2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

An ASABE Meeting Presentation

Paper Number: 095942

Potential Runoff and Erosion Comparison of Four Center Pivot Sprinklers

Bradley A. King, Research Agricultural Engineer

USDA ARS Northwest Irrigation and Soils Research Laboratory, 3793 N. 3600 E., Kimberly ID 83341, brad.king@ars.usda.gov.

David L. Bjorneberg, Supervisory Research Agricultural Engineer

USDA ARS Northwest Irrigation and Soils Research Laboratory, 3793 N. 3600 E., Kimberly ID 83341, dave.bjorneberg@ars.usda.gov.

Written for presentation at the
2009 ASABE Annual International Meeting
Sponsored by ASABE
Grand Sierra Resort and Casino
Reno, Nevada
June 21 – June 24, 2009

Mention any other presentations of this paper here, or delete this line.

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 measured runoff percentages and measured erosion rates between center pivot sprinkler types for the soils tested and experimental conditions. The magnitude of the differences among sprinklers was equal to or greater than the differences between the soils tested. The I-Wob and S3000 sprinklers exhibited the greatest measured runoff percentages and measured erosion rates and the R3000 sprinklers exhibited the least runoff and erosion for the three soils tested. In general, sprinkler types that visually appear to more evenly distribute sprinkler droplets over the wetted area with respect to time exhibited the greatest measured runoff and measured erosion rates. The relative ranking of the sprinklers in terms of measured runoff percentages and measured erosion rates was consistent when four and six irrigation events were used to apply 75 mm of water. The relative differences in runoff between the sprinklers tested were not directly proportional to sprinkler* *droplet kinetic energy per unit water volume applied. This outcome is in conflict with conventional theory on soil surface sealing from droplet impact. Possible explanations include incorrect representation of sprinkler 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.*

Keywords. Sprinkler irrigation, center pivot, runoff, erosion.

Introduction

Center pivot sprinkler irrigation systems are often the preferred type of 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 irrigation systems. Over 41% of the irrigated area in the U.S. is irrigated by center pivot and lateral move sprinkler irrigation systems (USDA, 2003). 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 can exceed soil infiltration rates for medium- and fine-textured soils, which can result in substantial runoff, erosion and spatial non-uniformity in water application depth on rolling topography, especially under the outer extent of center pivot sprinkler irrigation systems. 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 these choices 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; 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.

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

Methods and Materials

Center pivot sprinkler water application was emulated 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 boom height 46 cm and adding additional sprinkler outlets along the boom length. Two additional sprinkler outlets were added between each existing outlet to provide 123 to 130 cm spacing between adjacent outlets. 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, 91 m drag hose. Travel speed of the boom was computer controlled at a specified constant rate. Specific details on the irrigation boom sprinkler system used to emulate center pivot irrigation are provided by King and Bjorneberg (2007).

The effect of center pivot sprinkler type on runoff and erosion was measured using 1 m wide by 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.

In 2007, the metal frames were installed on a Portneuf silt loam soil with a slope of 4 to 6 percent. In 2008, the frames were installed on elevated soil boxes 1.2 m wide by 2.6 m long with different end heights to provide a nominal slope of 5% as shown in figure 1. The bottom of 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. This provided a soil depth of 15 cm for runoff and erosion evaluation. For both test conditions, the metal frames were installed at a constant slope of 5%. The soil surface within the metal frames was graded to a 5% slope and smoothed. 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 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 rather than actual field rates, but provide a means to compare runoff and erosion characteristics of the sprinkler types under controlled conditions.

Sixteen runoff frames were installed in a four row by four column arrangement to provide a Latin Square statistical design for data analysis. Four sprinkler types (treatments) were randomly assigned to the sixteen plots with one treatment per row and column. Twelve of the sixteen plots were covered with waterproof polyethylene tarps when the irrigation boom sprinkler system passed over the plot area with a particular sprinkler treatment. 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 sixteen runoff plots was 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. A line of ten catch cans, with 0.7 m spacing between adjacent cans and placed near the start of the runoff plots was used to measure water volume applied. The catch cans, measuring 15.2 cm (6 in.) in diameter and 20.3 cm (8 in.) 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 UT) prior to an irrigation event. Sediment mass in collected runoff was measured using vacuum filtration and 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 commercial center pivot sprinklers used in this study are listed in table 1. Runoff test 1 was conducted in 2007 and the remainder in 2008. In 2007, two layers of fiberglass screen material laid on a wire frame with 8 cm square openings was used as a sprinkler treatment to eliminate sprinkler droplet impact directly on the bare soil surface. The wire frame was supported 2 cm above the soil surface by the runoff plot metal frame. Senninger pressure regulators were used on the I-Wob sprinklers and Nelson pressure regulators were used on the Nelson sprinkler products. Flow rates for the sprinklers were selected to be representative of those found on the outer extent of 390 m long center pivot sprinkler irrigation systems in Idaho. Nozzles sizes were selected from manufacturer published sprinkler information. Sprinkler height was approximately 1.2 m in 2007 and 0.9 m above the surface of the runoff plot boxes in 2008. Sprinkler spacing

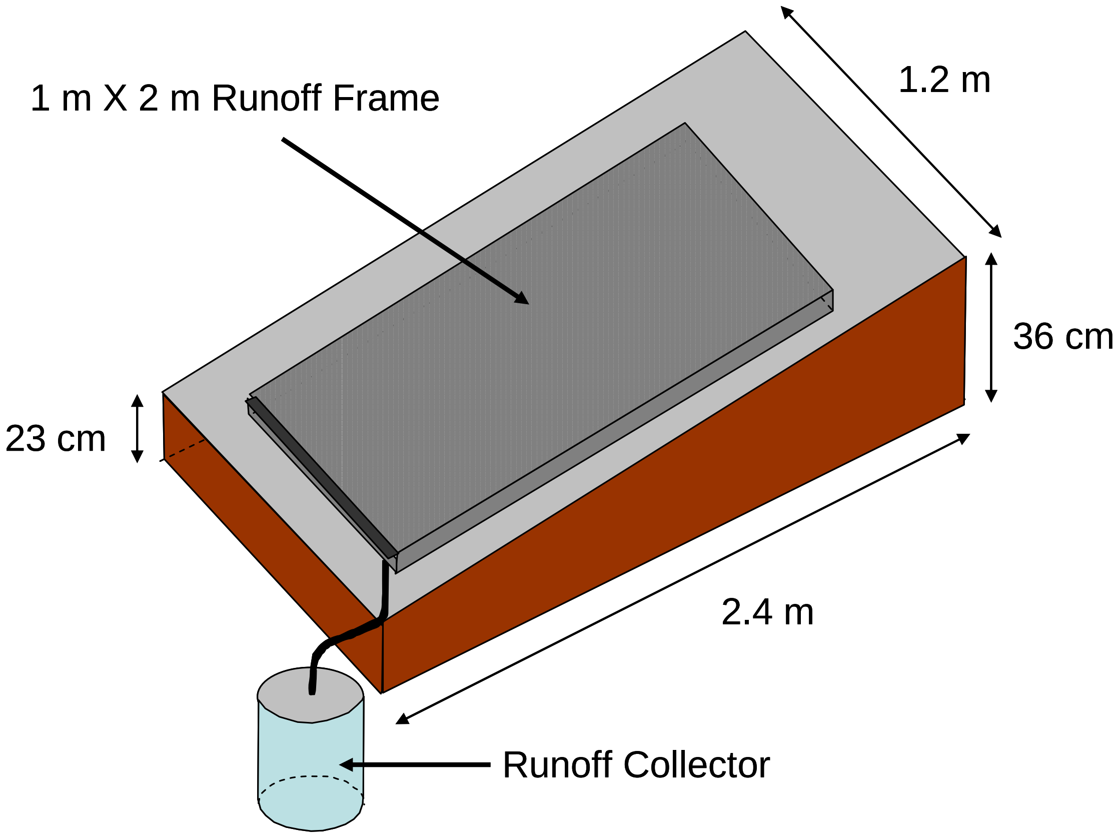

Figure 1. Diagram showing layout, dimensions and features of elevated soil box with metal frame used for runoff plots in 2008 runoff tests.

along the irrigation boom was 2.4 to 2.6 m with a total of nine sprinklers used to emulate center pivot sprinkler pattern overlap over the runoff plots.

Flow rate of sprinklers used in this study was determined by weighing the mass of water emitted from the nozzle in a 5 to 10 minute period of time. Flow rate measurements were repeated three times. Flow rates were determined using the pressure regulator used in the field study directly attached to the sprinkler body. A 345 kPa pressure regulator, located 0.5 m upstream of the sprinkler-pressure regulator assembly, was used to minimize pressure variations between subsequent tests. The specific gravity of the water emitted by the nozzle in flow measurements was adjusted for water temperature. Independent flow measurements on sprinkler nozzles obtained from a commercial supplier in March 2009 were performed by the Center for Irrigation Technology (California State University Fresno, Fresno, CA) using their standard procedures. A calibrated turbine meter was used to measure sprinkler nozzle flow rate. A pressure tap located 18 cm upstream from the base of the sprinkler was used to measure sprinkler operating pressure with a calibrated pressure gage. A gate valve located 30 cm upstream of the pressure tap was used to control operating pressure of the sprinkler. The test piping used in the test apparatus was19 mm diameter and positioned horizontally. The flow meter was located upstream of the gate valve. Five sprinkler nozzle samples were used to determine average flow rate for a given sprinkler nozzle size and operating pressure.

Table 1. Irrigation Sprinklers, pressures, and nozzle diameters and flow rates used in each runoff test.

Test and Sprinklers	Soil Name	Pressure kPa	Nozzle Diameter mm	Flow Rate* L/min
Test 1				
I-Wob Standard 9-groove Plate	Portneuf Silt Loam	103	8.33	43.2
R3000 Brown Plate	Portneuf Silt Loam	138	7.54	42.7
D3000 Flat Plate	Portneuf Silt Loam	103	8.14	43.4
D3000 Flat Plate Covered Soil	Portneuf Silt Loam	103	8.14	43.4
Test 2				
I-Wob Standard 9-groove Plate	Portneuf Silt Loam	103	8.33	43.2
R3000 Brown Plate	Portneuf Silt Loam	138	7.54	42.7
R3000 Red Plate	Portneuf Silt Loam	138	7.54	42.7
S3000 Purple Plate	Portneuf Silt Loam	103	8.14	43.4
Test 3				
I-Wob Standard 9-groove Plate	Chijer Fine Sandy Loam	103	8.33	43.2
R3000 Brown Plate	Chijer Fine Sandy Loam	138	7.54	42.7
R3000 Red Plate	Chijer Fine Sandy Loam	138	7.54	42.7
S3000 Purple Plate	Chijer Fine Sandy Loam	103	8.14	43.4
Test 4				
I-Wob Standard 9-groove Plate	Sluka Silt Loam	103	8.33	43.2
R3000 Brown Plate	Sluka Silt Loam	138	7.54	42.7
R3000 Red Plate	Sluka Silt Loam	138	7.54	42.7
S3000 Purple Plate	Sluka Silt Loam	103	8.14	43.4
Test 5				
I-Wob Standard 9-groove Plate	Portneuf Silt Loam	103	8.33	43.2
R3000 Brown Plate	Portneuf Silt Loam	138	7.54	42.7
R3000 Red Plate	Portneuf Silt Loam	138	7.54	42.7
S3000 Purple Plate	Portneuf Silt Loam	103	8.14	43.4

*Manufacturer's published data.

Runoff and erosion evaluations for the sprinklers were conducted on one soil type in 2007 and three soil types in 2008. In both years a series of four irrigation events with nominal application depths of 25, 20, 15, and15 mm totaling 75 mm was applied to each soil type. In 2008, a series of six irrigation events with nominal application depth of 12.5 mm each, totaling 75 mm, were also applied to one soil type. In 2008, after a series of four irrigation events, soil was removed from each runoff plot box by hand and filled with new soil. The soils used in the 2008 tests 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 truck. The soil was stock piled on site until used. The soil was used to fill the elevated soil boxes without compaction or mechanical manipulation of the soil structure other than to smooth it to a 5% slope. Soil texture analysis was determined for each soil using the hydrometer method.

Results and Discussion

Texture analysis results for the three soils used in the study are listed in table 2. 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 was limited due to local availability.

Average water application depth measured for each sprinkler and irrigation event for runoff tests 1 through 4 are listed in table 3. Irrigation boom travel speed was equal for each irrigation event. Measured water application depth was influenced by wind speed differences between tests which varied but was less than 5 m/s for all tests. In general, cumulative measured water application depths for the Senninger I-Wob were as much as 12% greater than for the Nelson D3000 sprinkler, and 9% greater than the other Nelson sprinklers. Flow rates of the sprinkler nozzles used in the runoff tests were measured after runoff test 5 to investigate the cause of the difference in measured water application depths. Measured flow rates for the Senninger I-Wob sprinkler nozzless are shown in figure 2. All measured flow rates of the I-Wob nozzles were greater than the manufacturer's published values. Three of the nozzles had flow rates exceeding 48 L/min. Further inspection of the nozzles revealed that the three nozzles were 8.53 mm diameter nozzles rather than 8.33 mm diameter nozzles. The 8.53 mm diameter nozzles were the same color as the 8.33 mm nozzles and lacked numerical marking of actual size. The average measured flow rate of the Senninger I-Wob 8.33 mm diameter nozzles was 46.3 L/min rather than 43.2 L/min published by the manufacturer, a 7.2% difference in flow rate. The flow rate of an additional set of ten 8.33 mm diameter nozzles was tested with a 103 kPa Senninger pressure regulator resulting in an average measured flow rate of 46.6 L/min, a 7.9% difference in flow rate. The extent of the discrepancy between manufacturer published and actual sprinkler nozzle flow rates was investigated by requesting sprinkler flow rate characterization tests from the Center for Irrigation Technology (CIT) (California State University Fresno, Fresno, CA). Results from CIT testing are summarized in figure 3. The difference between measured flow rates and manufacturer published values ranged from -4.6 to 8.6% for the three pressures tested.

Measured flow rates from Nelson sprinkler nozzles used in this study with 138 and 103 kPa pressure regulators are shown in figures 4 and 5, respectively. With a 138 kPa Nelson pressure regulator, average measured flow rate for the 7.54 mm diameter nozzle was 42.7 L/min, equivalent to the manufacturer's published flow rate value. With a 103 kPa Nelson pressure regulator, average measured flow rate for the 8.14 mm diameter nozzle was 42.9 L/min rather

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 2007	16	63	21
Portneuf Silt Loam 2008	14	65	21
Sluka Silt Loam	27	63	10

Table 3. Measured water application depth in mm for runoff tests 1 through 4.

Test and Sprinklers	Irrigation Event 1	2	3	4	Cumulative
Test 1					
I-Wob Standard 9-groove Plate	26.7	16.1	18.3	17.3	78.3
R3000 Brown Plate	26.2	16.1	14.9	14.4	71.7
D3000 Flat Plate	23.7	17.1	16.7	12.2	69.7
D3000 Flat Plate Covered Soil	23.7	17.1	16.7	12.2	69.7
Test 2					
I-Wob Standard 9-groove Plate	26.3	22.8	17.7	18.9	85.7
R3000 Brown Plate	28.4	21.7	14.8	13.5	78.4
R3000 Red Plate	27.2	22.2	16.7	14.7	80.8
S3000 Purple Plate	25.2	21.0	15.6	15.3	77.1
Test 3					
I-Wob Standard 9-groove Plate	28.7	21.6	14.5	17.8	82.6
R3000 Brown Plate	23.4	20.9	14.3	16.1	74.7
R3000 Red Plate	21.8	20.9	15.6	14.4	72.6
S3000 Purple Plate	26.1	19.5	14.1	14.0	73.7
Test 4					
I-Wob Standard 9-groove Plate	26.6	20.3	16.6	18.2	81.7
R3000 Brown Plate	24.3	19.8	14.5	15.0	73.7
R3000 Red Plate	24.5	20.5	14.6	15.9	75.6
S3000 Purple Plate	25.9	17.6	14.0	14.4	72.0

than the 43.5 L/min published by the manufacturer, a -1.4% difference. Results from CIT testing of Nelson sprinkler product nozzle flow rates are summarized in figure 6. The difference between measured flow and manufacturer's published sprinkler nozzle flow rates ranged from -1.0 to 3.2% for the three pressures tested.

The discrepancy between intended application depth and measured application depth in the study is attributed to a difference between manufacturers published and measured sprinkler nozzle flow rates and the use of incorrect size of sprinkler nozzles due to a lack of clear numerical marking of nozzle diameter. To account for the difference between intended application depth and measured application depth, measured runoff was divided by measured application depth for each irrigation event to normalized measured runoff values.

The soil profile in the runoff plots was allowed to dry by evaporation for a period of 7 to 10 days between subsequent irrigation events. Average soil water content measured in each runoff plot prior to an irrigation event is shown in table 4. There were few significant differences in soil water contents prior to an irrigation event for the different sprinklers and no consistent trend in water content for any sprinkler. The three exceptions are for irrigation event 4 in runoff test 1, irrigation event 2 in runoff test 2 and irrigation event 3 in runoff test 3. Apparently, test conditions were not sufficient for the soil profile to completely dry prior to irrigation on these

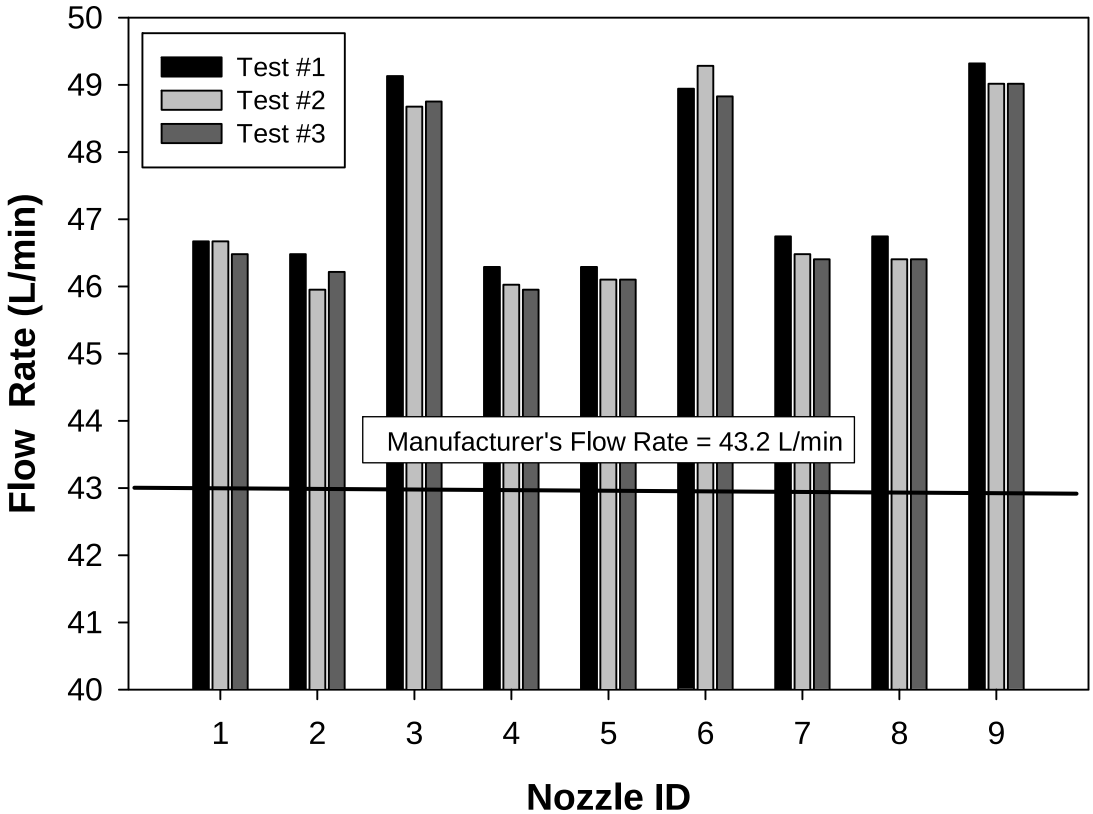

Figure 2. Measured flow rates of Senninger I-Wob sprinkler nozzles used in runoff tests. Further inspection revealed that sprinklers 3, 6 and 9 were 8.53 mm nozzles rather than 8.33 mm nozzles. All tests used the same 103 kPa Senninger pressure regulator. Flow rate measurement of each sprinkler nozzle was repeated three times.

three occasions. The differences in soil water contents were less than 0.03 mm/mm and likely had little influence on measured runoff differences between sprinklers.

Measured runoff expressed as a percentage of measured water application for each sprinkler and irrigation event for runoff tests 1 through 4 are listed in table 5. 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 as evident from experiment 1 where runoff from the covered soil was significantly less than the uncovered soils for all irrigation events. This outcome is consistent with the findings of Thompson and James (1985), DeBoer et al., (1988), Agassi et al., (1994) and Lersch and Kincaid (2000) which found a significant reduction in infiltration rate due to sprinkler droplet impact. The development of a soil surface seal after the first irrigation was evident for all the soils as the runoff percentage often increased with the second irrigation with less water application depth.

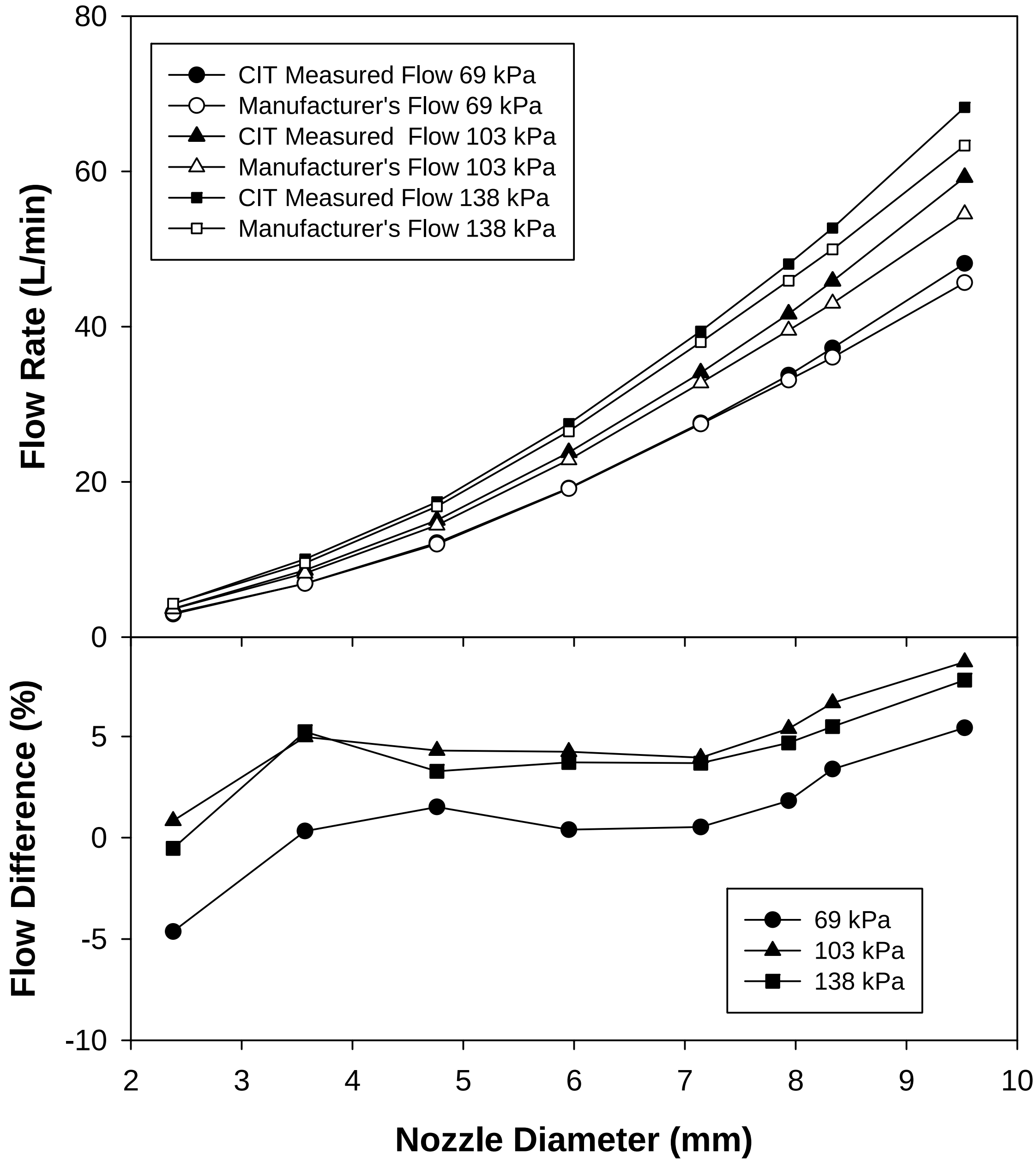

Figure 3. Comparison of flow rates measured by CIT with manufacturer's published values for the Senninger I-Wob sprinkler for selected nozzle sizes.

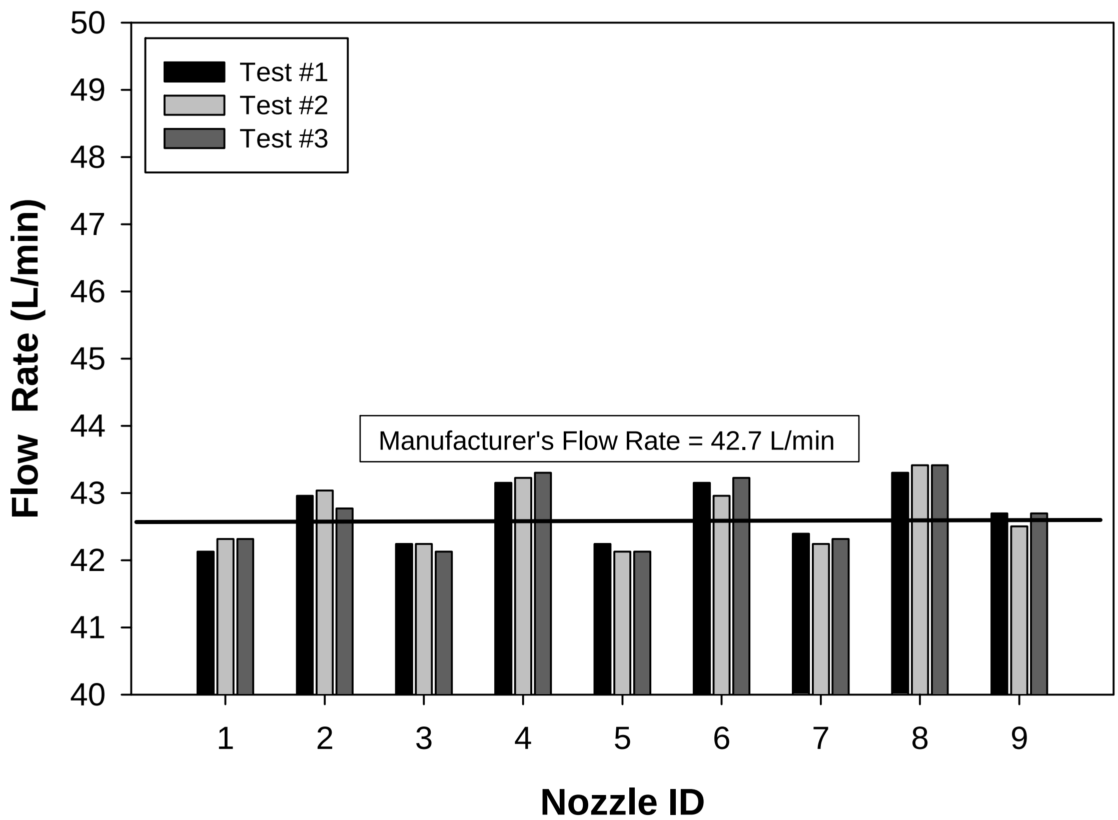

Figure 4. Measured flow rates of Nelson R3000 7.54 sprinkler nozzles used in runoff tests. All tests used the same 138 kPa Nelson pressure regulator. Flow rate measurement of each sprinkler nozzle was repeated three times.

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.

There were significant differences in cumulative percent runoff between sprinkler types for runoff tests 1 through 4 (table 5). The I-Wob sprinkler always ranked within the sprinklers with the greatest runoff percentage and the R3000 with red plate sprinkler always ranked within the sprinklers within the least runoff percentage, for all the soils tested. For runoff test 1, there was no significant difference in cumulative runoff percentage between the I-Wob and D3000

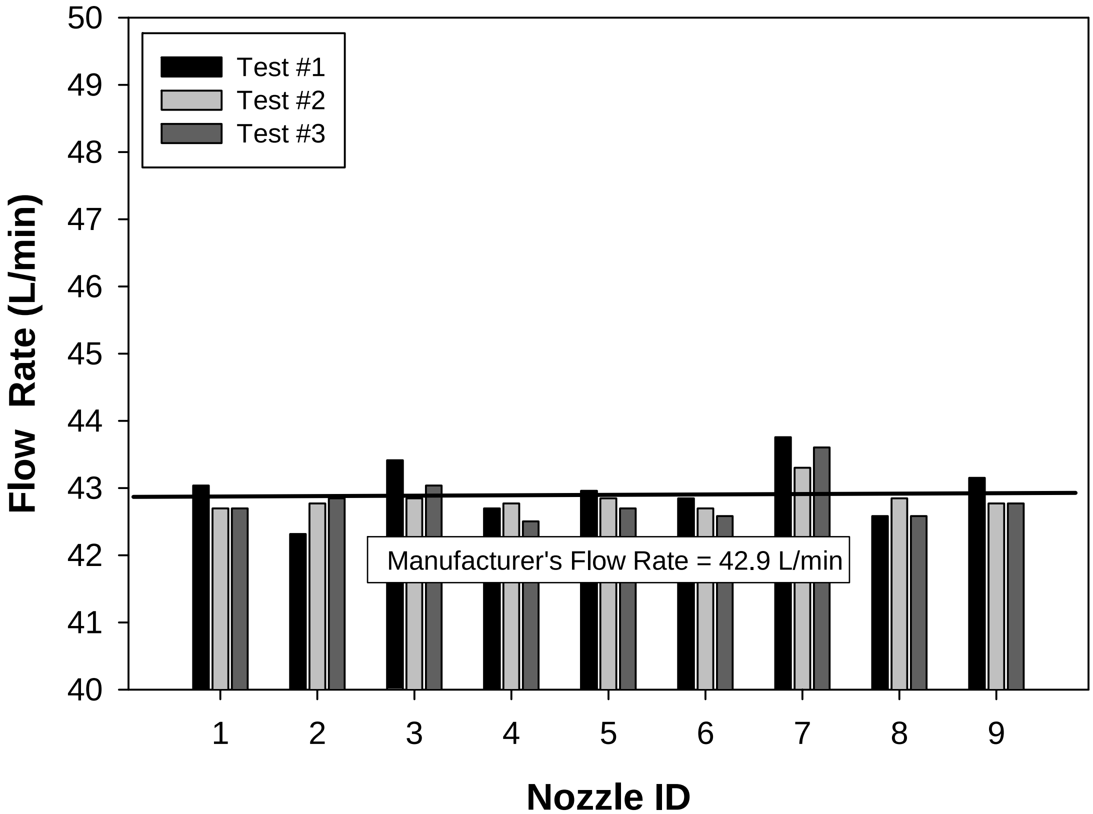

Figure 5. Measured flow rates of Nelson R3000 of 8.14 mm sprinkler nozzles used in runoff tests. All tests used the same103 kPa Nelson pressure regulator. Flow rate measurement of each sprinkler nozzle was repeated three times.

sprinkler for bare soil conditions. For runoff tests 2 and 4 there were no significant differences between cumulative runoff percentages for the I-Wob and S3000 sprinklers. The I-Wob, S3000, and D3000 sprinklers 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 percentage for bare soil conditions. The magnitude of the differences in cumulative runoff percentage between sprinkler types is as great as or greater than the differences between the soils tested. Conventional theory on sprinkler droplet induced soil surface sealing and infiltration reduction is based on droplet kinetic energy being the primary factor for bare soil conditions. Kincaid (1996) calculated the kinetic energy per unit volume of water applied for common sprinkler types and developed a model for calculating sprinkler droplet kinetic energy as a function of sprinkler type, nozzle size and operating pressure. Based on this model, the kinetic energy per unit volume of water applied by the D3000, S3000 and R3000 with red plate sprinklers is 13.6, 16.9 and 16.3 J/L, respectively. Kinetic energy values for the I-Wob and R3000 with brown plate sprinklers are unavailable. DeBoer (2002) also calculated kinetic energy per unit volume of water applied

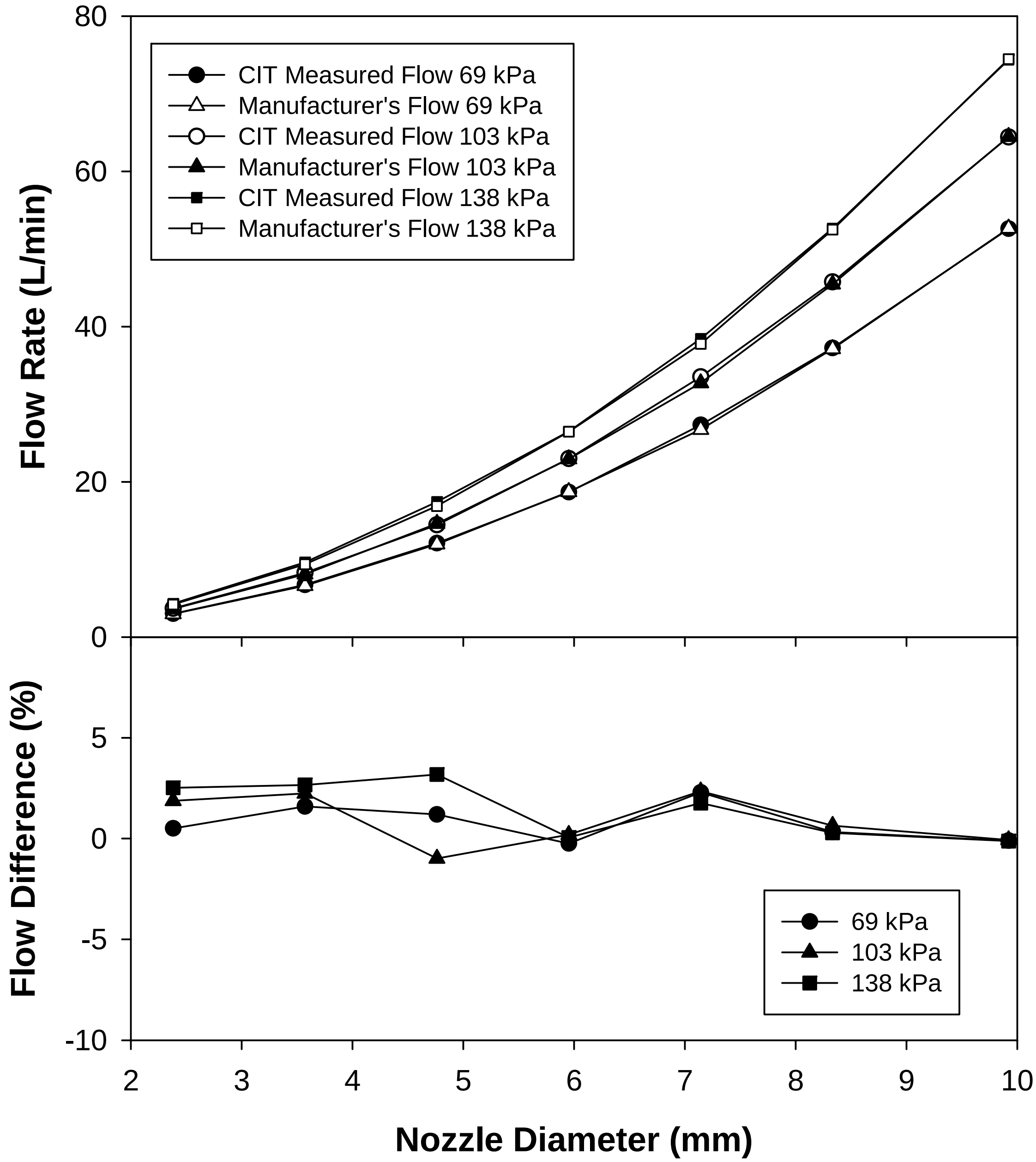

Figure 6. Comparison of flow rates measured by CIT with manufacturer's published values for Nelson sprinklers for selected nozzle sizes.

Table 4. Average measured soil water content in mm/mm in the top 20 cm of the soil profile prior to each irrigation event for runoff tests 1 through 4. Values with the same letter for an irrigation event and runoff test are not significantly different at the 0.05 level.

	Irrigation Event			
Test and Sprinklers	1	2	3	4
<u>Test 1</u>				
I-Wob Standard 9-groove Plate	----	0.13[a]	0.14[a]	0.14[ab]
R3000 Brown Plate	----	0.13[a]	0.14[a]	0.15[a]
D3000 Flat Plate	----	0.13[a]	0.14[a]	0.13[b]
D3000 Flat Plate Covered Soil	----	0.13[a]	0.14[a]	0.15[a]
<u>Test 2</u>				
I-Wob Standard 9-groove Plate	----	0.14[a]	0.18[a]	0.13[a]
R3000 Brown Plate	----	0.15[a]	0.17[a]	0.12[a]
R3000 Red Plate	----	0.15[a]	0.15[b]	0.14[a]
S3000 Purple Plate	----	0.16[a]	0.16[ab]	0.15[a]
<u>Test 3</u>				
I-Wob Standard 9-groove Plate	----	0.17[a]	0.15[a]	----
R3000 Brown Plate	----	0.12[b]	0.16[a]	0.09[a]
R3000 Red Plate	----	0.12[b]	0.13[a]	0.10[a]
S3000 Purple Plate	----	0.12[b]	0.13[a]	0.12[a]
<u>Test 4</u>				
I-Wob Standard 9-groove Plate	0.10[a]	0.11[a]	0.13[a]	0.13[a]
R3000 Brown Plate	0.10[a]	0.13[a]	0.14[a]	0.13[a]
R3000 Red Plate	0.11[a]	0.11[a]	0.13[a]	0.12[a]
S3000 Purple Plate	0.10[a]	0.12[a]	0.13[a]	0.13[a]

for Nelson sprinklers similar to the S3000 and R3000 and developed a model for sprinkler droplet kinetic energy as a function of pressure. Based on the DeBoer (2002) model, the kinetic energy per unit volume for the S3000 and R3000 with red plate is 15.4 and 17.0 J/L, respectively. DeBoer (2002) estimated peak instantaneous kinetic energy flux rates for S3000 and R3000 type sprinklers equivalent to 20 mm/hr and 200 mm/hr rainfall intensities, respectively, suggesting the R3000 type sprinklers would be more detrimental to soil surface structure and infiltration. The results of the current study indicate that R3000 maintain relatively greater infiltration rates than S3000 type sprinklers. The S3000 and R3000 sprinklers used in this study had similar wetted diameters resulting in similar peak application rates. The wetted diameter of the D3000 sprinkler is about 50% less than either the S3000 or R3000 sprinklers resulting in peak application rates about 50% greater. This difference could be responsible for the relatively high runoff percentage for the D3000 sprinkler despite having least kinetic energy per unit volume of applied water. Both models of sprinkler kinetic energy indicate a relatively small difference in kinetic energy between the S3000 and R3000 sprinklers with conflicting ranking between the two sprinklers based on sprinkler droplet kinetic energy, yet there are significant differences in cumulative runoff percentage for all three soils used in this study. Possible explanations for this outcome include incorrect representation of sprinkler droplet kinetic energy, conventional soil surface sealing theory does not apply to the soils used in this

Table 5. Percent runoff measured for runoff tests 1 through 4. Values with the same letter for an irrigation event and runoff test are not significantly different at the 0.05 level.

Test and Sprinklers	Irrigation Event 1	2	3	4	Cumulative
Test 1					
I-Wob Standard 9-groove Plate	23.2[a]	11.7[a]	16.4[ab]	33.1[a]	21.4[a]
R3000 Brown Plate	11.3[b]	7.8 [b]	14.5[bc]	22.6[ab]	13.4[b]
D3000 Flat Plate	20.5[a]	6.5[b]	22.6[a]	35.6[a]	20.2[a]
D3000 Flat Plate Covered Soil	7.1[b]	2.6[c]	6.8[c]	14.8[b]	7.3[b]
Test 2					
I-Wob Standard 9-groove Plate	17.4[a]	15.4 [a]	22.9[b]	34.9[a]	22.0[a]
R3000 Brown Plate	7.3[a]	18.2 [a]	33.9[a]	39.1[a]	20.8[a]
R3000 Red Plate	1.6	21.1 [a]	21.0[b]	25.8[a]	15.5[b]
S3000 Purple Plate	6.5[a]	16.9 [a]	36.0[a]	33.7[a]	20.6[a]
Test 3					
I-Wob Standard 9-groove Plate	17.0[a]	40.6[a]	50.9[a]	55.5[a]	42.6[a]
R3000 Brown Plate	7.1[a]	20.5[b]	34.1[b]	40.8[a]	24.0[b]
R3000 Red Plate	0.2[a]	22.5[b]	29.5[b]	39.9[a]	18.5[c]
S3000 Purple Plate	5.2[a]	41.4[a]	36.5[b]	29.9[a]	27.7[b]
Test 4					
I-Wob Standard 9-groove Plate	28.2[a]	28.7[a]	32.4[a]	45.4[a]	35.7[a]
R3000 Brown Plate	10.1[b]	22.5[a]	37.6[a]	38.8[a]	24.1[b]
R3000 Red Plate	14.7[b]	18.6[a]	32.5[a]	45.7[a]	25.7[b]
S3000 Purple Plate	27.5[a]	24.8[a]	39.9[a]	44.1[a]	31.0[ab]

study, or some unknown factor is dominating the infiltration and runoff process for the study conditions. Additional research is needed to determine the kinetic energy applied by the sprinklers used in this study under the study conditions and examine the infiltration and runoff processes in more detail in order to explain the results.

Measured soil erosion expressed as sediment loss per unit of measured applied water for each sprinkler and irrigation event for runoff tests 1 through 4 are listed in table 6. Sediment loss is highly correlated with runoff volume because greater runoff provides a greater opportunity for sediment transport. In general, sediment loss for individual irrigation events closely follows runoff. Cumulative sediment loss divided by cumulative measured water applied for each soil type was calculated and statistically compared to reduce the effect of random variability is also shown in table 6. There were significant differences in cumulative sediment loss between sprinkler types (table 6) for each runoff experiment. The I-Wob sprinkler always ranked within the sprinklers with the greatest sediment loss and the R3000 with red plate sprinkler always ranked with the sprinklers having the least sediment loss, for all the soils tested. For runoff test 1, the D3000 sprinkler produced the greatest sediment loss for the bare soil condition and the least sediment loss for the covered soil condition. For runoff tests 2 and 3, the I-Wob sprinkler exhibited the greatest soil loss among the sprinklers tested. Sprinkler types that visually appear to more evenly distribute sprinkler droplets over the wetted area with respect to time exhibit the greatest sediment loss. This functional difference in water application may cause sediment to remain in suspension in overland flow for a longer duration relative to the R3000 type

Table 6. Sediment Yield in kg/ha/mm measured for runoff tests 1 through 4. Values with the same letter for an irrigation event and runoff test are not significantly different at the 0.05 level.

	Irrigation Event				
Test and Sprinklers	1	2	3	4	Cumulative
Test 1					
I-Wob Standard 9-groove Plate	24.2^{a}	15.0^{a}	19.7^{b}	34.1^{b}	23.5^{b}
R3000 Brown Plate	9.6^{b}	7.9^{b}	14.6^{b}	24.8^{b}	13.3^{c}
D3000 Flat Plate	27.7^{a}	10.7^{b}	44.2^{a}	65.7^{a}	34.2^{a}
D3000 Flat Plate Covered Soil	4.3^{b}	3.8^{c}	8.3^{b}	13.5^{b}	6.8^{c}
Test 2					
I-Wob Standard 9-groove Plate	18.7^{a}	33.2^{a}	40.5^{a}	48.0^{a}	33.5^{a}
R3000 Brown Plate	7.5^{bc}	12.1^{a}	24.1^{b}	26.6^{b}	15.2^{c}
R3000 Red Plate	5.1^{c}	23.3^{a}	32.2^{ab}	18.1^{b}	18.1^{bc}
S3000 Purple Plate	13.5^{ab}	18.8^{a}	40.6^{a}	32.8^{ab}	24.2^{b}
Test 3					
I-Wob Standard 9-groove Plate	16.7^{a}	48.0^{a}	85.9^{a}	90.0^{a}	52.8^{a}
R3000 Brown Plate	9.1^{a}	20.8^{a}	39.8^{b}	45.9^{b}	26.2^{b}
R3000 Red Plate	1.5^{a}	20.2^{a}	31.8^{b}	34.1^{b}	19.8^{b}
S3000 Purple Plate	6.9^{a}	43.8^{a}	40.8^{b}	53.3^{b}	32.0^{b}
Test 4					
I-Wob Standard 9-groove Plate	32.1^{a}	28.2^{a}	57.8^{a}	74.6^{a}	45.8^{a}
R3000 Brown Plate	9.0^{a}	14.4^{a}	28.4^{b}	35.7^{a}	19.7^{b}
R3000 Red Plate	10.3^{a}	15.2^{a}	30.8^{b}	47.4^{a}	23.4^{b}
S3000 Purple Plate	26.2^{a}	28.6^{a}	65.0^{a}	67.4^{a}	42.6^{a}

sprinklers allowing sediment to be more readily transported down slope and removed from the runoff plot.

The effect of irrigation application depth on runoff and erosion was investigated in runoff test 5 by applying six 12.5 mm irrigation events instead of four irrigation events of varied application depth (runoff tests 1-4) to nominally apply 75 mm of water. Measured water application depth, average soil water content prior to irrigation, measured applied water, measured runoff percentage and measured soil erosion loss are given in table 7. The results are consistent with the results from runoff tests 2, 3 and 4. Measured water applied was greatest for the I-Wob sprinkler due to the manufacturer's published flow rate being low and the nozzle size selection error. Soil water content in the runoff plots prior to each irrigation event was not significantly different despite the difference in measured applied water. There were significant differences in cumulative runoff percentage and sediment loss for the different sprinklers. The I-Wob sprinkler produced the greatest cumulative runoff percentage and the R3000 sprinklers produced the least cumulative runoff percentage. The I-Wob and S3000 sprinklers produced more runoff than the R3000 sprinklers consistent with the results from runoff tests 2, 3 and 4. Measured soil erosion was correlated with runoff percentage. The I-Wob sprinkler produced the greatest measured soil erosion and the R3000 sprinklers produced the least measured soil erosion.

Table 7. Measured water application depth, soil water content prior to irrigation, percent runoff and sediment yield for each runoff test 5. Values with the same letter for an irrigation event are not significantly different at the 0.05 level.

Parameter and Sprinklers	Irrigation Event 1	2	3	4	5	6	Cumulative
Water Application Depth (mm)							
I-Wob Standard 9-groove Plate	14.0	15.4	13.7	14.9	15.6	12.8	86.3
R3000 Brown Plate	13.8	13.4	12.9	12.6	12.9	12.1	77.7
R3000 Red Plate	13.1	12.7	12.5	13.2	13.7	13.1	78.4
S3000 Purple Plate	11.8	12.4	12.5	13.1	13.4	12.3	75.4
Soil Water Content (mm/mm)							
I-Wob Standard 9-groove Plate	0.15[a]	0.14[a]	0.14[a]	0.15[a]	0.15[a]	0.15[a]	----
R3000 Brown Plate	0.14[a]	0.13[a]	0.14[a]	0.15[a]	0.15[a]	0.15[a]	----
R3000 Red Plate	0.14[a]	0.13[a]	0.14[a]	0.15[a]	0.14[a]	0.14[a]	----
S3000 Purple Plate	0.14[a]	0.12[a]	0.12[a]	0.14[a]	0.13[a]	0.14[a]	----
Percent Runoff (%)							
I-Wob Standard 9-groove Plate	0	12.7[b]	29.9[a]	41.4[a]	47.9[a]	37.4[a]	31.5[a]
R3000 Brown Plate	0	2.3[a]	20.9[b]	38.3[a]	38.3[b]	30.5[ab]	21.4[c]
R3000 Red Plate	0	1.7[a]	23.1[b]	37.2[a]	33.9[b]	27.5[b]	20.4[c]
S3000 Purple Plate	0	2.5[a]	31.9[a]	41[a]	46[a]	37.6[a]	25.4[b]
Sediment Yield (kg/ha/mm)							
I-Wob Standard 9-groove Plate	---	---	37.5[a]	37.9[a]	40.8[a]	46.1[a]	30.4[a]
R3000 Brown Plate	---	---	13.9[b]	22.5[a]	22.5[b]	26.5[bc]	14.7[b]
R3000 Red Plate	---	---	13.6[b]	25.0[a]	18.9[b]	18.6[c]	13.9[b]
S3000 Purple Plate	---	---	38.6[a]	36.1[a]	37.5[a]	37.5[ab]	24.3[a]

The I-Wob and S3000 sprinklers which visually appear to more evenly distribute sprinkler droplets over the wetted area with respect to time produced the greatest measured runoff percentages and measured soil erosion rates compared to the R3000 sprinklers for the bare soil conditions.

Conclusion

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 measured runoff percentages and measured 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 between the soils tested. The I-Wob and S3000 sprinklers exhibited the greatest measured runoff percentage and measured erosion rates and the R3000 sprinklers exhibited the least runoff and erosion 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 greatest measured runoff and measured erosion rates. The relative ranking of the sprinklers in terms of measured runoff percentages and measured erosion rates was consistent when four or six irrigation events were used to apply 75 mm of water. The relative differences in runoff between the sprinklers tested were not directly proportional to sprinkler droplet kinetic energy per unit volume water applied. This outcome is in conflict with conventional theory on soil surface sealing from droplet impact. Possible explanations include incorrect representation of sprinkler 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 determine the kinetic energy applied by the sprinklers used in this study under the study conditions and examine the infiltration and runoff processes in more detail in order to explain the results. Research into the effect intermittent water application on the millisecond time scale ("instantaneous" application rate) has on infiltration and erosion processes would be beneficial.

Acknowledgements

The Briggs Irrigation boom used in this study was provided by Nelson Irrigation Corp. Walla Walla, WA through a material transfer agreement with the USDA ARS Northwest Irrigation and Soils Research Laboratory.

References

Agassi, M., D. Bloem, and M. Ben-Hur. 1994. Effect of drop energy and soil and water chemistry on infiltration and erosion. *Water Resources Research* 30(4):1187-1193.

DeBoer, D.W. 2002. Drop and energy characteristics of a rotating spray-type sprinkler. *J. Irrig. Drain. Eng. ASCE* 128(3):137-146.

DeBoer, D.W. 2001. Sprinkler application pattern shape and surface runoff. *Trans. ASAE* 44(5):1217-1220.

DeBoer, D.W., Asghar Moshref-Javadi, and S.T. Chu. 1988. Application of the Green-Amp infiltration equation to sprinkler irrigation management. *Applied Agricultural Research* 3(3):128-132.

Faci, J.M., R. Salvador, E. Playan, and H. Sourell. 2001. A comparison of fixed and rotating spray plate sprinklers. *J. Irrig. Drain. Eng. ASCE* 127(4):224-233.

Kincaid, D.C. 2005. Application rates from center pivot irrigation with current sprinkler types. *Applied Engineering in Agriculture* 21(4):605-610.

Kincaid, D.C. 1996. Spraydrop kinetic energy from irrigation sprinklers. *Trans. ASAE* 39(3):847-853.

Kincaid, D.C., K.H. Solomon and J.C. Oliphant. 1996. Drop size characteristics for irrigation sprinklers. *Trans. ASAE* 39(3):839-845.

King, B.A. and D.L. Bjorneberg. 2007. Center pivot simulator for evaluating system design and management effects on infiltration and erosion. In: *Proc. 28th International Irrigation Show, San Diego, CA, Dec. 9-11, 2007*. Irrigation Association, Falls Church, VA. 10 pp.

Lersch, G.A. and D.C. Kincaid. Sprinkler droplet energy effects on infiltration and near-surface, unsaturated hydraulic conductivity. In: *Proc. 2nd Int. Symp. Preferential flow: water movement and chemical transport in the environment, Honolulu, HI, Jan. 3-5, 2001*. pp. 283-286. ASAE, St. Joseph, MI.

Playan, E., S. Garrido, J.M. Faci and A. Galan. 2004. Characterizing pivot sprinkler using an experimental irrigation machine. *Agricultural Water Management* 70:177-193.

SAS. 2007. *Statistical Analysis Software version 9.1.3.* Statistical Analysis Institute, Inc., Cary, NC, USA.

Sourell, H., J.M. Faci, and E. Playan. 2003. Performance of rotating spray plate sprinklers in indoor experiments. *J. Irrig. Drain. Eng. ASCE* 129(5):376-380.

Thompson, A.L. and L.G. James. 1985. Water droplet impact and its effect on infiltration. *Trans. ASAE* 28(5):1506-1510.

USDA. 2003. 2003 farm and ranch irrigation survey: census of agriculture. National Agricultural Statistics Database. Washington, D.C.: USDA National Agricultural Statistics Service. Available at: www.nass.usda.gov/census/census97/fris/fris.htm. Accessed 10 February 2009.