# Productivity losses from soil erosion on dry cropland in the intermountain area

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*ABSTRACT: Soil erosion substantially reduces the productivity of deep, loessial soils on dry cropland in the intermountain region. The eroded areas usually coincide with steeper slopes where runoff is a problem. Reduced soil moisture limits crop growth, although the eroded soils also have fertility limitations. Where erosion was simulated by removing various amounts of topsoil from more level land, similar stored soil moisture readings were obtained on all plots. On those plots, however, added fertilizer did not fully replace lost topsoil for maintaining production. Also, poor soil profile moisture extraction by crops led to reduced infiltration and increased runoff during fallow. Erosion thus seems to be somewhat self-perpetuating, and there is no simple remedy once it has occurred.*

EROSION on wheat-fallow land in the Idaho-Utah Intermountain area has removed the brown topsoil and exposed the whitish, lime-enriched subsoil on 15 to 20% of the area. Winter wheat is unthrifty on these severely eroded areas. Snowmelt runoff, sometimes enhanced by Chinook winds and/or winter or spring rains, is the primary cause of erosion. Summer cloudbursts and to a lesser degree dust storms are also factors.

Deficit soil moisture and low soil fertility may limit production on these severely eroded areas. But neither factor has been quantified. Early work in Washington's somewhat similar Palouse area showed that runoff on sloping soils was 2.5 times greater where erosion had exposed the subsoil than where it had not (2). Therefore, moisture loss due to runoff might limit the stored soil moisture available for crop use. Also, wheat growing on these eroded areas exhibits visual characteristics of drought stress.

Wheat produced in shallow soils on knolls in the Palouse showed marked response to N and P fertilizers (7). Thus, fertility parameters for wheat production in eroded soils of the Intermountain area need to be investigated. However, results from irrigated Idaho soils with similar parent material as those in this study showed that the erosion effect was irreversible "by any method presently known, ex-

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cept possibly returning the topsoil to eroded areas" (1).

Technological advancements, however, mask the erosion effect, as found on Washington dryland (3). Power and associates concluded, "Data by which we can quantify effects of soil depth upon productivity from controlled experiments are essentially lacking for semiarid regions" (8).

Herein, we report the effect of topsoil depth on soil moisture regimes and on fertilizer response for cropping dryland wheat after fallow in the Intermountain region. We used two approaches: first, we duplicated an artificial erosion and deposition experiment at two sites; second, we established fertilizer plots on a series of farmers' fields that had severe to negligible erosion. For comparison, other reviews of soil erosion effects on productivity indicate that erosion-induced limitations on productivity are diverse and not always well quantified (6, 9).

## Study methods

We established two artificial erosion experimental sites near Albion, Idaho. The duplication assured that a range of dryland soils were represented. The most prominent soil series of the region belong to the Lanoak-Rexburg-Newdale-Wheelerville association. These soils were formed from deep deposits of calcareous, loessial parent material. All are silty, mixed, frigid Haploxerolls, except the Wheelerville, which is a Torriorthents. A prominent feature of this association is the depth to which the calcareous material has leached during weathering. Lanoak is the deepest to free lime, about 1 m (39.4 inches). The respective other series are decreasingly deep. The Wheelerville series may even contain calcareous material at the surface, especially where tillage has mixed the plow layer. We used a Rexburg silt loam to represent a productive dryland soil and a Newdale silt loam to represent a less productive marginal soil.

We established three main topsoil depth plots at each site by removing 0, 15, and 30 cm (0, 6, and 12 inches) of topsoil with a paddlewheel scraper. In a fourth treatment we placed 15 cm (6 inches) of additional topsoil over the original profile. The main plots were split into subplots fertilized with 0, 34, and 68 kg N/ha (0, 30, and 60 pounds N/acre), thus providing all combinations of erosion depth and N fertilizer treatments. At each location a duplicate set of plots received 54 kg P/ha (48 pounds P/acre). We did not use a factorial design. This prevented the added P from being mixed with the zero-P plots by tillage. Individual plots were 5 x 15 m (16 x 48 feet), facilitating the use of normal field implements. A fallow-wheat cropping sequence was used, with one full set of plots cropped and another fallowed each year.

Ammonium nitrate was the primary N source. We included enough ammonium sulfate to give an N:S ratio of 10:1 to avoid unexpected S deficiencies. Fertilizer was applied in late fall after planting Jeff winter wheat. We took triplicate soil moisture samples each April at the initiation of spring crop growth and each fall after harvest from nearly all cropped and fallowed plots to a 150-cm (5-foot) depth by 30-cm (1-foot) increments. After normal stubble-mulch fallowing and cropping, we determined wheat yields and quality. We recorded precipitation at the sites. Other weather records were obtained from the National Weather Service station 24 km (15 miles) away.

Our second study approach used farm field plots. We wanted to assure that we assessed a representative range of eroded and normal dryland soils under normal slope and aspect conditions. Beginning in 1978 we selected four to six eroded sites on farm fields that received 0, 45, and 90 kg/ha N (0, 40, and 80 pounds/acre), 0 and 20 kg/ha P (0 and 18 pounds/acre), and 0 and 5.6 kg/ha S (0 and 5 pounds/acre, in nearly all combinations as a modified factorial. Three replications were used.

The eroded soils, usually Newdale or Wheelerville silt loam, contained visible free lime at the surface.

For comparison, we selected nearby uneroded soils and repeated the experiment. The uneroded soils tended to belong to the Rexburg and Newdale series. Each had more topsoil over the free lime. The uneroded soils usually were less sloping, thus soil moisture storage and water runoff could vary.

We took soil profile moisture measurements in 30-cm (1-foot) increments each spring and after harvest to a 152-cm (5-foot) depth on each replication of the unfertilized plot and on the 45 kg/ha N - 20 kg/ha P - 5.6 kg/ha S treatment. We did not sample moisture while the plots were in summer fallow because fields were selected after the farmer had performed this operation. Wheat yields and wheat quality components were determined after the plots were hand-harvested.

**Table 1. Available soil profile moisture (to 152 cm) in the spring of crop year and after harvest and crop use (difference) of that moisture due to artificial erosion treatment. Years, soil series (site), and fertilizer P differences were all nonsignificant and are averaged.**

| Artificial Erosion Treatment | Soil Profile Moisture (cm) | | |
|---|---|---|---|
| | Spring (Crop Year) | Post-Harvest | Crop Use (Col. 1 – Col. 2) |
| 15 cm soil added | 17.3 | 6.4 | 10.9 |
| Untreated | 17.8 | 9.1 | 8.6 |
| 15 cm soil removed | 17.8 | 12.2 | 5.6 |
| 30 cm soil removed | 18.0 | 11.7 | 6.4 |
| LSD at 0.01* | nonsignificant | 1.5 | 1.3 |

*Duncan's multiple range analysis indicated that the same significant differences existed if the noted LSD is used to compare all treatments within appropriate columns.

## Artificial erosion plot results

Stored soil profile moisture at the beginning of the crop year was 17.3 to 18.0 cm (7 inches) on all plots, regardless of year, soil series, or treatment (Table 1). Thus, we could compare the effects of artificial erosion and fertilizer treatments on crop growth without a moisture variable.

During the growing season, however, wheat on the most productive plots extracted the most soil profile moisture; the intermediately productive plots extracted an intermediate amount, etc. (Table 1). By harvest, net crop use of profile moisture was significantly greater, 10.9 cm (4.3 inches), on the plots with 15 cm of soil added. The next highest extraction, 8.6 cm (3.4 inches), was from untreated plots (no soil removed). Moisture use on the plots with 15 or 30 cm of soil removed was 5.6 and 6.4 cm (2.2 and 2.5 inches), respectively. The later two treatments did not differ significantly.

The greatest amount of unused, available profile moisture after harvest (Table 1) was in the 15- and 30-cm removal plots, 12.2 and 11.7 cm (4.8 and 4.6 inches), respectively. These means were not significantly different. Significantly less moisture remained in the untreated plots, 9.1 cm (3.6 inches), and even less moisture, significantly less, remained in the plots with 15 cm of soil added, 6.4 cm (2.5 inches).

Differences in unused soil moisture perhaps would not have been anticipated if estimated only from the visual appearance of the crop before harvest. Where soil was added to plots, and to a lesser extent where no soil was removed, wheat appeared lush and thrifty until ripening. In comparison, wheat on plots with 15 or 30 cm of soil removed was stunted, had fewer tillers, and the lower leaves took on a burned appearance and then died early in the growing season as though the plants lacked moisture. In retrospect, we believe these visual symptoms were primarily fertility related.

In the Intermountain region, where snowmelt runoff is a problem, differences in profile moisture in the fall may affect the subsequent infiltration of winter and early spring precipitation. For example, long-term soil water profile storage averags 73% of precipitaton between harvest and the spring of summer fallow. In contrast, from the fall of summer fallow until the next spring—during the same calendar period, but with a partially filled profile—only 16% of precipitation is further stored (*4*). This storage difference is due presumably to antecedent soil moisture.

In our study all plots contained similar profile moisture amounts by the spring of the crop year. That is, the inefficient crop use of stored moisture on eroded plots contributed to the inefficient storage and associated extra runoff of subsequent precipitation. Thus, our results may coincide with those from the Palouse indicating more runoff from eroded plots (*3*).

Yields did not vary significantly due to either P applications or sites. But topsoil addition or removal caused large and significant yield differences (Table 2). Without N additions, yields increased from 1,810 kg/ha (26.8 bushels/acre) on the untreated topsoil plots to 3,050 kg/ha (45.2 bushels/acre) where 15 cm of topsoil were added. Yields fell to 970 kg/ha (14.4 bushels/acre) on plots with 15 cm of topsoil removed and to 710 kg/ha (10.6 bushels/acre) where 30 cm of topsoil were removed. These latter two yields did not differ significantly. Thus, loss of the top 15 cm of topsoil was most detrimental to yield. Further subsoil losses only slightly worsened the condition.

Plots with topsoil added did not respond to N fertilizer (Table 2). Undoubtedly, the double topsoil itself provided enough N to make it nonlimiting under these dryland conditions. The other main erosion plots responded to N. However, yields on the plots with 15 cm of topsoil removed, and more so on those plots with 30 cm of topsoil removed, lagged behind the untreated erosion plots at any given rate of N. We doubt that higher N rates would have further increased yields, as indicated by other research with fertilizer N in this region (*3*) and noting the poor N use efficiency (Table 2). Thus, the high yields on the plots with added topsoil cannot be duplicated merely by adding large amounts of N fertilizer to soils having less topsoil or no topsoil.

**Table 2. Average wheat yields on artificial erosion plots and abbreviated analysis of variance.**

| *Artificial Erosion Treatment* | *Yields with Various N Applications* 0 kg/ha N | 34 kg/ha N | 68 kg/ha N |
|---|---|---|---|
| | kg/ha | | |
| 15 cm soil added | 3,050 | 2,920 | 3,180 |
| Untreated | 1,810 | 2,010 | 2,370 |
| 15 cm soil removed | 970 | 1,560 | 2,070 |
| 30 cm soil removed | 710 | 1,460 | 1,880 |

LSD (interaction, for all possible row, column comparisons) at .01 = 490 kg/ha.
LSD (interaction, for all possible row, column comparisons) at .05 = 370 kg/ha.

*Analysis of Variance*

| Source of Error | Degrees of Freedom | Calculated F |
|---|---|---|
| Main plots (erosion, N) | 11 | 35.5 ** |
| Erosion | (3) | 101.6 ** |
| N | (2) | 31.7 ** |
| Erosion x N, interaction | (6) | 3.86** |
| Location | | |
| (Rexburg vs. Newdale soil site) | 1 | NS |
| Phosphorus fertilization | 1 | NS |
| Main plots x location | 11 | NS |
| Pooled error | 58 | |
| Total | 95 | |

**Table 3. Average soil profile moisture (to 152 cm) available in the spring of the crop year and crop yields from eroded and uneroded soils without (– N) and with (+ N) fertilizer N on farm trial plots.**

| | *Eroded Soils* Profile Moisture (cm) | Yield (kg/ha) – N | + N | *Comparative Uneroded Soils* Profile Moisture (cm) | Yield (kg/ha) – N | + N |
|---|---|---|---|---|---|---|
| All-plot average | 12.2 | 1,230 | 1,540 | 16.3 | 1,640 | 2,160 |
| Low moisture plots | 3.8 | 700 | 780 | 8.6 | 1,360 | 1,370 |
| High moisture plots | 23.9 | 1,890 | 2,410 | 21.3 | 3,190 | 4,190 |

While N applications (Table 2) offset some negative effects of erosion, it is meaningful to compare the yield and moisture use where no topsoil was removed and where 15 cm of topsoil were added and 34 kg N/ha applied to both plots. With topsoil added, water use was only 2.3 cm (0.9 inch) greater than where no topsoil was added. Yet the plots with added topsoil produced 910 kg/ha (13.5 bushels/acre) more wheat (Table 2). Thus, in terms of moisture-use efficiency over this range, there was a 396 kg/ha yield increase per cm of water used (15 bushels/acre/inch). This is unrealistic for Intermountain dryland crops. Past research has shown there is about a 66 kg/ha increase in winter wheat yield per cm (2.5 bushels/acre/inch) of extra moisture used (*4, 5*). We concluded that the 15-cm-soil-added treatment provided a completely different—increased—moisture-use efficiency. This implies that insufficient topsoil exists in the Intermountain area, even without erosion, for the most efficient use of contingent soil moisture.

### Farm field plot results

Results from fertilizer trials on farm fields were similar to those from the artificial erosion plots. Most eroded soil sites, however, contained less soil-stored moisture in the spring of the crop year than did nearby uneroded soils. Available moisture in the 152-cm profile averaged 12.2 cm (4.8 inches) in the eroded plots and 16.3 cm (6.4 inches) in the normal soils (Table 3). Undoubtedly, these differences were due partially to the steeper slopes and greater runoff associated with the eroded sites. Rill erosion was noted on the plot areas in the spring of the growing year from overwinter runoff. Although it was not measured, we saw consideraly more recent erosion on the eroded soils than on the normal soils.

Crops did not respond to S applications, and P fertlization usually had no effect.

Table 3 shows average yields from six sites with the lowest moisture conditions. Neither eroded soils nor normal soils responded to fertilizer N under drought conditions. While wheat yields on the uneroded soils were almost twice those on eroded soils, we could not determine if the difference was due to topsoil depth or the stored soil moisture because there was a profile moisture variable, 3.8 cm in eroded soil profiles versus 8.6 cm in normal soils (1.5 vs. 3.4 inches). This lack of cause and effect was also true when all plots (32 sites) were averaged (Table 3). But the overall detrimental effect associated with the eroded soils on reduced soil moisture storage and lower yield remained evident. With high moisture conditions, where eroded soils had even slightly more profile moisture than normal soils, unfertilized production directly related to soil erosion (Table 3). N fertilizer under these conditions was beneficial. Yield on the eroded soil was 2,400 kg/ha (35.8 bushels/acre), an increase of 520 kg/ha (7.8 bushels/acre). Yield on normal soil was 4,170 kg/ha (62.2 bushels/acre), an increase of 1,000 hg/ha (14.9 bushels/acre).

Although we attempted to offset erosion's effects with fertilizer, crop response to fertilizer was only about one-half that on normal soils when moisture became less limiting.

## Conclusions

Water erosion was more severe on previously eroded sites. These sites usually occurred on steeper slopes, which undoubtedly contributed to increased runoff and associated soil loss. On artificial erosion sites, however, we found that reduced soil fertility caused crops to be unthrifty and to extract less of the available soil profile moisture. The subsequent high soil moisture created poorer infiltration characteristics for impending precipitation during the fallow period, which resulted in more runoff and erosion. In other words, the runoff-erosion-lower yield cycle perpetuated itself.

Although soil moisture usually limits crop yields in this region, we found that uneroded topsoil depths also limited moisture-use efficiency and yield. Additional topsoil losses worsened the moisture-use efficiency and yield relationships.

Adding N overcame some of the detrimental effects of erosion, provided that soil moisture was plentiful. Even so, the full N requirements of wheat from fertilizer sources were more readily met on uneroded soils than on eroded soils. An extreme example was on farm sites with high moisture. There, fertilizer N was twice as efficient on uneroded soils as on eroded soils for increasing yields. There was no response to fertilizer N where topsoil was added to the normal profile. We concluded that the added topsoil itself provided the full N requirement.

S applications did not and P applications usually did not increase yields. Also, unreported exploratory trials with K and trace elements on these and other Intermountain dryland soils showed no yield response. The addition of fertilizer nutrients, therefore, cannot fully substitute for surface soil.

Further research is needed to determine why production is impaired on these eroded soils when fertility is not limiting and moisture is reasonably adequate. Perhaps the soil's high Ca content may either limit plants' nutrient uptake or rooting tendency under a no-physical-barrier situation. These causes are speculative. No plausible explanations resulted from this or from similar work comleted to date.

Soil lost by erosion is detrimental to agriculture in the Intermountain region. The greatest recovery from erosion can be achieved where it is economical to return deposited material to eroded areas, then managing soil resources with recommended practices.

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