillage.

One approach aimed at quantifying erosion effects on productivity is to simulate the erosion process by desurfacing or 'scalping', whereby incremental depths of topsoil are mechanically removed and subsequent effects on soil productivity are monitored (Dormaar et al., 1986; Ives and Shaykewich, 1987; Tanaka, 1990).

The objective of this study was to assess the effects of simulated erosion on soil productivity expressed in terms of gross output (dollars/ha) of spring wheat. It examines the effects where no attempt was made to restore productivity by means of chemical fertilizer or other amendments. It particularly addresses the yield loss incurred for each incremental centimeter loss of topsoil to 20 cm depth.

METHODS

Four sites in southern Alberta were selected for desurfacing in spring 1990. Criteria for selection included uniformity of Ap horizon depth and topography. The sites were: Lethbridge Dryland, Lethbridge Irrigated (Dark Brown Chernozems); Taber Dryland (Brown Chernozem) and Hill Spring Dryland (Black Chernozem). All soils had Ap horizons of 12-15 cm depth overlying a thin B horizon (0-10 cm thick). The Lethbridge soils were sandy clay loams while the Taber and Hill Spring soils were clay loams.

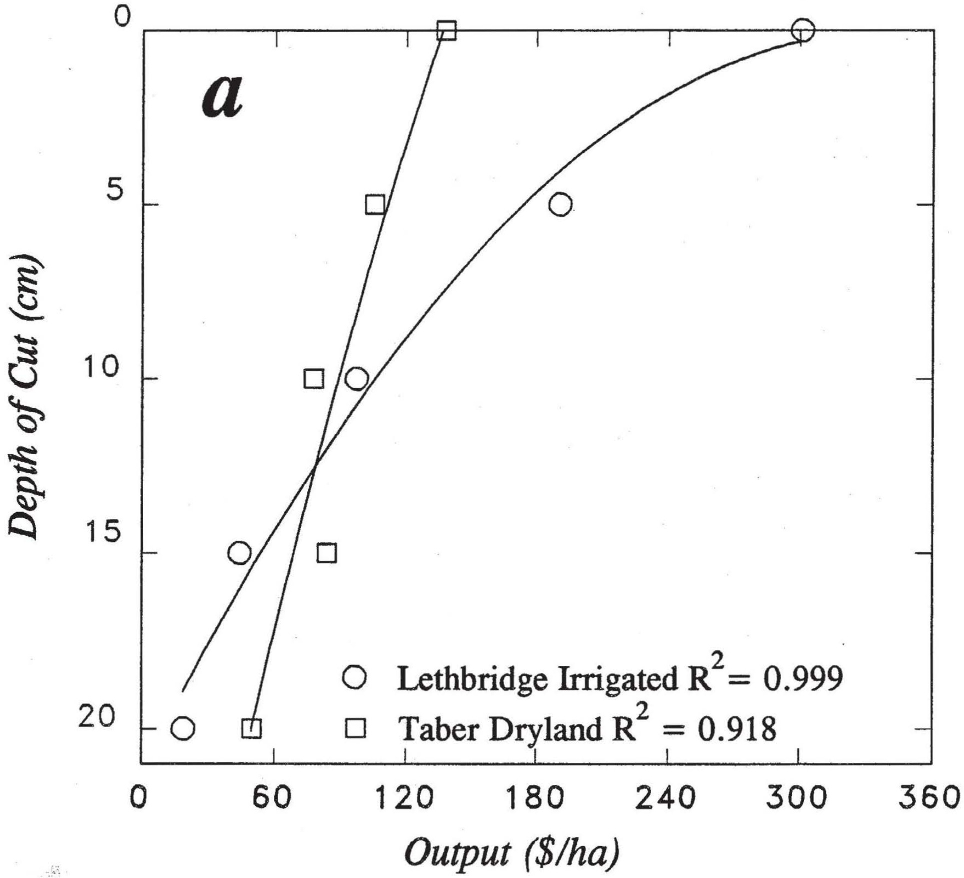
Five main desurfacing treatments or cuts (12 X 10 m plots) were established at each site by carefully removing 5, 10, 15 or 20 cm of topsoil using an excavator with a grading bucket and leaving a check (0 cm removed). Amendments aimed at restoring productivity were superimposed on each of the cuts (Larney et al., 1991) but they will not be discussed in this paper.

All plots were replicated 4 times. It was intended to initiate all 4 sites in 1990. However a wetter-than-normal May/June period in 1990 at Hill Spring delayed the scalping operation until September 1990. This resulted in 1991 being the first cropped year at Hill Spring, one year behind the other 3 sites. All treatments were seeded to spring wheat (*Triticum aestivum* L., cv. Lancer) with a hoe drill at recommended seeding rates. The Lethbridge Irrigated site received 17.5 cm of water during the 1990 growing season to ensure that root zone soil moisture was not a limiting factor.

Yields were calculated from six 5 m row lengths hand-harvested from each sub-plot. Output (dollars/ha) was calculated on a wheat price of $120 per tonne.

RESULTS AND DISCUSSION

The effects of artificial erosion on soil productivity at the Lethbridge Irrigated and Taber Dryland sites in 1990 are compared in Fig. 1a. The relationships were highly significant and non-linear suggesting that each increment of soil does not possess the same productivity. The output on the non-eroded (0-cm cut) soil at the Lethbridge Irrigated site ($301/ha) was over twice that at the Taber Dryland site ($137/ha) as would be expected when comparing irrigated and dryland management systems. However, the yield potential dropped rapidly on the Lethbridge Irrigated site as topsoil was removed. In fact the Taber Dryland site



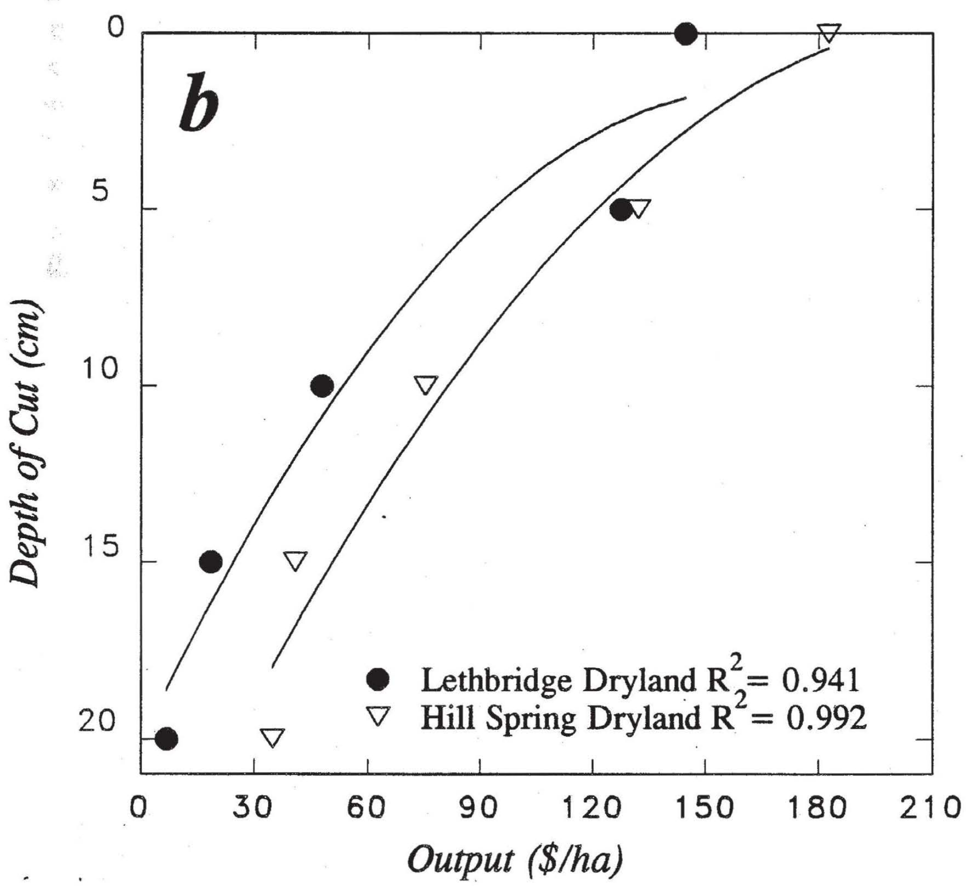


Fig. 1. Influence of simulated erosion on ouput of spring wheat at (a) Lethbridge Irrigated and Taber Dryland and (b) Lethbridge Dryland and Hill Spring Dryland sites.

outyielded the Lethbridge Irrigated site when > 12.5 cm of topsoil was removed. This shows that application of water did not compensate for loss of topsoil. Outputs on the 20-cm cuts were $19/ha on the Lethbridge Irrigated site and $50/ha on the Taber Dryland site representing approximately 16-fold and 3-fold decreases in yield compared with the non-eroded (0-cm cut) surfaces.

Fig. 1b compares the effect of simulated erosion on output for Lethbridge Dryland in 1990 and Hill Spring Dryland in 1991. The actual yields for each site may not be compared since they are from different growing seasons. However trends within a site may be observed. Again the relationships were highly significant and non-linear. The slopes were slightly different in the 0-10 cm depth of topsoil removal. The Black soil at Hill Spring lost its yield potential faster as the surface 0-10 cm layer was removed compared with the Dark Brown soil at Lethbridge. The output difference at the Lethbridge Dryland site between the 0-cm cut ($145/ha) and the 20-cm cut ($7/ha) was 20-fold. At the Hill Spring site the equivalent output values were $182/ha and $35/ha representing a 5-fold difference.

The following question is often posed when attempts are made to estimate erosion losses on soil productivity: how does the loss of one centimeter of topsoil effect soil productivity? Since our results show that the relationship between topsoil depth and productivity is non-linear the answer depends on which particular centimeter depth was removed by erosion. It depends on soil type and whether the soil is dryland or irrigated. Since the polynomial form of the yield-topsoil depth function shown in Figs.1a and 1b provides such good fits (R^2 values of 0.918-0.999) their equations may be used to generate yield losses for each centimeter increment of topsoil loss between 0 and 20 cm. Results from such an exercise are shown in Fig. 2 and are expressed in kg/ha yield loss for 1 through 20 cm of topsoil removal.

The most noticeable feature of Fig. 2 is the decrease in productivity of each incremental centimeter depth of topsoil. Removing the surface increment (0-1 cm) reduced spring wheat yield by 214, 115, 92 and 47 kg/ha at the Lethbridge Irrigated, Hill Spring Dryland, Lethbridge Dryland and Taber Dryland sites respectively. This represents a loss in returns of approximately $26, $14, $11 and $5/ha, respectively for the surface centimeter of topsoil. The trend shows that the surface centimeter has a greater impact on returns under irrigation than under dryland. On dryland the trend is one of Black > Dark Brown > Brown in terms of the returns from the surface centimeter of topsoil. This pattern follows the inherent productivity of these soils. Black soils are generally higher yielding than Dark Brown soils which in turn yield higher than Brown soils.

The 9-10 cm increment of topsoil was worth 123, 68, 65 and 33 kg/ha of grain at the Lethbridge Irrigated, Hill Spring Dryland, Lethbridge Dryland and Taber Dryland sites, respectively. This represents a loss in returns of approximately $15, $8, $8 and $4/ha for that particular increment of topsoil, respectively. In rough

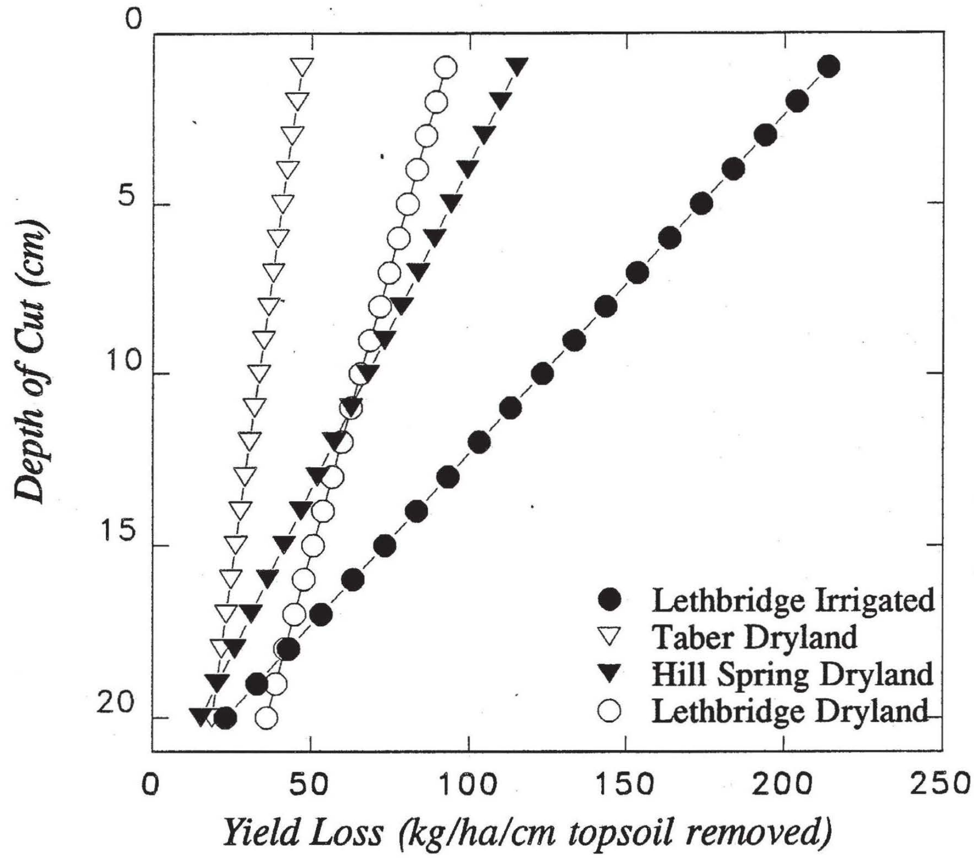


Fig. 2. Yield loss associated with each incremental centimeter loss of topsoil at four study sites.

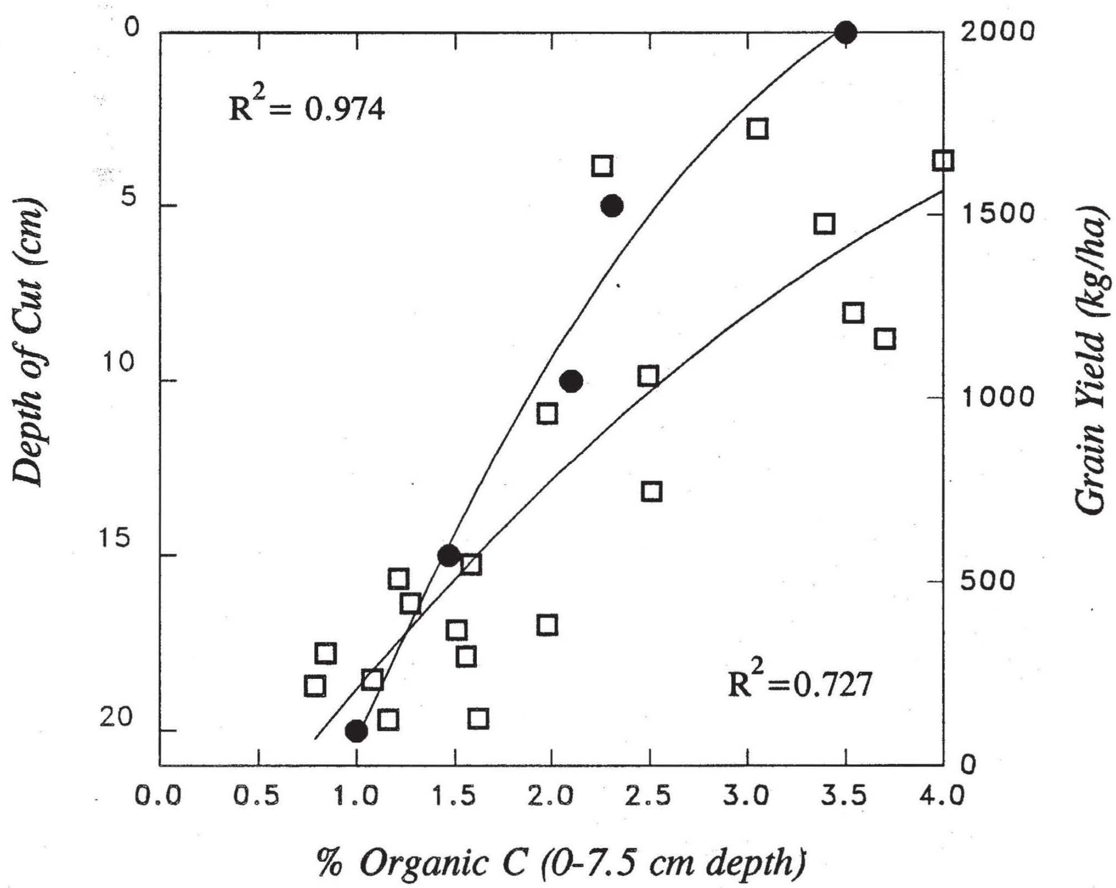


Fig. 3. Relationship of depth of cut with organic C (●) and organic C with grain yield (□) at Hill Spring, 1991.

terms the value of this increment at the Lethbridge Irrigated site is worth about the same as the surface centimeter at the Lethbridge Dryland site. As depth of erosion increased the value of soil at all four sites converged. The 19-20 cm increment of soil was almost identical in loss in returns at all four sites: ranging from $2 at Hill Spring to $4 at Lethbridge Dryland.

The incremental loss in returns from topsoil loss for each site can be observed by the slopes of the lines in Fig. 2. The largest difference in the value of returns between the surface layer (0-1 cm) and the deepest increment removed (19-20 cm) was on the Lethbridge Irrigated site with $23, followed by Hill Spring Dryland with $12, Lethbridge Dryland with $7 and lastly Taber Dryland with only $3.

How deep was it necessary to erode before the loss in returns from the surface centimeter of topsoil was halved? Interestingly, at both Lethbridge Irrigated and Hill Spring Dryland the 11-12 cm increment was worth half of the surface centimeter while at both the Lethbridge and Taber Dryland sites it was the 16-17 cm increment.

Natural wind erosion, by reducing topsoil depth, depletes surface organic matter. Artificial erosion has a similar effect on organic matter albeit more accelerated. In order to elucidate the reasons for the loss of productivity, yields at Hill Spring in 1991 were related to organic carbon content in the surface 0-7.5 cm (Fig. 3). The relationship between depth of cut and organic carbon content was highly significant ($R^2 = 0.97$). Similarly the relationship between organic carbon and grain yield was significant ($R^2 = 0.73$). This shows that organic carbon content in the surface 0-7.5 cm layer accounted for 73% of the variation in grain yield. Loss of productivity on eroded soils may be due to absent soil physical and microbial conditions associated with topsoil (Mielke and Schepers, 1986). These properties will be examined in the future to help further explain the reasons for loss of productivity. Some soil physical properties that may be affected by topsoil removal are surface texture, soil water storage, effective root zone and soil temperature. These parameters are likely more important in dryland areas where rainfall is limited.

CONCLUSIONS

1. The yield-topsoil depth response functions were of a polynomial form showing that each incremental centimeter depth of topsoil did not possess the same productivity.

2. What is the value of topsoil? Our results show that the answer to this question depends on: (a) which particular depth increment of topsoil is being lost to erosion; (b) whether the soil is dryland or irrigated; and (c) soil type.

3. Loss of organic carbon due to simulated erosion accounted for 73% of the yield variation at the Hill Spring site in 1991. Other soil chemical, physical and microbiological properties will be measure in the future to elucidate the causal factors of lost productivity on eroded soils.

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