Evaluation of Potential Runoff and Erosion of Four Center Pivot Irrigation Sprinklers

B. A. King, D. L. Bjorneberg

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 for specific soil types. The objective of this study was to evaluate potential runoff and erosion from four commercial center pivot sprinklers on four widely distributed, south central Idaho soils. A modified commercial irrigation boom system was used to simulate 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 black plate. Significant differences in runoff and erosion between sprinkler types were observed but were not consistent across all runoff tests or soil types. However, on occasions sprinkler types that visually appear to more evenly distribute sprinkler droplets over the wetted area with respect to time produced the greatest soil erosion for bare soil conditions. This functional difference in spatial distribution of water application with respect to time may have caused sediment to remain in suspension in overland flow for a longer duration allowing sediment to be more readily transported down slope and removed from runoff plots. A 50% reduction in sprinkler flow rate reduced runoff and soil erosion 60% to 80% for the same volume of water applied in six irrigations. The practice of reducing sprinkler flow rate early in the growing season prior to crop canopy development could be an effective management tool for reducing center pivot sprinkler irrigation runoff and erosion.*

Keywords. *Sprinkler irrigation, Center pivot, Runoff, Erosion.*

Center pivot sprinkler irrigation systems are often the preferred type of sprinkler irrigation system by producers due to their relatively high water application uniformity and degree of automation which can substantially reduce labor costs compared to other types of sprinkler irrigation systems. Over 48% of the irrigated area in the United States is irrigated by center pivot and lateral move sprinkler irrigation systems (USDA, 2009). Despite the advantages of center pivot sprinkler irrigation systems, they are not necessarily the best irrigation system choice for all site conditions. Water application rates under the outer extent of center pivot sprinkler irrigation systems can exceed soil infiltration rates for medium- and fine-textured soils, which can result in runoff (Undersander et al., 1985; DeBoer et al., 1992; Hasheminia, 1994; Ben-Hur et al., 1995, Silva, 2006), erosion, and spatial non-uniformity in water application depth. Over the past two decades, center pivot sprinkler manufacturers have continued to develop sprinklers that reduce peak water application rates and droplet kinetic energy as a means to sustain water infiltration rates and reduce runoff and erosion potential. Consequently, there are numerous center pivot sprinkler choices available to the irrigation system designer and producer, but little quantitative information that relates sprinkler choice to performance on a particular soil type in regards to infiltration, runoff, and erosion.

The operational characteristics of center pivot sprinklers such as wetted diameter, application rate pattern shape, and drop size distribution have been studied (e.g. Kincaid et al., 1996; DeBoer, 2001; Faci et al., 2001; Sourell et al., 2003; Playan et al., 2004; Kincaid, 2005). Doplet kinetic energy from center pivot sprinklers has been reported by Kincaid (1996) and DeBoer (2002). However, studies evaluating the effect operating characteristics of a particular sprinkler have on infiltration, runoff, and erosion of specific soil types are limited (Undersander et al., 1985; DeBoer et al., 1992; Silva, 2006). With the wide range in operating characteristics of center pivot sprinklers currently available, the potential to select sprinklers that minimize runoff and erosion may exist. However, data or models relating sprinkler operating characteristics to runoff and erosion for specific soil types are limited. Models relating potential runoff to sprinkler peak application rate have been developed by Dillion et al. (1972), Slack (1978), Gilley (1984), DeBoer et al. (1988), Allen (1990), and Wilmes et al. (1993). von Bernuth and Gilley (1985) developed a model for center pivot sprinkler irrigation runoff which included infiltration rate reduction due to water drop impact on bare soil. Silva (2006) evaluated runoff and erosion for two fixed spray-plate center pivot sprinklers on a single soil type. Data sets needed to develop and validate center pivot sprinkler system runoff and erosion models are

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The authors are **Bradley A. King, ASABE Member Engineer,** Research Agricultural Engineer, and **David L. Bjorneberg, ASABE Member Engineer,** Supervisory Research Agricultural Engineer, USDA ARS NWISRL, Kimberly, Idaho. **Corresponding author:** Bradley A. King, USDA ARS NWISRL, 3793 N. 3600 E., Kimberly, ID 83341-5076; phone: 208-423-6501; fax: 208-423-6555; e-mail: brad.king@ars.usda.gov.

virtually nonexistent. The few that do exist are for out of production sprinkler products or one or two types of sprinklers on a single soil.

The objectives of this study were to measure runoff and erosion from four common center pivot sprinklers on four south central Idaho soils under simulated center pivot sprinkler irrigation and compare measured runoff and erosion between sprinklers to assess the potential for selecting sprinklers based on runoff and erosion potential.

Methods and Materials

Sprinklers used in this study were selected to be representative of those commonly used on center pivot sprinkler irrigation systems in Idaho. Sprinklers used in this study were:

- Senninger I-Wob with standard 9-groove black plate (Senninger Irrigation Inc., Clermont, Fla.) and a Senninger 103-kPa (15-psi) pressure regulator.
- Nelson R3000 with a brown plate (Nelson Irrigation Corp., Walla Walla, Wash.) and a Nelson 138 kPa (20 psi) pressure regulator.
- Nelson R3000 with red plate and a Nelson 138-kPa (20-psi) pressure regulator.
- Nelson S3000 with purple plate and a Nelson 103-kPa (15-psi) pressure regulator.
- Nelson D3000 with flat plate and a Nelson 103-kPa (15-psi) pressure regulator.

The I-Wob sprinkler utilized an oscillating plate with nine grooves of equal geometry to breakup the nozzle jet and create discrete water drops. The R3000 sprinklers used rotating plates with grooves to break up the nozzle jet and create discrete streams of water leaving the plate edge. The R3000 sprinkler with the brown plate had ten grooves with multiple trajectories angles and widths. The R3000 sprinkler with the red plate had six grooves of equal trajectory angle (12°) and width. Both R3000 sprinklers had plate rotational speeds of 2 to 4 rpm. The S3000 sprinkler also used a rotating plate with grooves to breakup the nozzle jet. The rotating plate had six grooves of equal trajectory angle (20°) and width and a rotational speed of 400 to 500 rpm. The D3000 sprinkler had a fixed flat plate to break up the nozzle jet into discrete water drops. Sprinkler operating pressures were selected to be representative of field installations on center pivot sprinkler irrigation systems in southern Idaho. Sprinkler nozzle sizes, operating pressures, and manufacturer design flow rates of the sprinklers are summarized in table 1. Sprinkler nozzle sizes and operating pressures were selected to provide equivalent flow rate comparisons based on manufacturer data.

Runoff and erosion evaluations for the selected sprinklers were conducted on four soil types over a 3-year period, 2007-2009. Soil texture analysis was determined for each soil using the hydrometer method (table 2). The soils were selected to cover the range in sand and clay fractions available locally

The effect of center pivot sprinkler type on runoff and erosion was measured using 1-m wide × 2-m long plot areas. A metal frame border was used to collect runoff and prevent plot run on from the surrounding area. The metal frame was made of 4.7-mm thick steel, 7.6 cm in width, orientated vertically on three sides. The bottom edge of the metal frame was driven into the ground to a depth of about 4 cm to channel the runoff into a collector and prevent run on from surrounding soil. The down slope outlet end of the metal frame had a horizontal metal lip along its length about 6 cm in width for runoff to leave the plot area within 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 metal frame. 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 8 cm. Water application to the lip and trough adds to the total runoff volume and was accounted for by subtracting the volume of water applied to the trough and lip area when determining plot runoff volume.

The metal frames were installed at a constant slope of 5% for all runoff and erosion tests. The soil surface within the metal frames was graded to a 5% slope and smoothed. There was no remaining soil surface residue on the plots. 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 near worse case conditions. Actual field runoff and erosion rates would likely be less due to greater soil surface storage, sustained higher infiltration rates due to crop residue management and less slope. The runoff and erosion rates obtained in this study represent potential runoff and erosion rather than actual field rates, but provide a means to compare runoff and erosion

Table 1. Operational characteristics of sprinklers used in runoff and erosion tests.

Sprinkler	Pressure Regulator (kPa)	Nozzle Size (mm)	Flow Rate[a] (L min^{-1})	Wetted Radius (m)	Peak Application Rate[b] (mm h^{-1})
Senninger I-Wob black plate	103	8.33	43.0	9.0	126
	103	7.93	39.5	9.0	118
	103	5.56	19.9	8.5	73
Nelson D3000 flat plate	103	8.14	43.4	4.0	207
Nelson R3000 brown plate	138	7.54	42.7	9.0	110
	138	5.36	21.2	9.0	61
Nelson R3000 red plate	138	7.54	42.7	9.0	106
	138	5.36	21.2	9.0	57
Nelson S3000 purple plate	103	8.14	43.4	7.5	122
	103	5.75	21.4	7.5	62

[a] Based on manufacturer's data.
[b] Peak application rate is for 2.5-m sprinkler spacing.

Table 2. Particle size fractions for the soils used in the study.

	Particle Size Fraction (%)		
Soil Name	Sand	Silt	Clay
Chijer fine sandy loam	39	45	16
Portneuf silt loam	14	65	21
Sluka silt loam	27	63	10
Feltham sand	93	3	4

characteristics of the sprinkler types under controlled conditions. All tests were conducted at the Northwest Irrigation and Soils Research Laboratory in Kimberly, Idaho.

In 2007, runoff and erosion tests were conducted on *in situ* Portneuf silt loam soil with a 4% to 6% slope. The metal frames were installed to provide a constant 5% slope for all runoff plots. In 2008 and 2009, the frames were installed on elevated soil boxes 1.2 m wide × 2.6 m long with different end heights to provide a nominal slope of 5% (fig. 1). Use of elevated soil boxes allowed runoff and erosion of differing soils to be easily evaluated under controlled conditions. Each elevated soil box was filled with Portneuf silt loam to a depth 15 cm below the top. The soil to be evaluated for runoff and erosion was then used to fill the remaining volume in the elevated soil box without compaction or mechanical manipulation of the soil other than to smooth it to a 5% slope. This provided a soil depth of 15 cm for runoff and erosion evaluation. The soils used in the 2008 and 2009 runoff and erosion tests were obtained from local commercial fields. A large articulated hydraulic loader was used to collect soil from the top 15 cm of the field and loaded it on a truck. The collected soil was transported to Kimberly, Idaho and stock piled on site until used. The Portneuf soil was collected each year from different sites, the Sluka and Chijer soils were collected in 2008, and the Feltham soil was collected in 2009.

Center pivot irrigation system water application was simulated using a 4-wheel commercial irrigation boom sprinkler system 50 m in length (Briggs Irrigation, Northhamptonshire, UK). The irrigation boom sprinkler system was modified by increasing the boom height 46 cm and adding additional sprinkler outlets along the boom length to provide a sprinkler height of approximately 1.2 m above ground level and a fixed sprinkler spacing of 2.43 to 2.59 m which varied randomly along the boom. A hydraulic driven cable winch system mounted on the front of a John Deere 1020 tractor was used to mobilize the irrigation boom. Water was supplied to the irrigation boom by a 76-mm diameter, 91-m long drag hose. Travel speed of the boom was computer controlled at a specified constant rate. A 2.5-m sprinkler spacing in combination with a sprinkler flow rate of 43 L min^{-1} (table 1) on the irrigation boom simulates the application rate 390 m from the pivot point on a 396-m center pivot irrigation system with a design capacity of 72 L min^{-1}

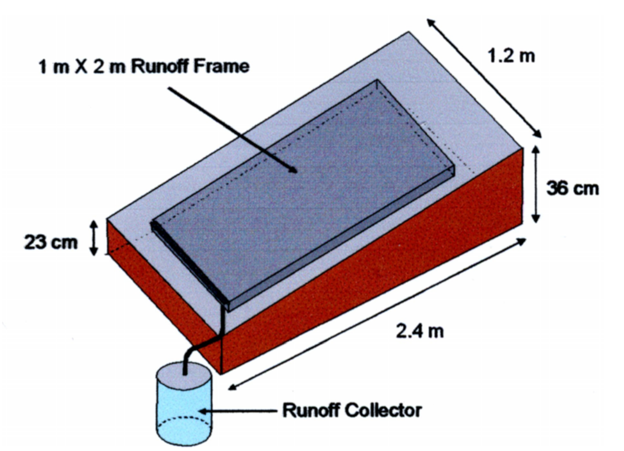

Figure 1. Diagram showing layout, dimensions, and features of elevated soil box with metal frame used for runoff plots in 2008 and 2009 runoff tests.

ha^{-1}, which is representative of design capacities found on center pivot irrigation systems in Idaho. A 2.5-m sprinkler spacing in combination with a sprinkler flow rate of 21 L min^{-1} (table 1) on the irrigation boom simulates the application rate 190 m from the pivot point on a 396-m center pivot irrigation system with a design capacity of 72 L min^{-1} ha^{-1} or 390 m from the pivot point on a 396-m center pivot irrigation system with a design capacity of 34.3 L min^{-1} ha^{-1}. Additional details on the irrigation boom sprinkler system used to simulate center pivot irrigation are provided by King and Bjorneberg (2007).

Runoff and erosion was evaluated using a series of four or six irrigation events. With the four irrigation event series, nominal water application depths were 25, 20, 15, and 15 mm totaling 75 mm. Corresponding travel speeds for the irrigation boom sprinkler system with the nominal sprinkler flow rate of 43 L min^{-1} were 0.66, 0.82, 1.1, and 1.1 m min^{-1}, respectively. The irrigation depths were chosen to ensure runoff occurred for each irrigation event to provide a performance measure for each sprinkler and irrigation event. The irrigation depths were also chosen to be representative of center pivot management practices in Idaho. Irrigators know that they can get the greatest amount of water in the soil on the first irrigation event following tillage with center pivot irrigation systems. Irrigators reduce subsequent irrigation depths to limit runoff problems. The four irrigation event series was selected to represent the irrigation events that would typically occur for crop germination and establishment in an arid environment prior to crop canopy development sufficient to protect the soil surface from droplet impact and its effect on soil surface seal formation. The four irrigation event series also allows comparison of cumulative runoff and erosion between sprinklers over multiple irrigation events.

Runoff and erosion was also evaluated using a series of six irrigation events with equal nominal application depths of 12.5 mm totaling 75 mm. The six irrigation events were conducted on the Portneuf silt loam soil only using two nominal sprinkler flow rates, 43 and 21 L min^{-1}. Corresponding travel speeds for the irrigation boom sprinkler system were 1.31 and 0.64 m min^{-1}, respectively. The six irrigation series was used to investigate the effect of irrigation depth and application rate on runoff and erosion. At least one center pivot sprinkler manufacturer makes a nozzle clip that attaches to the center pivot sprinkler to hold a second nozzle of smaller size so application rate can be reduced at the beginning of the irrigation season for germination and early crop development. The purpose of the second nozzle is to reduce runoff by reducing the effect of droplet impact on formation of soil surface seal.

All runoff and erosion tests used 16 runoff frames installed in a four row by four column arrangement to provide a Latin Square statistical design (fig. 2). The four sprinkler types (treatments) were randomly assigned to the sixteen plots with one treatment per row and column. Twelve of the 16 plots were covered with waterproof polyethylene tarps when the irrigation boom sprinkler system passed over the plot area with a particular sprinkler treatment (fig. 3). Then the irrigation boom sprinklers were changed, the tarps repositioned and the irrigation boom sprinkler system repositioned and towed upslope over the plot area again to apply a different sprinkler treatment. An irrigation event for all 16 runoff plots was completed over a 1- or 2-day period.

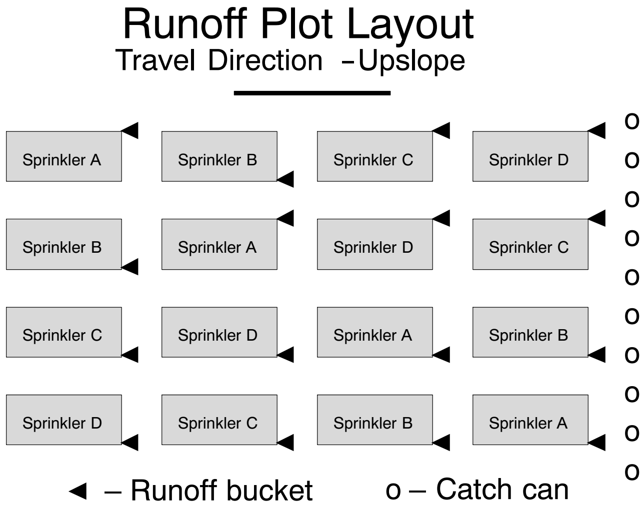

Figure 2. Diagram showing experimental design, runoff plot layout, and instrument measurement locations.

Figure 3. Experimental setup for sprinkler runoff and erosion tests in 2008 and 2009.

All the tarps were installed and removed at the same time to minimize differences in soil drying between sprinkler treatments and irrigation events. The soil profile in the runoff plots was allowed to dry by evaporation for a period of 5 to 10 days between subsequent irrigation events.

A line of 10 catch cans, with 70-cm spacing between adjacent cans, aligned parallel to the irrigation boom near the start of the runoff plots was used to measure water volume applied (fig. 2). The catch cans, measuring 15.2 cm in diameter and 20.3 cm in height, were placed on the ground and leveled. Average soil moisture in the top 20 cm of the soil profile in each runoff plot was measured using time domain reflectometry (TDR100, Campbell Scientific, Inc., Logan, Utah) prior to each irrigation event. Sediment mass in collected runoff was measured using vacuum filtration and filter paper.

In 2007, runoff and erosion from the I-Wob, D3000, and R3000 brown plate sprinklers were evaluated using a four irrigation series on *in situ* Portneuf silt loam soil only. To investigate the effect that soil surface sealing plays in runoff and erosion, two layers of fiberglass screen material laid on a wire frame with 8-cm square openings to suspend the screen material directly above the soil surface was used as a sprinkler treatment to eliminate sprinkler droplet impact on the bare soil surface. The wire frame was supported 2 cm above the soil surface by the runoff plot metal frame. The D3000 sprinkler was used to apply water with the fiberglass screen material treatment. The screen material was only used in 2007 for the one runoff and erosion test. Sprinkler height was approximately 1.2 m in 2007.

In 2008, runoff and erosion of the I-Wob, S3000, and R3000 brown and red plate sprinklers were evaluated using three soil types; Portneuf silt loam, Chijer fine sandy loam, and Sluka silt loam. A series of four irrigation events was used on each soil and each soil was evaluated separately. Sprinkler flow rates were nominally 43 L min^{-1} (table 1). Irrigation boom travel speed was set equal for all sprinklers for a given nominal application depth (irrigation event). Manufacturer design flow rates (table 1) varied by less than 2% between sprinklers at the selected pressures (table 1). Sprinkler boom speed control accuracy was approximately 3%. Thus, sprinkler boom travel speed was not adjusted according to flow rate differences between sprinklers. In 2008, runoff and erosion of the same sprinklers were also evaluated using a series of six irrigation events on the Portneuf silt loam soil only. Sprinkler height was approximately 0.9 m above the surface of the runoff plot boxes in 2008.

In 2009, runoff and erosion comparisons of the I-Wob, S3000, and R3000 brown and red plate sprinklers were repeated (from 2008) using the same three soil types; Portneuf silt loam, Chijer fine sandy loam, and Sluka silt loam. A runoff and erosion test on Feltham sand was also conducted in 2009. In 2009 the I-Wob sprinkler flow rate was 39.5 L min^{-1} rather than 43.0 L min^{-1} (table 1) in order to obtain more equivalent application depths among sprinklers. In 2009, runoff and erosion of the same sprinklers were also evaluated using a series of six irrigation events on the Portneuf silt loam soil only with a nominal sprinkler flow rate of 21 L min^{-1}. Sprinkler height was approximately 0.9 m above the surface of the runoff plot boxes in 2009.

Radial application rate distributions for the sprinklers used in the field tests were determined by indoor testing. The indoor tests used one of each sprinkler type and associated pressure regulator mounted at a height of 1 m. Catch cans 150 mm in diameter and 180 mm tall spaced at 0.5-m increments from the sprinkler in one radial direction were used to collect water. The duration of each test was 30 to 60 min. Water collected in each can was measured using a graduated cylinder. Application rate was calculated based on the diameter of the catch cans and duration of the each test. Sprinkler wetted radius (table 1) was defined as the distance from the sprinkler to the first catch can with zero measureable water application. The measured radial application rate distributions were used to simulate no wind application rate profiles occurring in the field when sprinkler patterns overlap and sprinklers were spaced 2.5 m along a lateral. Peak application rate was defined as the maximum application rate simulated by overlapped radial application rate patterns (table 1).

The linear statistical model for the Latin Square experimental design was solved using SAS GLM procedure (SAS, 2007). Tukey's Studentized range test was used for sprinkler treatment mean comparisons of soil moisture prior to irrigation, runoff percentage and sediment yield (SAS, 2007).

Results and Discussion

Mean soil water content of the runoff plots prior to an irrigation event were statistically compared between sprinkler treatments for all runoff tests (data not shown). There were few significant differences between the sprinkler treatments of a runoff test and no consistent trend in water content of an irrigation series for any sprinkler treatment. The differences in soil water contents were less than 0.03 mm mm^{-1} and likely had little influence on measured runoff differences between sprinklers because the soil surface layer was equally dried by evaporation between irrigation events and infiltration was largely controlled by formation of a soil surface seal due to droplet impact on bare soil.

Mean water application depths measured for runoff tests conducted in 2007 and 2008 are shown in figures 4 through 8. Irrigation boom travel speed was the same for each sprinkler treatment in an irrigation event. Measured water application depth was influenced by wind speed which varied between runoff tests but was less than 5 m/s for all runoff tests. Wind drift and evaporation loss (WDEL) measured using catch cans have been shown to range from 1.5% to 40% depending upon environmental conditions, most notably wind speed (Yazar, 1985; Faci et al., 2001; Dechmi et al., 2003; Playan et al., 2004, 2005; Ortiz et al., 2009). In general, mean cumulative measured water application depths over four irrigation events for the Senninger I-Wob were as much as 12% greater than for the Nelson D3000 sprinkler, and 9% greater than other Nelson sprinklers. Based on manufacturer published sprinkler nozzle flow rates the magnitude of the differences in cumulative water application was expected to be much less. Flow rates of the sprinkler nozzles used in the runoff tests were measured at the end of 2008. The I-Wob sprinkler flow rates were found to be approximately 8% higher than manufacturer's data. For this reason, nozzle size of the I-Wob sprinkler was reduced one size increment for subsequent tests in 2009 to provide more equivalent flows between sprinklers. The higher flow rate of the I-Wob sprinkler may have affected runoff and erosion results in 2007 and 2008 relative to the other sprinklers. Water application depths measured in subsequent 2009 tests are shown in figures 5 through 8. Variability in mean measured cumulative water application depths between sprinkler treatments for an irrigation event was as high as 11% despite nozzle flow rates having less than 2% difference in flow. This variability in measured water application depth was attributed to the effect of variable wind speed and direction on sprinkler application pattern and WDEL differences between sprinkler treatment tests.

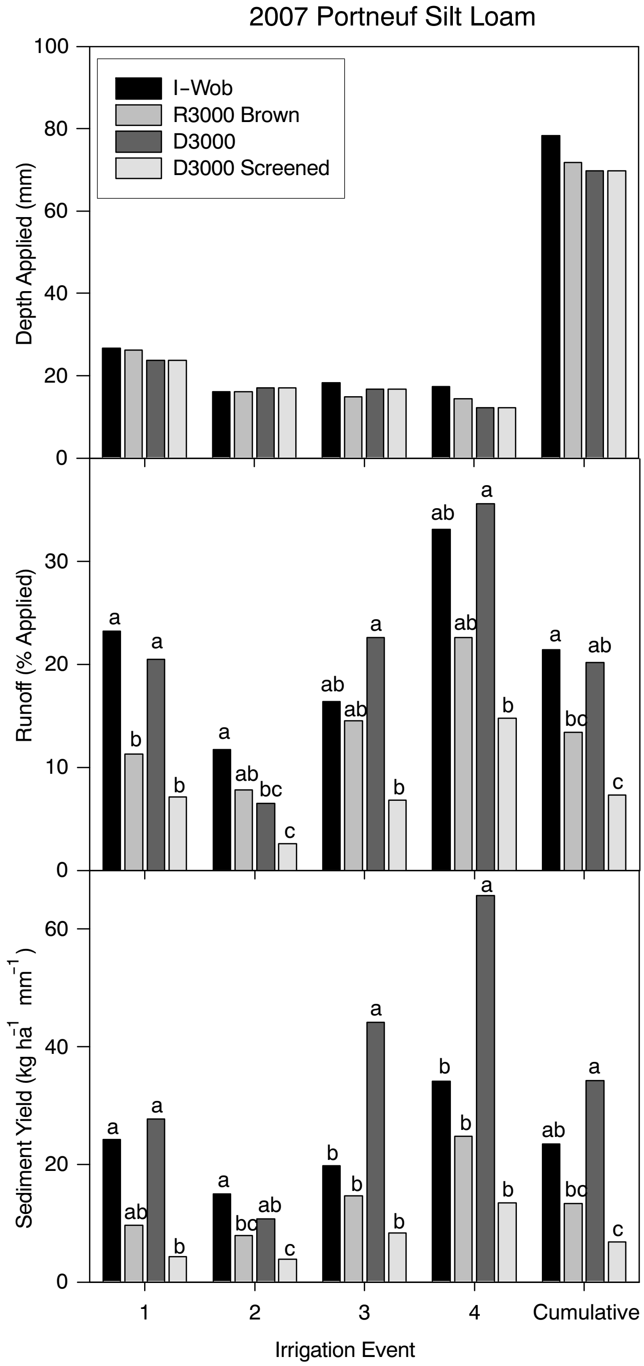

Figure 4. Water application, runoff percentage, and sediment yield for 2007 runoff tests on Portneuf silt loam soil. For each irrigation event, sprinkler treatments with the same letter are not significantly different at the 0.05 probability level.

Portneuf Silt Loam

Runoff

Measured runoff expressed as a percentage of measured water application for each sprinkler treatment and irrigation event in 2007 is shown in figure 4. The percent runoff was minimized when the soil surface was protected from sprinkler droplet impact by the screen covering. Runoff from the screen covered treatment was consistently the lowest for all irrigation events. This result is attributed to reduced infiltration rate caused by formation of a soil surface seal due to sprinkler droplet impact on the bare soil and consistent with the findings of Thompson and James (1985), DeBoer et al. (1988), Agassi et al. (1994), and Lehrsch and Kincaid (2010) which found a significant reduction in infiltration rate due to sprinkler droplet impact. 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 treatments. For example, irrigation event 2 where runoff percentage of the D3000 sprinkler was not significantly different from the screen covered treatment versus irrigation events 1, 3, and 4 where runoff percentage was significantly greater. Sources of random variability include soil placement and compaction in the runoff plot

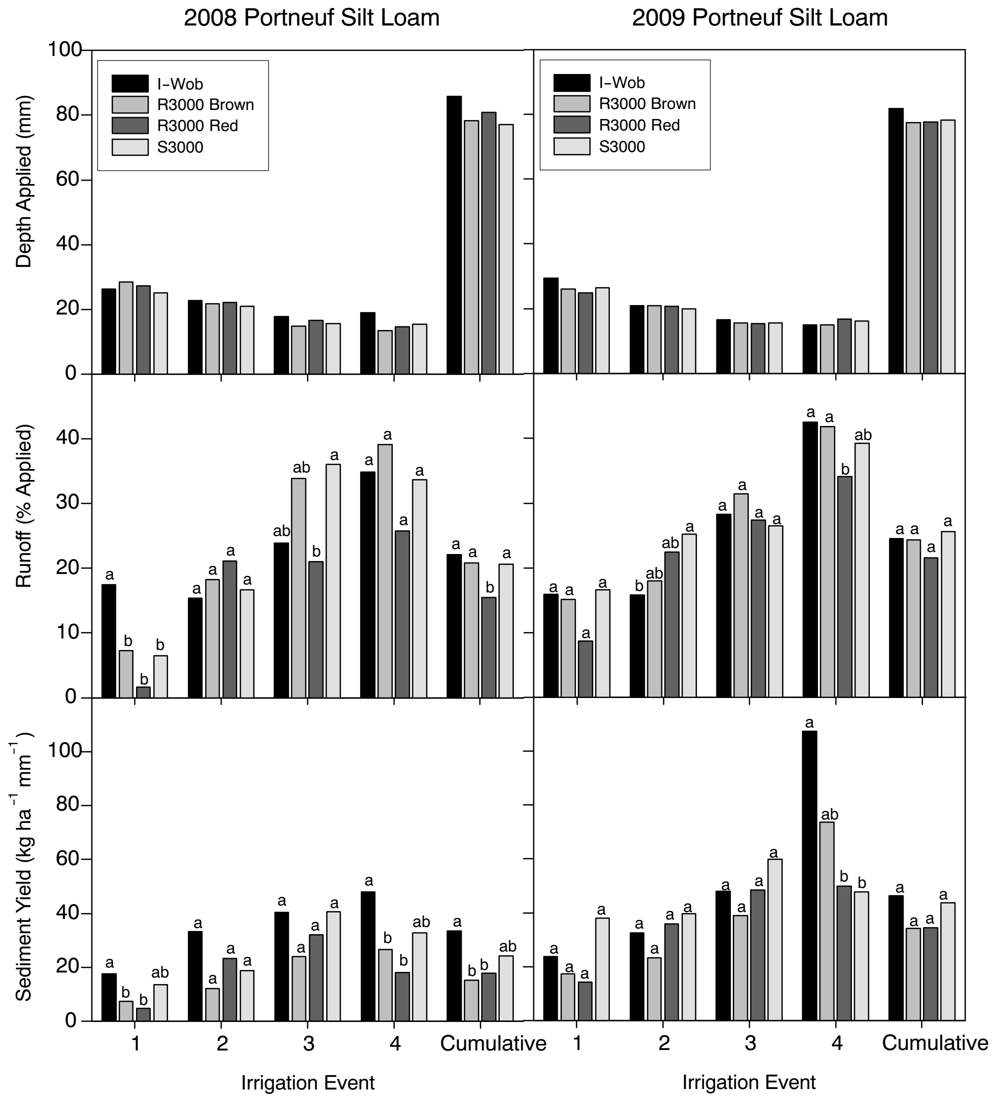

Figure 5. Water application, runoff percentage, and sediment yield for 2008 and 2009 runoff tests on Portneuf silt loam soil. For each irrigation event, sprinkler treatments with the same letter are not significantly different at the 0.05 probability level.

boxes, soil surface smoothness and structure, location of box within sprinkler overlap pattern and wind speed and direction variability between and within sprinkler treatments. To minimize the effect these random factors have on detection of significant differences between sprinkler treatments, 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. Mean cumulative runoff percentage was significantly greater for the I-wob and D3000 sprinkler treatments than the screen covered treatment. The R3000 brown plate sprinkler treatment was not significantly different from the screen covered treatment.

In 2008, runoff percentage increased with each subsequent irrigation event (fig. 5). This result is attributed to continual reduction of infiltration rate caused by continual development of a soil surface seal with each irrigation event due to sprinkler droplet impact on the bare soil surface. There was no consistent sprinkler treatment trend across all irrigation events and there were no significant treatment differences for irrigation events 2 and 4, despite substantial differences in treatment means. Mean cumulative runoff percentage was significantly less for the R3000 red plate sprinkler treatment compared to the other treatments.

An increase in runoff percentage with subsequent irrigation events in 2009 (fig. 5) is consistent with the 2008 results as is the lack of a consistent sprinkler treatment trend across irrigation events. There were significant sprinkler treatment differences in irrigation events 2 and 4 but they were not consistent and averaged out over the 4 irrigation events resulting in no significant difference in mean cumulative runoff percentage between sprinkler treatments.

Runoff percentage for the six irrigation event tests in 2008 increased through the first four irrigation events and then began to decrease through irrigation events 5 and 6 (fig. 6). There was no runoff on the first irrigation event with the 12.5-mm application depth. There were significant sprinkler treatment differences in three of the six irrigation events, with I-Wob and S3000 sprinklers often having the highest runoff percentage. There were significant differences in mean cumulative runoff percentage with the I-Wob and S3000 sprinkler treatments producing the highest runoff.

Runoff percentage for the six irrigation event test in 2009 with reduced water application rate (sprinkler flow rate) is

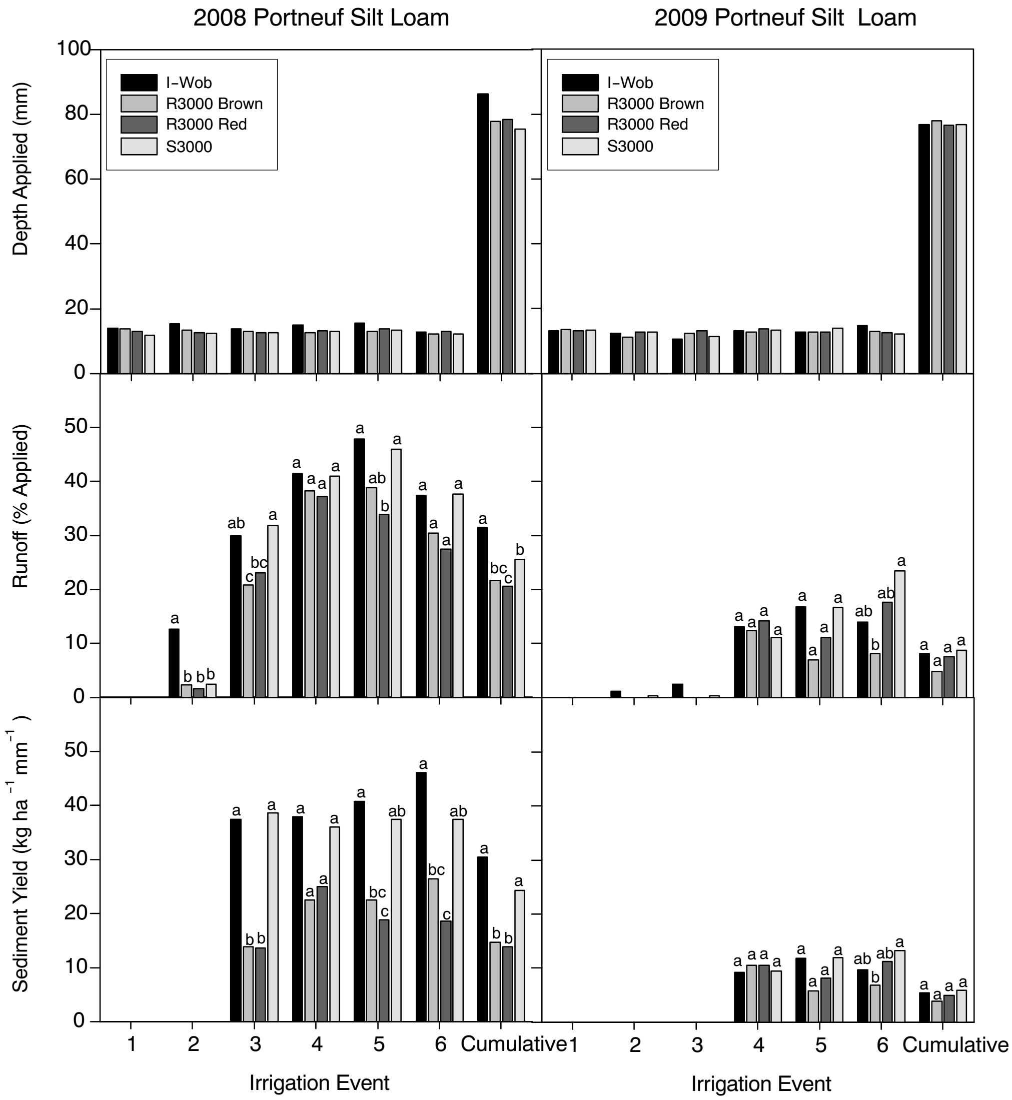

Figure 6. Water application, runoff percentage, and sediment yield for six 12.5-mm irrigation events in 2008 and six 12.5-mm irrigation events with reduced application rate in 2009 on Portneuf silt loam soil. For each irrigation event, sprinkler treatments with the same letter are not significantly different at the 0.05 probability level.

shown in figure 6. There was essentially no runoff generated until the fourth irrigation event. There was a significant difference among sprinkler treatments for the sixth irrigation event only. There were no significant differences in mean cumulative runoff percentage among the sprinkler treatments. Comparison of runoff percentage between 2008 and 2009 for the six irrigation event tests demonstrates the importance water application rate has in runoff generation under center pivot irrigation. However, formation of a soil surface seal was still evident as runoff percentage increased over time.

Erosion

Measured soil erosion expressed as sediment loss per unit area and per unit of measured applied water (sediment yield) for the four irrigation event test in 2007 is shown in figure 4. In general, sediment yield for sprinkler treatments and irrigation events closely followed runoff. Sediment yield is highly correlated with runoff volume because greater runoff provides a greater opportunity for sediment transport. There were significant treatment differences for each irrigation event. The screen covered treatment consistently had the least sediment loss. Protecting the soil surface from the destructive effects of sprinkler droplet impact was effective in minimizing soil erosion. The D3000 sprinkler produced the highest erosion in all but the second irrigation event and mean cumulative sediment yield (cumulative sediment loss per unit area divided by cumulative measured water applied) was the highest even through the I-Wob sprinkler had more total water application and equivalent runoff percentage.

In 2008 there were significant sprinkler treatment differences for only the first and fourth irrigation event (fig. 5). The R3000 brown sprinkler consistently produced the least amount of sediment yield despite not having the least runoff. Mean cumulative sediment yield for the R3000 brown plate sprinkler was the least and greatest for the I-Wob sprinkler. In 2009 there was only a significant sprinkler treatment difference in the fourth irrigation event with I-Wob producing the greatest sediment yield without having the greatest water application depth or runoff percentage (fig. 5). There were no significant differences in mean cumulative sediment yield in 2009.

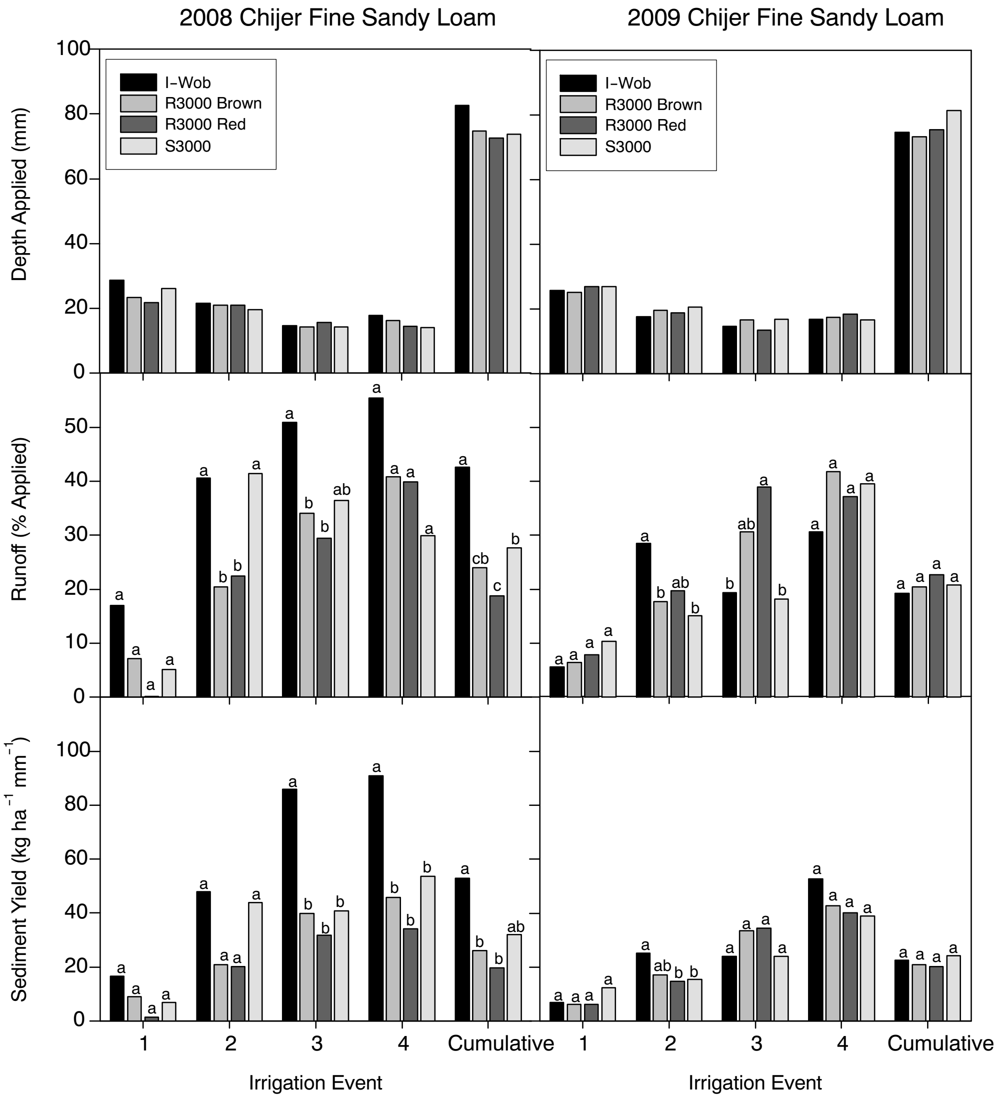

Figure 7. Water application, runoff percentage, and sediment yield for 2008 and 2009 runoff tests on Chijer fine sandy loam soil. For each irrigation event, sprinkler treatments with the same letter are not significantly different at the 0.05 probability level.

In the six irrigation event series in 2008 (fig. 6), there were significant sprinkler treatment differences for three of the four irrigation events that produced runoff. The R3000 sprinklers consistently produced the least amount of sediment and the I-Wob sprinkler consistently produced the greatest amount of sediment. Mean cumulative sediment yield was the least for the R3000 sprinklers and the greatest for the I-Wob and S3000 sprinklers, consistent with differences in runoff.

Sediment yield for the six irrigation event test in 2009 with reduced water application rate is shown in figure 6. There were significant sprinkler treatment differences in only the last irrigation event consistent with treatment differences in runoff. There were no significant differences in mean cumulative sediment yield among the sprinkler treatments.

Chijer Fine Sandy Loam

Runoff

In 2008 there were significant sprinkler treatment differences in runoff percentage for only the second and third irrigation event (fig. 7). The I-Wob sprinkler treatment consistently produced the greatest runoff percentage. Mean cumulative runoff percentage was least for the R3000 sprinklers and greatest for the I-Wob sprinkler. In 2009 there were significant sprinkler treatment differences in runoff percentage for the second and third irrigation event, but no consistent treatment trend (fig. 7). Runoff percentage differences between sprinkler treatments tended to cancel out such that there was no significant difference in sprinkler treatments for cumulative runoff percentage in 2009.

Erosion

In 2008 there were significant differences in sediment yield in only the third and fourth irrigation event (fig. 7). Mean cumulative sediment yield was greater for the I-Wob sprinkler treatment than the R3000 sprinkler treatments. In 2009 there was a significant difference among sprinkler treatments for sediment yield in only the second irrigation event with the I-Wob producing the greatest erosion. Sprinkler treatment differences tended to cancel out as there were no significant treatment differences in mean cumulative sediment yield in 2009.

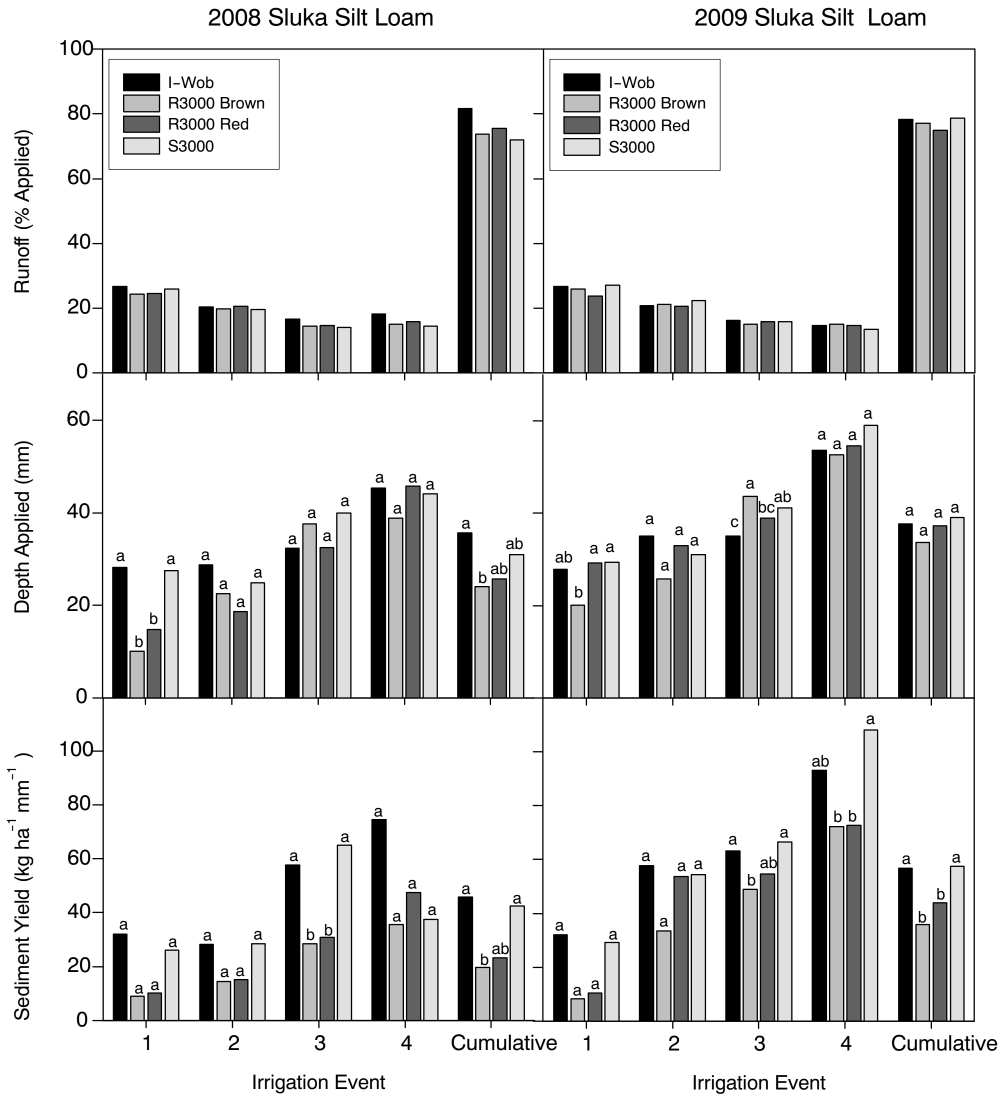

Figure 8. Water application, runoff percentage, and sediment yield for 2008 and 2009 runoff tests on Sluka silt loam soil. For each irrigation event, sprinkler treatments with the same letter are not significantly different at the 0.05 probability level.

Sluka Silt Loam

Runoff

In 2008 there were only significant sprinkler treatment differences in runoff percentage for the first irrigation event (fig. 8). Overall runoff percentage increased with subsequent irrigation events. Mean cumulative runoff percentage for the I-Wob sprinkler was significantly greater than for the R3000 brown plate sprinkler treatment. In 2009 there were significant differences among the sprinkler treatments for the first and third irrigation event. Runoff percentage increased with each subsequent irrigation event. Although there were significant sprinkler treatment differences for half the irrigation events, there were no significant differences between treatments for mean cumulative runoff percentage.

Erosion

In 2008 there were significant differences among sprinkler treatments in sediment yield for only the third irrigation event even though there were substantial mean treatment differences in every irrigation event (fig. 8). Cumulative sediment yield was the least for the R3000 brown plate sprinkler treatment and greatest for the I-Wob and S3000 sprinkler treatments. In 2009 there were significant differences in sediment yield among sprinkler treatments for the third and fourth irrigation event. Cumulative sediment yield was greatest for the I-Wob and S3000 sprinkler and least for the R3000 sprinklers, consistent with 2008 results.

Feltham Sand

No runoff occurred with any sprinkler treatment for the Feltham sand soil over the four irrigation event series. The Feltham sand had no structure due to the low silt and clay content (table 2) and lacked sufficient fine particles to form an effective soil surface seal. Since runoff from this soil did not occur it will not be discussed any further.

Discussion

Across all irrigation events and soil types there were no consistent significant differences among the I-Wob, R3000, and S3000 sprinkler treatments. The D3000 sprinkler often had the greatest runoff and erosion relative to R3000 brown plate sprinkler (fig. 4) for the Portneuf silt loam test in 2007. The D3000 sprinkler has a relatively small drop size distribution as evident by a wetted radius of only 4 m (table 1), which results in a peak application rate of 207 mm h^{-1} (table 1). This high application rate is the primary reason for the high runoff percentage relative to R3000 brown plate sprinkler, which has twice the wetted radius and about half the peak application rate (table 1).

In several irrigation events or irrigation series, the R3000 sprinklers produced the least runoff and erosion (figs. 5-8). The peak application rate of the R3000 sprinklers is about 13% less than for the I-Wob and S3000 sprinklers (table 1). The wetted radii of the R3000 and I-Wob sprinklers are equivalent (table 2). Other than a difference in peak application rates, the I-Wob, S3000, and D3000 sprinklers all visually appear to apply the water by more evenly distributing sprinkler droplets over the wetted area with respect to time compared to the R3000 sprinklers. In general, sprinkler types that visually appear to more evenly distribute sprinkler droplets over the wetted area with respect to time produced the greatest runoff and soil erosion for bare soil conditions. This functional difference in spatial distribution of water application with respect to time may have caused sediment to remain in suspension in overland flow for a longer duration allowing sediment to be more readily transported down slope and removed from the runoff plot.

A 50% reduction in sprinkler flow rate reduced runoff and soil erosion 60% to 80% for the same volume of water applied over six equal irrigations (fig. 6). The practice of reducing sprinkler flow rate early in the growing season prior to crop canopy development could be an effective management tool for reducing sprinkler runoff and erosion. One major center pivot sprinkler manufacturer offers a clip which stores a secondary nozzle at the sprinkler so that sprinkler nozzles to reduce application rate can be readily retained at the correct center pivot lateral outlet location. The secondary nozzle can be easily installed and used early in the season for germination and early season irrigation, effectively reducing runoff and erosion.

CONCLUSIONS

Runoff and erosion of four center pivot sprinklers commonly used in Idaho was evaluated on four Idaho soils. The four sprinklers had similar wetted diameters and peak application rates. There was no consistent trend in runoff and erosion between sprinklers. However, on occasions sprinkler types that visually appear to more evenly distribute sprinkler droplets over the wetted area with respect to time produced the greatest soil erosion for bare soil conditions. This functional difference in spatial distribution of water application with respect to time may have caused sediment to remain in suspension in overland flow for a longer duration allowing sediment to be more readily transported down slope and removed from runoff plots. Research into the effect intermittent water application on the millisecond time scale ("instantaneous" application rate) has on infiltration and erosion processes would be beneficial.

Based on the results of this study, there appears to be no consistent difference between sprinkler types of similar wetted diameters in regards to runoff and erosion.

Runoff and erosion was significantly greater when sprinkler wetted diameter was reduced by 50% and peak application is increased by 50%. Protection of the bare soil surface from droplet impact significantly reduced runoff and erosion, demonstrating the importance soil surface seal formation from drop impact has in determining runoff and erosion under center pivot irrigation. A 50% reduction in sprinkler flow rate reduced runoff and soil erosion 60% to 80% for the same volume of water applied over six irrigations. The practice of reducing sprinkler flow rate early in the growing season prior to crop canopy development could be an effective management tool for reducing center pivot sprinkler irrigation runoff and erosion.

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