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Erosion–productivity–soil amendment relationships for wheat over 16 years

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ABSTRACT

Soil erosion remains a threat to our global soil resource. This study was conducted to ascertain the effects of simulated erosion on soil productivity and methods for its amendment. Incremental depths (0, 5, 10, 15, and 20 cm) of surface soil, or cuts, were mechanically removed to simulate erosion at two sites (one Dryland, one Irrigated) in southern Alberta in 1990. Three amendment treatments (nitrogen + phosphorus fertilizer, 5 cm of topsoil, or 75 Mg ha^{-1} of feedlot manure) and a check were superimposed on each of the cuts. The sites were cropped annually until 2006. Average grain yield reductions during 16 years were 10.0% for 5 cm, 19.5% for 10 cm, 29.0% for 15 cm, and 38.5% for 20 cm of topsoil removal. There was evidence that the restoration of productivity levelled off at a value less than the non-eroded treatment rather than gradually converging on it, within the timeline of the study. Average grain yield loss was 50 kg ha^{-1} cm^{-1} yr^{-1} at the Dryland site and 59 kg ha^{-1} cm^{-1} yr^{-1} at the Irrigated site. As the depth of cut increased, the average residual effect (1993–2006) of manure increased, e.g., on the 5 cm cut, the residual effect (over the equivalent cut check treatment) was 20.9%, climbing to 41.9% on the 20 cm cut. Amendments ranked manure > topsoil > fertilizer in terms of restoring productivity to the desurfaced soils. The average grain yield during 16 years on the check treatment fell 2.1% cm^{-1} depth of topsoil removal on the Dryland site and 1.7% cm^{-1} for the Irrigated site. In contrast, grain yield on the manure treatment fell by 0.8% cm^{-1} on the Dryland site and 0.9% cm^{-1} on the Irrigated site. The study reinforces the need to prevent erosion and indicates that application of livestock manure is an option for restoring soil productivity in the short term.

1. Introduction

Recent reports agree that erosion continues to endanger global soil resources (Montgomery, 2007; Van Oost et al., 2007; Wilkinson and McElroy, 2007). Climate change, with its effects on temperature, timing and amounts of precipitation, and soil moisture, may increase erosion risk on agricultural land (Soil and Water Conservation Society, 2003; Zhang and Nearing, 2005). To adequately assess the effects of soil erosion on agricultural production, an understanding of the response of crop productivity to soil erosion is essential (Bakker et al., 2004). One of the problems in assessing erosion–productivity relationships is the difficulty in detecting a decline in productivity that results from erosion. Imperceptible yield change caused by imperceptible soil loss due to erosion may not be recognized. Mutchler et al. (1988) believed that promotion of soil conservation was difficult because significant soil loss rates of 20–40 Mg ha^{-1} yr^{-1} were not easily discernible, even by trained observers. However, Boardman (2007) suggested that the issue of imperceptible change versus catastrophic event has encumbered many erosion studies and argued that large-scale events, or a sequence of them, were responsible for high proportions of observed erosion.

Bakker et al. (2004) concluded that it was impossible to directly measure the effects of erosion on productivity, by monitoring the evolution of yields on eroding sites through time. Consequently, various indirect methods have been utilized such as (1) simulated erosion by mechanical topsoil removal or desurfacing, (2) adding topsoil to eroded soils, (3) comparing eroded phases of landscape transects, (4) comparing plots with different levels of historical erosion but similar characteristics (landscape position, management practices, slope, etc.), or (5) using simulation models of crop growth response to erosion. Bakker et al. (2004) discussed the pros and cons of each of these five approaches.

den Biggelaar et al. (2004) gathered information from published site-specific soil erosion–productivity experiments on a global scale. Of a total of 329 records, investigation of yield differences on differentially eroded phases was the most commonly used method

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(35%) to determine the effects of erosion. This was followed by topsoil removal or addition studies (29%). As well as being one of most widely use approaches aimed at understanding erosion–productivity relationships (Eck, 1987; Gollany et al., 1992; Ives and Shaykewich, 1987; Oyedele and Aina, 2006; Tanaka and Aase, 1989), topsoil removal (simulated erosion) is one of the simplest. Nevertheless, a potential drawback with the approach is that negative effects of erosion on productivity may be exaggerated (Bakker et al., 2004), since natural erosion, by water, wind or tillage operations, occurs gradually over many years and does not result in total disappearance of topsoil. However, if we follow the argument of Boardman (2007), topsoil removal may be more akin to catastrophic event erosion rather than imperceptible change erosion and hence may better simulate natural large-scale events, which cause the greatest proportion of soil loss due to erosion. Moreover, if the topsoil removal increments are many and closely spaced (e.g., 0, 5, 10, 15 and 20 cm) and the subsequent surfaces are cropped for a long period of time, the limitations of the approach may be overcome. Bakker et al. (2004) suggested that the longer the time span following desurfacing, the more realistic the results.

As well as being a means of quantifying erosion–productivity relationships, addition of amendments to restore productivity to the desurfaced soils may also be studied with the simulated erosion approach (Dormaar et al., 1997). Various studies have looked at amending desurfaced soils with fertilizer (Larney et al., 1995b; Tanaka and Aase, 1989) or manure (Dormaar et al., 1988; Larney and Janzen, 1996, 1997; Punshon et al., 2002).

The study described in this paper was initiated in 1990 and used a simulated erosion approach whereby incremental depths of topsoil were mechanically removed and subsequent effects on crop productivity (continuous spring wheat, *Triticum aestivum*) were monitored. Following topsoil removal, the resulting surfaces were amended with fertilizer, manure, or topsoil addition as a one-time application aimed at restoring soil productivity. Larney et al. (1995a) reported on erosion, but not amendment, effects in the initial year at four sites in southern Alberta and two sites in north-central Alberta. The early impact (first 3 years) on crop (Larney et al., 2000b) and soil (Larney et al., 2000a) responses at the four southern Alberta sites has been reported as has crop response (first 5 years) at the two north-central Alberta sites (Izaurralde et al., 2006).

This paper updates the findings on two of the southern Alberta sites which have been maintained since 1990. Specifically, we focus on effects of topsoil removal and one-time amendment treatments on subsequent annual wheat yield as well as average effects in the earlier (1990–1997), later (1998–2006) and overall (1990–2006) monitoring periods. Our objectives were to examine (1) if the deleterious effects of erosion diminished with time and (2) the longevity of the mitigation effect of soil amendments on erosion.

2. Materials and methods

2.1. Experimental treatments

The study methods have been described in detail by Larney et al. (2000a,b). In summary, two sites (one Dryland, one Irrigated) on Dark Brown Chernozemic sandy clay loam soils (Typic Haploborolls) were desurfaced in spring 1990 at the Agriculture and Agri-Food Canada Research Centre at Lethbridge, Alberta (49° 43′ N, 112° 48′ W). Five simulated erosion treatments (12 m × 10 m main plots) were established at each site by mechanically removing 0, 5, 10, 15 or 20 cm of topsoil (hereby referred to as cuts) using an excavator with a grading bucket. In the initial year only (1990), four sub-treatments (3 m × 10 m sub-plots) were superimposed (split-plot) on each of the main treatments: check, an optimum rate of N and P fertilizer (75 kg ha^{-1} N, 22 kg ha^{-1} P), or 75 Mg ha^{-1} (wet weight) of feedlot manure (0.35 kg kg^{-1} water content, with 190 g kg^{-1} total C, 22 g kg^{-1} total N on a dry weight basis), or re-application of 5 cm of topsoil. Fertilizer N and P rates were doubled at the Irrigated site. Plots were replicated four times in a randomized complete block design (5 cuts × 4 amendments × 4 replicates = 80 plots).

2.2. Soil management

In 1990, seedbed preparation consisted of one pass of a powered rotary cultivator to 10 cm depth as the desurfaced plots were dry and compact. Subsequently the sites were managed under no-till. No further amendments were applied in order to monitor residual effects of one-time additions. After 1990, all plots received broadcast applications of 40 kg ha^{-1} N and 9 kg ha^{-1} P (rates were doubled at the Irrigated site). Spring wheat was seeded at a 17.5 cm row spacing in May or early June of each year from 1990–2006, except in 2004 when both sites were chemical fallowed (herbicides used for weed control) in an effort to control the build-up of wild oats (*Avena fatua* L.) and green foxtail (*Setaria italica* (L.) P. Beauv. subsp. *viridis* (L.) Thell.). Also, yield data were not collected at the Irrigated site in 2003 because a severe infestation of wild oats compromised treatment effects. Hence, the experiment ran for 16 years (1990–2006) or 17 growing seasons with yield data from 16 growing seasons at the Dryland site and 15 growing seasons at the Irrigated site. Depending on precipitation amounts, the Irrigated site received from 100 to 200 mm of irrigation water during the growing season to ensure that root zone soil moisture was non-limiting.

2.3. Crop measurements

For grain and straw yield, six 5 m long rows were hand-harvested from each sub-plot in 1990–1991, while 13–15 m^2 of the 30 m^2 sub-plot area was harvested with a plot combine from 1992–2006 (excluding the Dryland site in 2002 when a 1 m^2 area was hand-harvested from each sub-plot). Straw was collected in removable bins attached to the rear of the plot combine. A severe hail storm caused 100% crop damage at the Irrigated site on 2 August 1992, necessitating biomass sampling (9 August) by hand (1 m^2) to salvage yield data. Straw from the unsampled portion of the plots was removed by baling in 1990–1991 but returned to the plots via a straw-shredder on a large combine in subsequent years. Grain and straw yield were expressed on a dry weight basis (after oven drying to 60 °C for five days).

As well as presenting annual yields, average yields were calculated for two periods, approximating the first and second halves of the study. The first period represented average data from the first eight growing seasons (1990–1997 inclusive) at both sites. The second period (1998–2006) represented average data from the second eight growing seasons at the Dryland site (1998, 1999, 2000, 2001, 2002, 2003, 2005, 2006) and seven growing seasons at the Irrigated site (1998, 1999, 2000, 2001, 2002, 2005, 2006).

Average yields for the entire study period were also calculated. For simplicity, the study period was assessed as 16 years even though it was technically 16 years 4 months (i.e., from seeding in May 1990 to harvest in September 2006, or 17 growing seasons, although crops were not harvested in all seasons).

Average yields were standardized by setting the 0 cm Cut-Check treatment at 100% and expressing all other cut × amend-amendment means as a percent of this value.

2.4. Statistical analyses

Statistical analysis was performed on all data using the General Linear Models Procedure (SAS Inst. Inc., 2007) with cut as the