# Potential Runoff and Erosion Comparison of Center Pivot Sprinklers on Three Idaho Soils

**Bradley A. King, Agricultural Engineer**

USDA ARS Northwest Irrigation and Soil Research Laboratory, 3793 N. 3700 E., Kimberly, Idaho 83341.

**David L. Bjorneberg, Agricultural Engineer**

USDA ARS Northwest Irrigation and Soil Research Laboratory, 3793 N. 3700 E., Kimberly, Idaho 83341.

**Abstract.** *The operational characteristics of center pivot sprinklers are well documented but few studies have been conducted to evaluate the effects that operating characteristics of a particular sprinkler have on infiltration, runoff, and erosion of specific soil types. The objective of this study was to evaluate potential runoff and erosion from common commercial center pivot sprinklers on three widely distributed, south central Idaho soils. A modified commercial irrigation boom system was used to emulate center pivot irrigation on experimental runoff plots. Sprinklers used in the study were: 1) Nelson R3000 with brown plate, 2) Nelson R3000 with red plate, 3) Nelson S3000 with purple plate, and 4) Senninger I-Wob with standard 9-groove plate. There were significant differences in runoff and erosion rates between sprinkler types for the soils tested and experimental conditions. The I-Wob exhibited the highest overall runoff and erosion rates and the R3000 sprinklers exhibited the lowest rates for the three soils tested. In general, sprinkler types that visually appear to more uniformly distribute sprinkler droplets over the wetted area with respect to time exhibited the highest runoff and erosion rates. The relative differences in runoff between the sprinklers tested for the three soils were not directly proportional to droplet kinetic energy. This outcome is in conflict with conventional theory on soil surface sealing from droplet impact.*

**Keywords.** Center Pivot, Runoff, Erosion

## Introduction

Center pivot irrigation is popular with producers but is not necessarily the best irrigation system choice for all site conditions. Water application rates along the outer portion of the system, which influences the most acres, often exceed soil infiltration rates for medium- and fine-textured soils may result in substantial runoff, erosion and spatial non-uniformity in water application depth on rolling topography. The primary emphasis for many center pivot sprinkler product developments and application studies has been high uniformity which really is not the main challenge for good water application at the outer end of the pivot system. Over the past two decades center pivot sprinkler manufacturers have developed sprinklers that minimize peak water application rates while sustaining high application uniformity. As a result there are numerous center pivot sprinkler choices available for the producer but little quantitative information that relates these choices to infiltration, runoff, and erosion on a particular soil.

The operational characteristics of center pivot sprinklers such as wetted diameter, application rate pattern shape and drop size distribution have been reported in the scientific literature (e.g. Kincaid et al., 1996; Faci et al., 2001; DeBoer, 2001; Sourell et al., 2003; Playan et al., 2004; Kincaid, 2005;). However, studies evaluating the effect operating characteristics of a particular sprinkler have on infiltration, runoff, and erosion of specific soil types are limited. This is especially true for low organic matter calcareous soils in the arid western U.S whose aggregate structure readily breaks down under sprinkler droplet impact to form surface seals that reduce water infiltration rates.

The objective of this study was to evaluate potential runoff and erosion from common commercial center pivot sprinklers on three widely distributed, south central Idaho soils under center pivot irrigation.

## Methods and Materials

A 4-wheel commercial irrigation boom 154 ft in length (Briggs Irrigation, Northhamptonshire, UK) was used to emulate center pivot water application on replicated soil plots. The irrigation boom was modified by increasing the boom height 18 inches and adding additional sprinkler outlets along the boom length. Two additional sprinkler outlets were added between each existing outlet to provide 48 to 51 inch spacing between adjacent outlets. A hydraulic cable winch system mounted on the front of a John Deere 1020 tractor was used to mobilize the irrigation boom. Water is supplied to the irrigation boom by a 3 inch, 300 ft drag hose. Travel speed of the boom is computer controlled at a specified constant rate. Specific details on the irrigation system used to emulate center pivot irrigation are provided by King and Bjorneberg (2007).

The effect center pivot sprinkler type has on runoff and erosion for a specific soil was evaluated using raised runoff plot boxes, figure 1. The elevated plot boxes were 4 feet wide by 8 feet long with different end heights to provide a nominal slope of 5%. The bottom of each runoff box was filled with Porneuf silt loam to a depth six inches below the top. The soil to be evaluated (Table 1) for runoff and erosion was then used to fill the remaining volume in the plot box. This provided a soil depth of 6 inches for runoff and erosion evaluation. A metal frame border measuring 3.3 feet (1 m) wide by 6.6 feet (2 m) long was installed on the box soil surface to collect runoff and prevent plot runon from the surrounding area and eliminate edge effects. The metal frame was made of 3/16-inch thick steel 3-inches in width orientated vertically on three sides. The bottom edge of the metal frame was driven into the soil to a depth of about 1.5 inches to channel the runoff and prevent runon. The down slope outlet end of the frame had a horizontal metal lip along its length about 2.5 inches in width for runoff to leave the frame without excessive erosion due to head cutting. Along the down slope length of the metal lip was a metal trough sloped to one edge of the metal frame to collect runoff and channel it to a collection bucket in a hole dug near the corner of the runoff plot box. The depth of water in the bucket was measured with a ruler to determine runoff volume. The bucket was covered to prevent water from sprinklers contributing to runoff water volume. The combined horizontal width of the lip and trough was about 3.25 inches. Water application to the lip and trough adds to the total runoff volume and was accounted for when calculating plot runoff volume.

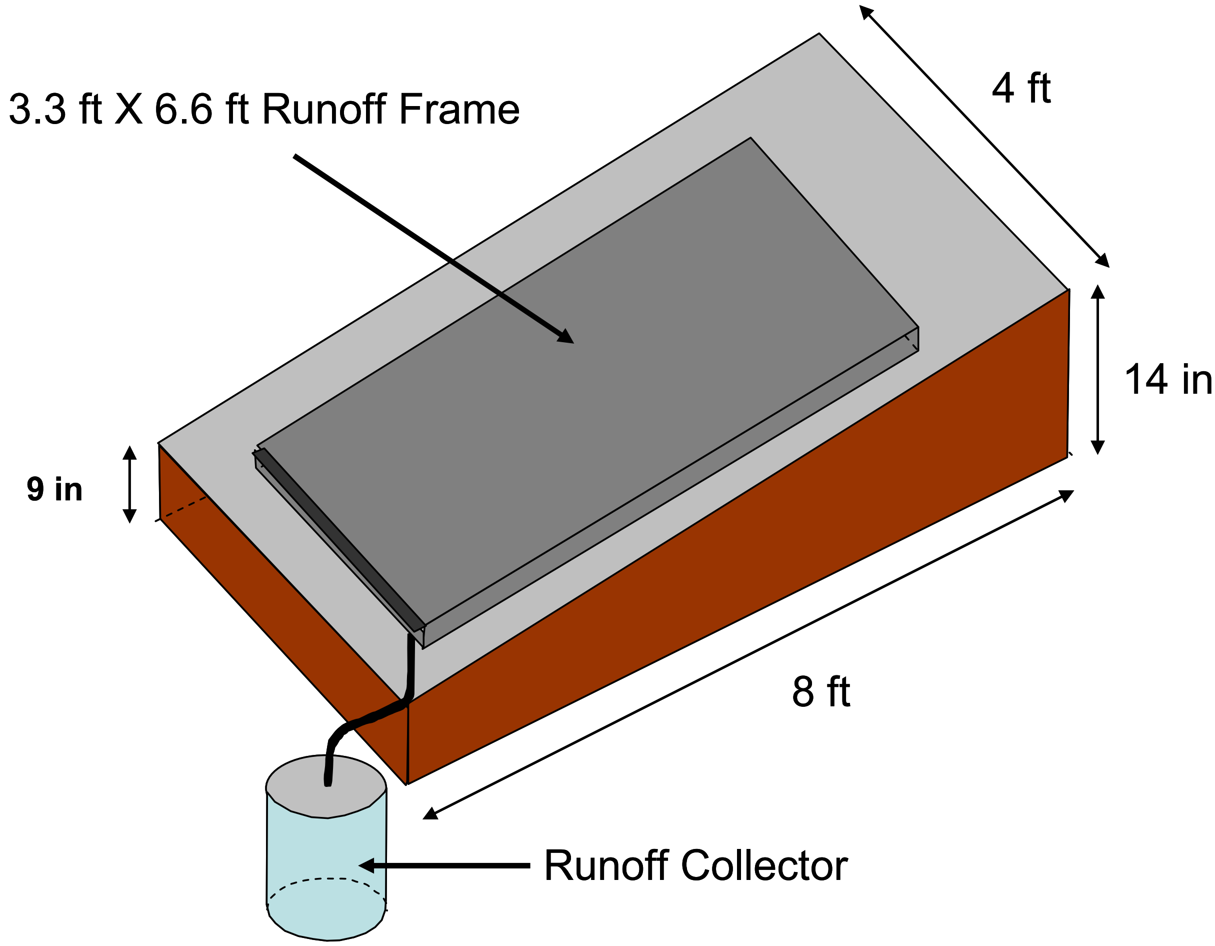


Figure 1. Diagram showing layout, dimensions and features of runoff plot box with metal frame.

Sixteen runoff plots boxes were installed in a four row by four column arrangement as shown in figure 2. The metal frames were installed at a constant slope of 5% on the surface of each runoff plot box and the soil within the metal frames graded smooth. The rather steep slope and smoothed soil surface of the plots was selected to minimize the unknown and variable surface storage component of the infiltration-runoff-erosion process. Consequently, the runoff and erosion rates measured in this study represent maximum rates for worse case conditions. Actual field runoff and erosion rates would be substantially less due to soil surface micro topography storage, sustained higher infiltration rates due to residue management and less slope. The runoff and erosion rates obtained in this study represent potential runoff and erosion for sloping conditions rather than actual field rates. Four common commercial sprinklers were used to evaluate infiltration, runoff and erosion differences. They were: 1) Nelson R3000 with brown plate (Nelson Irrigation Corp., Walla Walla, WA) with a Nelson 20 psi regulator, 2) Nelson R3000 with red plate with a Nelson 20 psi regulator, 3) Nelson S3000 with

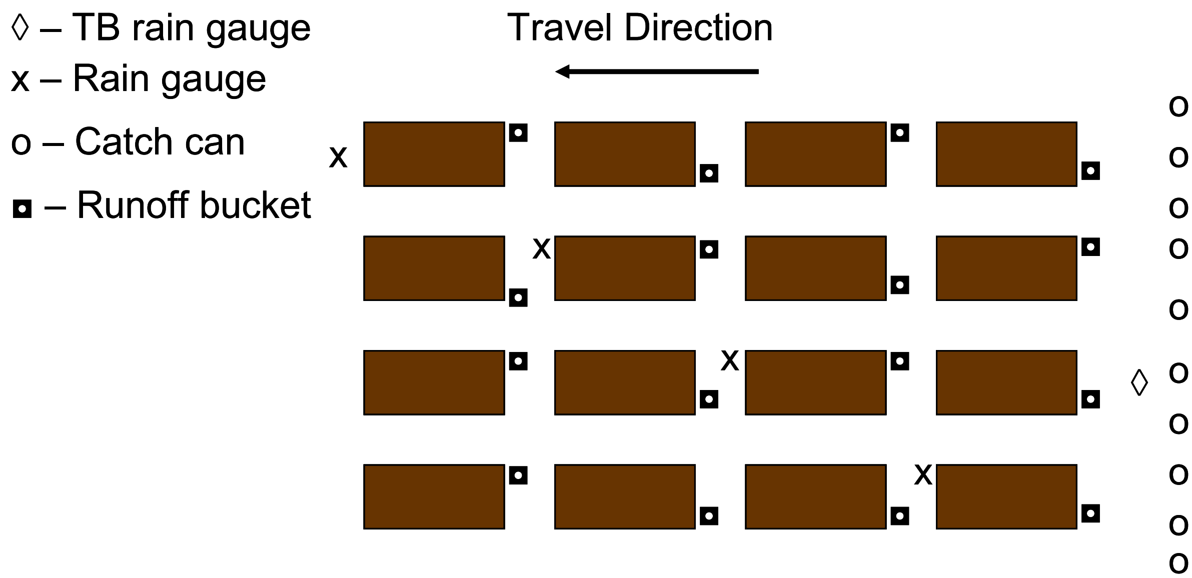


Figure 2. Diagram showing experimental plot layout used to evaluate center pivot sprinkler runoff and erosion potential.

purple plate with a Nelson 15 psi regulator, and 4) Senninger I-Wob with standard 9-groove plate (Senninger Irrigation Inc., Clermont, FL) with Senniger 15 psi regulator. Using manufacturer's data, sprinkler nozzle sizes were selected to be representative of those used on the outer end of ¼-mile center pivot systems in Idaho. The sprinkler nozzle sizes were also selected to provide approximately the same flow rate per sprinkler regardless of operating pressure or manufacturer. The selected sprinkler nozzle sizes and corresponding flow rates were; 1) 0.297 inch (#38) rated at 11.28 gpm, 2) 0.297 inch (#38) rated at 11.28 gpm 3) 0.320 inch (#41) rated at 11.48 gpm, and 4) 0.328 inches (#21) rated at 11.36 gpm, respectively. Sprinkler height was approximately 3 feet above the surface of the runoff plot boxes. Sprinkler spacing along the boom was 96 to 102 inches. Four consecutive irrigations were applied to the runoff plots with an irrigation interval of 5 to 10 days to allow the soil surface to dry and soil profile to drain between irrigations. All irrigation applications were to bare soil conditions. Only half the length of the irrigation boom was used to apply water to the runoff plots.

The four sprinkler configurations (treatments) were randomly assigned to the sixteen plots with one treatment per row and column in order to obtain a Latin Square statistical design. Twelve of the sixteen plots were covered with waterproof polyethylene tarps to protect the soil surface and prevent water application when the irrigation boom passed over the plot area with a particular sprinkler treatment. Then the irrigation boom sprinklers were changed, the tarps repositioned and the irrigation boom repositioned and towed upslope over the plot area again to apply a different sprinkler treatment. Irrigation treatments were completed over a one or two day period. All the tarps were installed and removed at the same time to minimize differences in soil drying between irrigation events. Sediment mass in runoff was measured using vacuum filtration and

Table 1. Soil particle size fractions for the three soils used in the study.

| Soil Name | Particle Size Fraction (%) | | |
|---|---|---|---|
| | Sand | Silt | Clay |
| Chijer Fine Sandy Loam | 39 | 45 | 16 |
| Portneuf Silt Loam | 14 | 65 | 21 |
| Sluka Silt Loam | 27 | 63 | 10 |

filter paper. Statistical analysis of the measurements was conducted using SAS GLM procedure and Duncan's multiple range tests for means comparison (SAS, 2007).

The runoff tests were repeated for each soil type (Table 1). Soil was removed from each runoff plot box by hand and filled with the new soil. The soils used in the test were obtained from commercial farm fields. A large articulated hydraulic loader was used to collect soil from the top six inches of the field and load it on a dump truck. The soil was stock piled on site until used. Soil texture analysis was conduced on each soil using the hydrometer method.

## Results

Texture analysis results for the three soils used in the study are listed in Table 1. The soils were selected to cover the range in sand and clay fraction available locally. A 25 percent range in sand fraction was fairly evenly split between the three soils. The range in clay fraction is limited due to the existence of predominately loam and silt loam textured soils in the local area.

Percent runoff (runoff volume / application volume x 100) for each sprinkler type, irrigation event and soil type are shown in figures 3 through 5. Target application depths for the four irrigation events in each series of tests for a specific soil were 0.96, 0.8, 0.6, and 0.6 inches, respectively. In general, the percent runoff for each soil increased with the number of irrigations. This result is attributed to reduced infiltration rates caused by soil surface sealing due to sprinkler droplet impact on the bare soil surface and is consistent with the findings of Thompson and James (1985), DeBoer et al., (1988), Agassi et al., (1994) and Lersch and Kincaid (2000). The development of a soil surface seal after the first irrigation was readily apparent for all the soils. Runoff measurements for a single irrigation event were highly variable despite the controlled experimental conditions and small distances between plots, limiting detection of significant differences in runoff among sprinkler types. Sources of random variability include soil placement and compaction in the runoff plot boxes, soil surface smoothness and structure, location of box within sprinkler overlap pattern and wind speed and direction. To minimize the effect these random factors have on detection of significant differences between sprinkler types, cumulative percent runoff for each sprinkler type was calculated as the sum of measured runoff divided by the sum of measured water application for the four irrigation events and statistically compared. Cumulative percent runoff for each soil type is shown in figure 6. There were significant differences in cumulative percent runoff between sprinkler types. Overall, the I-Wob sprinkler

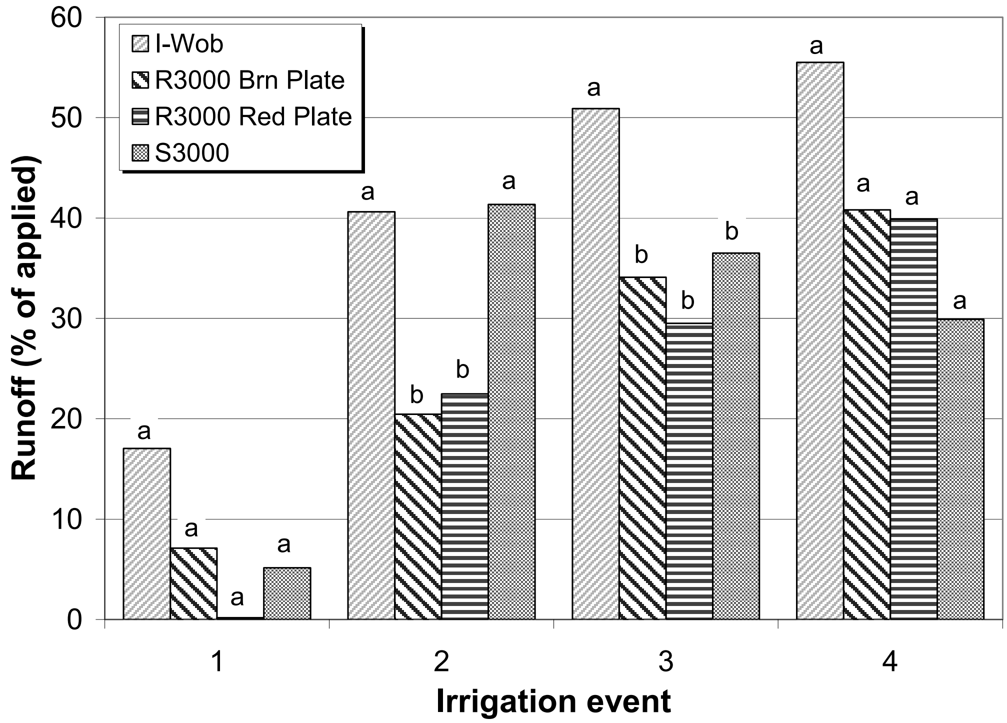


Figure 3. Runoff percentage measured for each of the four irrigation events on the Chijer fine sandy loam. Columns with the same letter for an irrigation event are not significantly different at the 0.05 level.

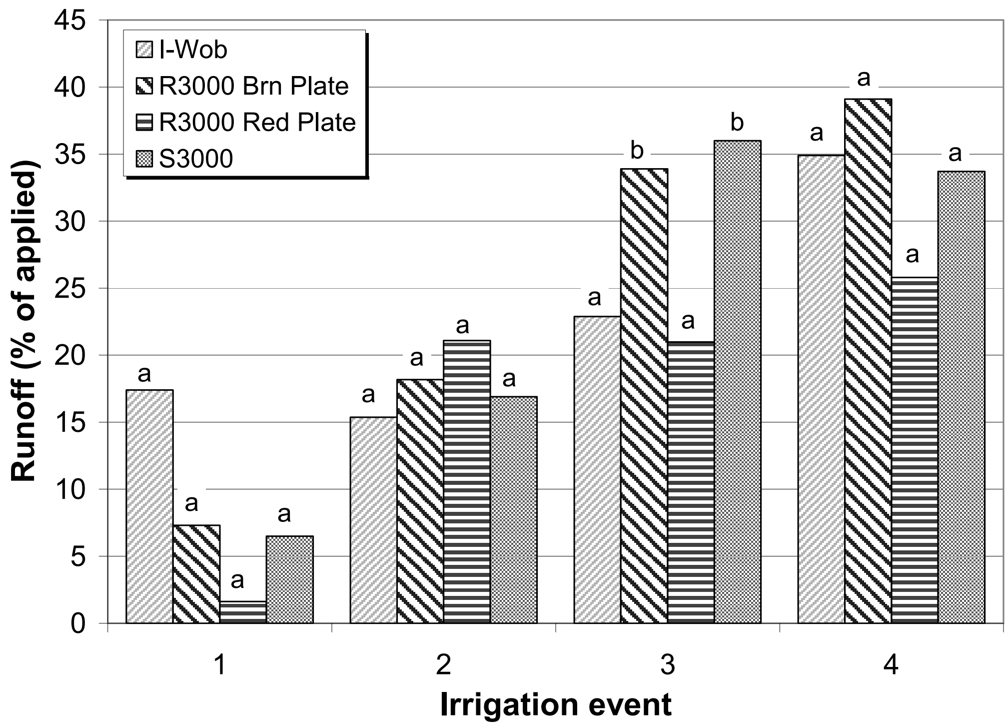


Figure 4. Runoff percentage measured for each of the four irrigation events on the Portneuf silt loam. Columns with the same letter for an irrigation event are not significantly different at the 0.05 level.

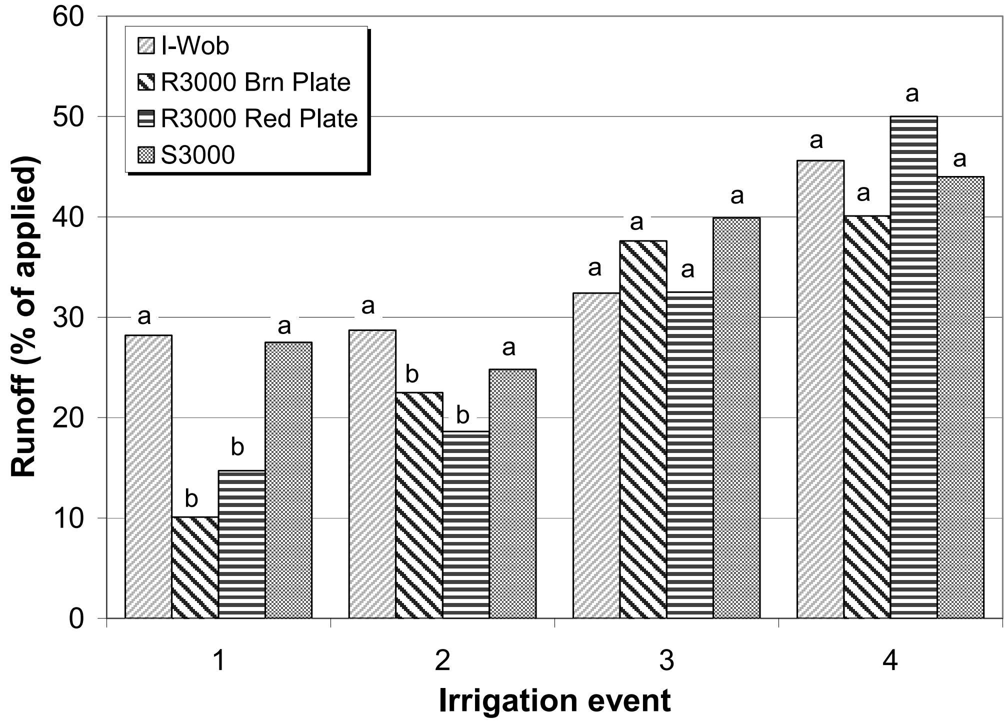


Figure 5. Runoff percentage measured for each of the four irrigation events on the Sluka silt loam. Columns with the same letter for an irrigation event are not significantly different at the 0.05 level.

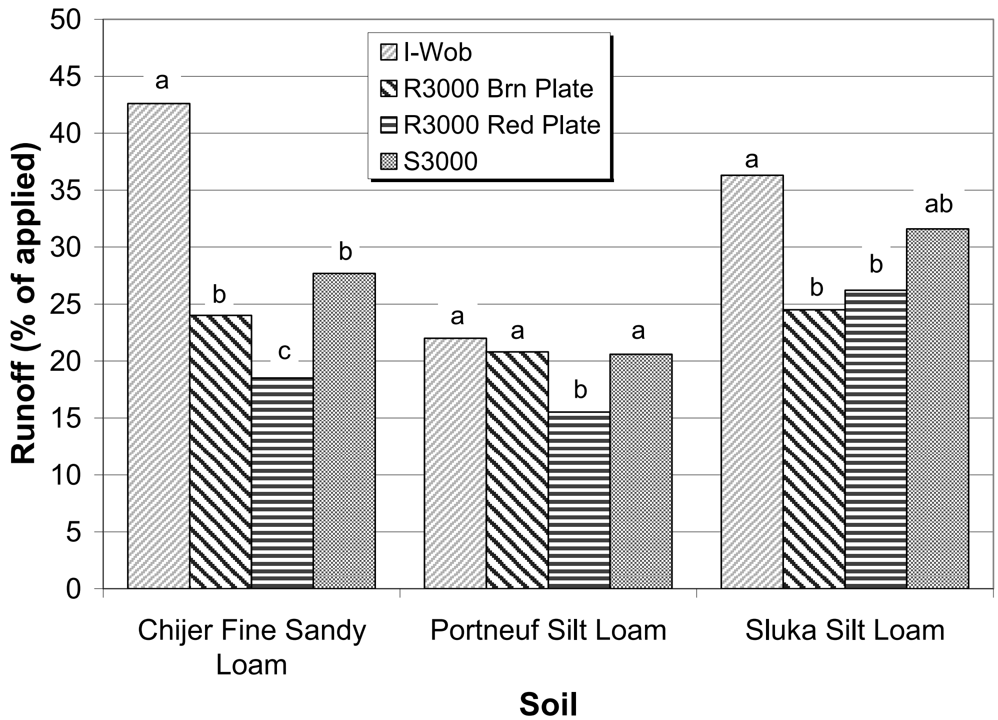


Figure 6. Runoff percentage summed over the four irrigation events for each soil tested. Columns with the same letter for each soil are not significantly different at the 0.05 level.

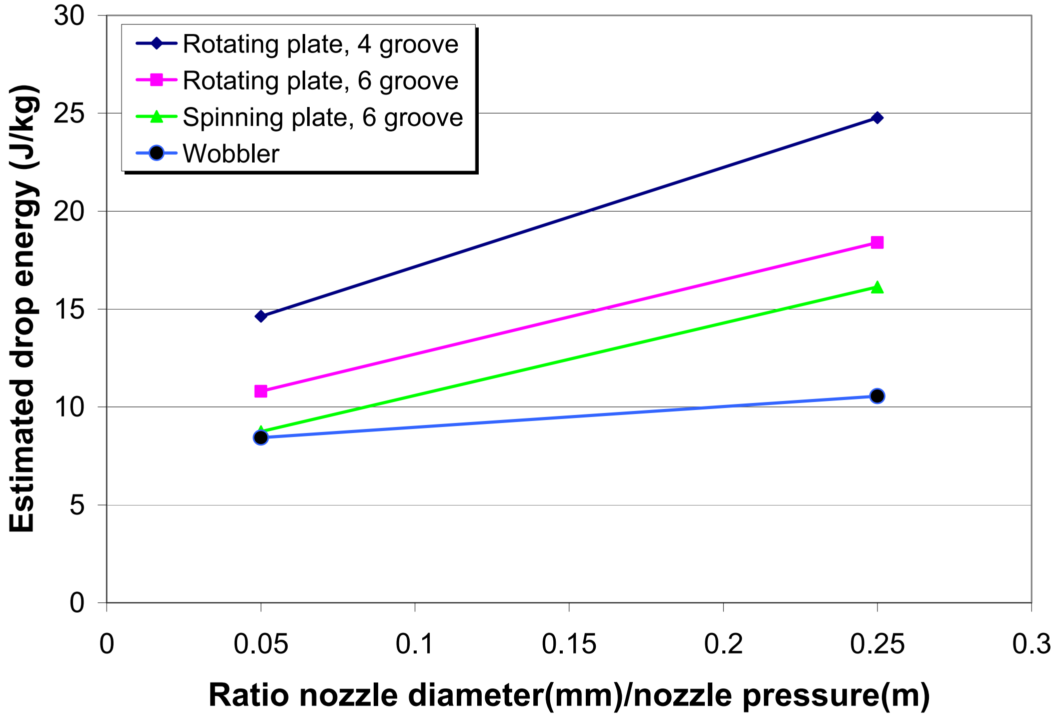


Figure 7. Approximate relative magnitude of droplet kinetic energy for sprinklers similar to those used in this study. Adapted from Kincaid (1996).

produced the highest runoff percentage and the R3000 with red plate sprinkler produced the lowest runoff percentage, for the soils tested. The magnitude of the differences in runoff percentage between sprinkler types is as great as or greater than the differences between the soils tested. In general, sprinkler types that visually appear to more uniformly distribute sprinkler droplets over the wetted area with respect to time produce the highest runoff percentage. Conventional theory on sprinkler droplet induced soil surface sealing and infiltration reduction is based on droplet kinetic energy as the driving factor. Estimated droplet kinetic energy for the sprinkler types used in this study is shown in figure 7 (Kincaid, 1996). Based on measured droplets sizes and modeled droplet velocity, the relative ranking of the sprinkler types in order of increasing kinetic energy is: 1) I-Wob, 2) S3000 spinner, and 3) R3000 red rotator. The results of this study, figure 5, are not directly related to droplet kinetic energy as determined by Kincaid (1996). Sprinkler types with the highest droplet kinetic energy have the lowest runoff (highest infiltration) and vise versa. Possible explanations for this outcome include incorrect representation of droplet kinetic energy, conventional soil surface sealing theory does not apply to the soils used in this study, or some unknown factor is dominating the infiltration and runoff process for the study conditions. Additional research is needed to examine the infiltration and runoff processes under the study conditions in more detail in order to explain the results.

Sediment loss per unit of applied water for each sprinkler type, irrigation event and soil type are shown in figures 8 through 10. Sediment loss is highly correlated with runoff volume because greater runoff provides a greater opportunity for sediment transport. In

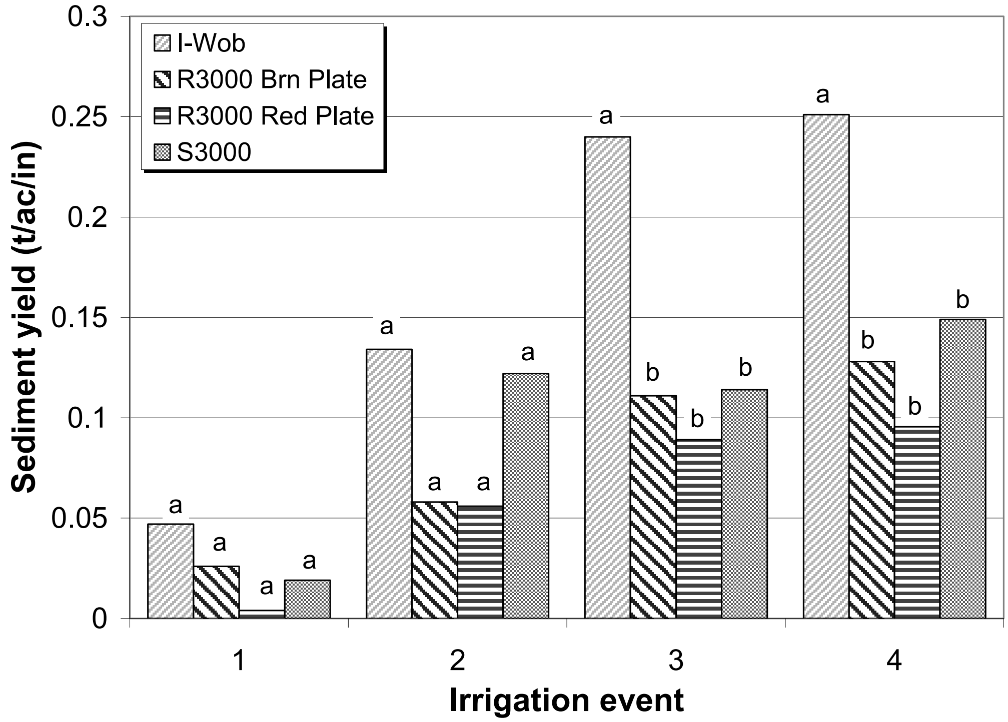


Figure 8. Sediment loss measured for each of the four irrigation events on the Chijer fine sandy loam. Columns with the same letter for an irrigation event are not significantly different at the 0.05 level.

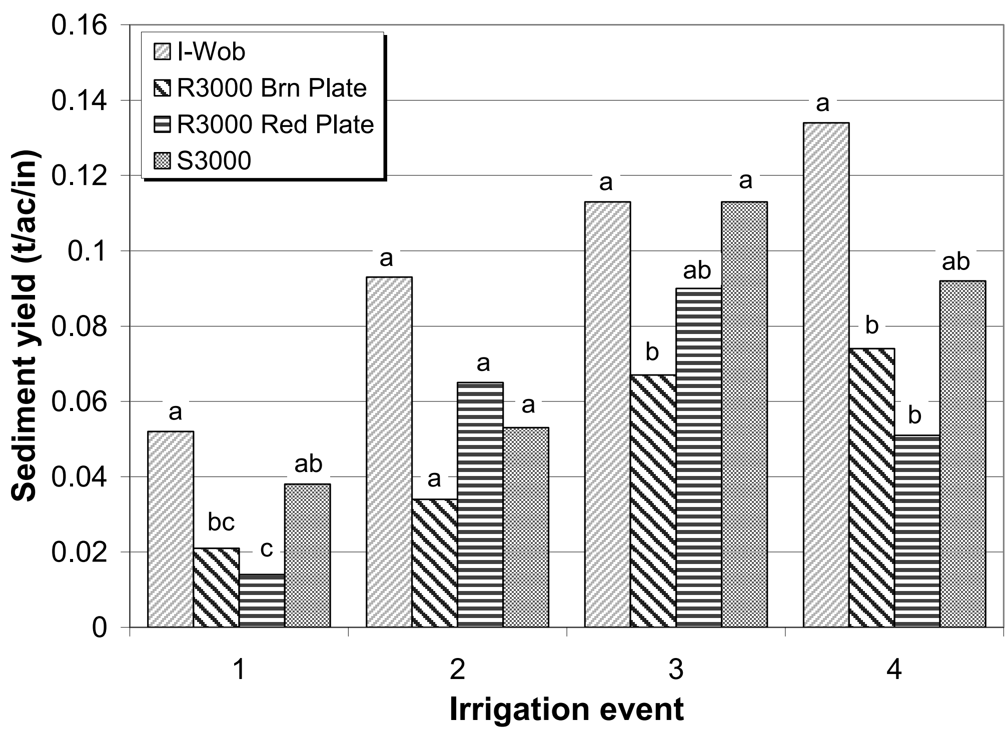


Figure 9. Sediment loss measured for each of the four irrigation events on the Portneuf silt loam. Columns with the same letter for an irrigation event are not significantly different at the 0.05 level.

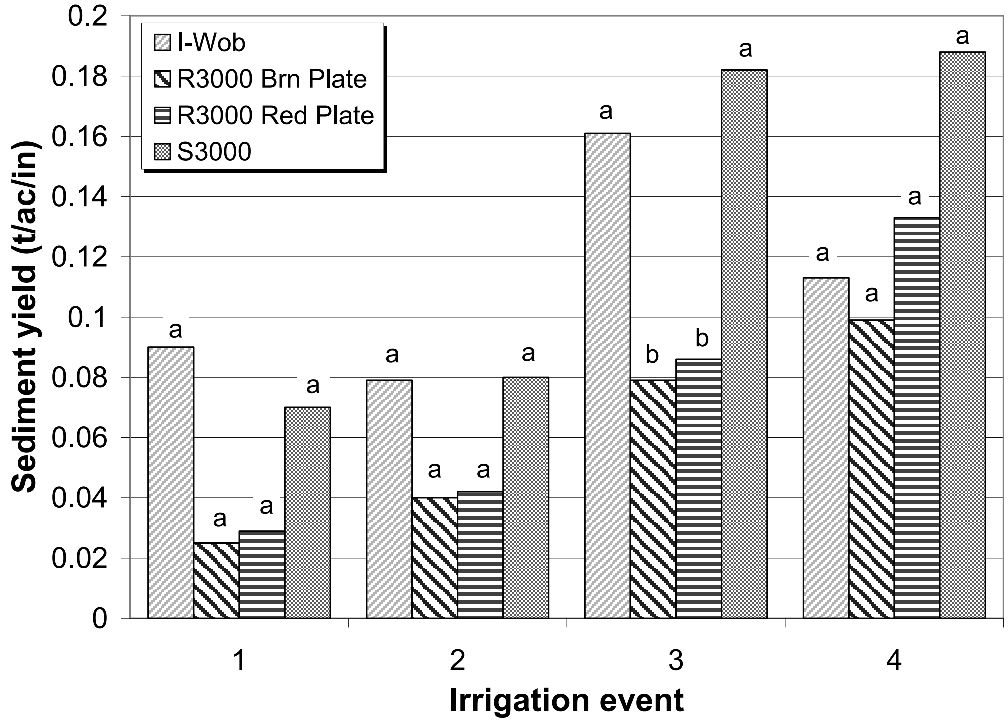


Figure 10. Sediment loss measured for each of the four irrigation events on the Sluka silt loam. Columns with the same letter for an irrigation event are not significantly different at the 0.05 level.

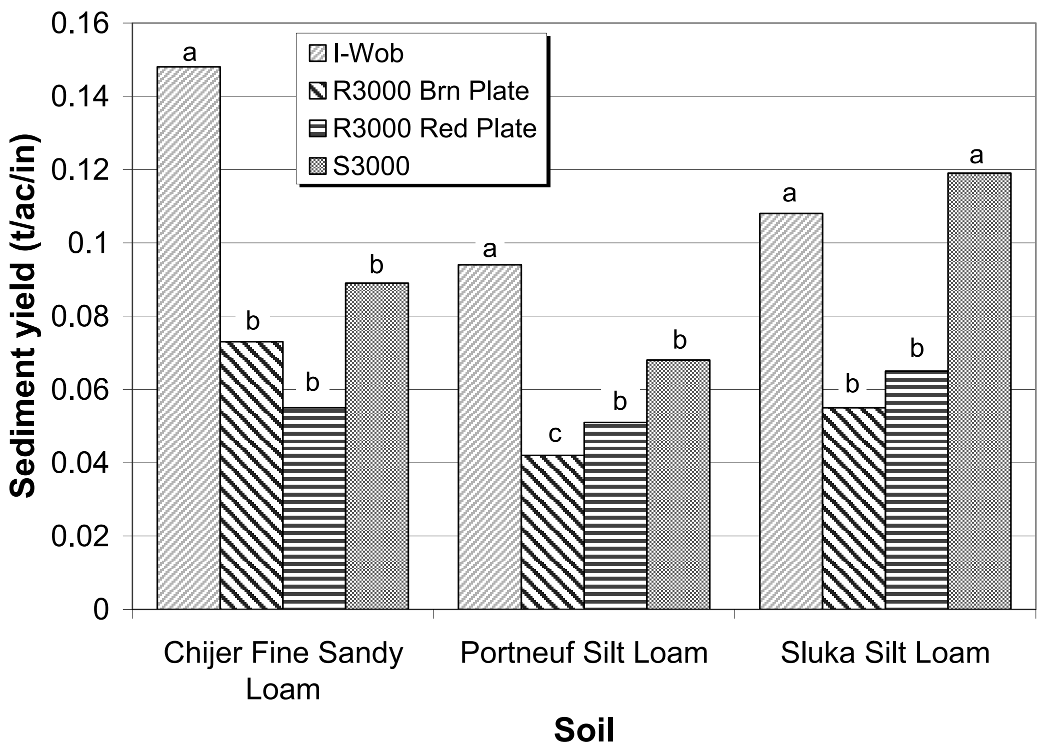


Figure 11. Sediment loss summed over the four irrigation events for each tested soil. Columns with the same letter for each soil are not significantly different at the 0.05 level.

general, sediment loss for individual irrigation events closely follows runoff. Cumulative sediment loss divided by cumulative water application for each soil type was calculated and statistically compared to reduce the effect of random variability. Cumulative sediment loss per unit of applied water is shown in figure 11. Significant differences in sediment loss between sprinkler types exist for each of the three soils tested. The relative ranking of sediment loss for each soil type closely follow the relative ranking for runoff. Overall, the I-Wob sprinkler produced the highest sediment loss and the R3000 with red plate sprinkler produced the lowest sediment loss. Sprinkler types that visually appear to more uniformly distribute sprinkler droplets over the wetted area with respect to time produce the highest sediment loss. This functional difference may cause sediment to remain in suspension in overland flow for a longer duration allowing it to be more readily transported down slope.

## Conclusions

Potential runoff and erosion from three Idaho soils were evaluated under emulated center pivot irrigation using four common commercial center pivot sprinkler types. There were significant differences in runoff and erosion rates between center pivot sprinkler types for the soils tested and experimental conditions. The magnitude of the differences is equal to or greater than the differences soils tested. Overall, the I-Wob exhibited the highest runoff and erosion rates and the R3000 sprinklers exhibited the lowest rates for the three soils tested. In general, sprinkler types that visually appear to more uniformly distribute sprinkler droplets over the wetted area with respect to time exhibited the highest runoff and erosion rates. The relative differences in runoff between the sprinklers tested were not directly proportional to droplet kinetic energy. This outcome is in conflict with conventional theory on soil surface sealing from droplet impact. Possible explanations include incorrect representation of droplet kinetic energy, conventional soil surface sealing theory does not apply to the soils used in this study, or some unknown factor is dominating the infiltration and runoff process for the study conditions. Additional research is needed to examine the infiltration and runoff processes under the study conditions in more detail in order to explain the results.

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