Efficacy of Boom Systems in Limiting Runoff on Center Pivots

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Abstract. Center pivot and linear move irrigation systems' design and operation are primarily limited by soil infiltration rates. Boom systems have been suggested to improve infiltration and decrease runoff by reducing the instantaneous water application rate of center pivots and linear move systems. In this research project, we compared runoff from plots irrigated with typical in-line sprinklers on a linear move irrigation system with those irrigated with off-set boom systems. In-line drops consistently generated greater runoff than 'the boom systems in all of the irrigation events. Differences in runoff between the drop types were significantly different for the second, third, fourth and fifth irrigation events. The runoff differences from in-line drops ranged from 3% to 24% greater than the boom systems. Runoff as a percentage of irrigation water applied increased with each irrigation event on both drop types.

Keywords. Center Pivot, Irrigation, Sprinklers, Offset, Boomback, Application Rate

Introduction

The use of mechanized sprinkler irrigation systems, particularly center pivots and linear move systems (or linears) have rapidly increased in the United States. Several surface irrigated areas are being gradually converted to sprinkler irrigation, especially center pivots. In 2007, center pivot and linear move irrigation systems accounted for 25 million acres (10.5 million ha) or 46% of the total area (56.8 million acres) irrigated in the United States (USDA, 2010). The growth in mechanized sprinkler irrigation systems, particularly center pivots in the recent years may be due to the automation built into them that allows for irrigation of many types of crops with minimal labor input, large area coverage, ability to operate on relatively rough topography, and finally, these systems can be highly efficient and uniform when they are designed and managed properly (Wilmes et al., 1993; Kincaid, 2005). However, the efficiency and uniformity of these systems can be considerably reduced by potential runoff as a result of the high application rates that are inherent with moving sprinkler systems (Kincaid et al., 1969; Thooyamani et al., 1987; Kincaid, 2005; Luz, 2011). Water application rates in moving sprinkler irrigation systems are generally much higher than those of stationary sprinkler systems. This is because moving systems must apply water over a given point in the field in a limited amount of time. When the application rate exceeds both the soil infiltration rate and the soil surface storage, water will flow on the soil surface producing runoff (Mielke et al., 1992; Luz and Heermann, 2004).

Potential runoff continues to be the major problem associated with moving sprinkler systems (Kincaid, 2005). Surface runoff is particularly more severe in center pivots or linears operated at low pressures (Wilmes et al., 1993; Thooyamani et al., 1986). The problem worsens at the outer end of the lateral for center pivots where the application rate is much higher than the other points closer to the pivot center (Allen, 1990; Kincaid et al., 1997; Bjorneberg, 2003; Bjorneberg et al., 2003; Smith and North, 2009).

Potential runoff can be reduced by increasing the lateral speed on the center pivot or the linear move systems, thereby reducing the irrigation depth applied during each irrigation 'run'. This however can be detrimental for plants needing deeper depths of irrigation. The major challenge in the design and operation of center pivots and linears then becomes designing systems that apply sufficient water to meets plants' water requirements with no or minimal surface runoff. The design should therefore be able to limit water application rates to values that are less than the sum of the soil's infiltration rate and the surface storage capacity at all times and along all points on the laterals (Allen, 1990). The infiltration rate varies with the soil type and the soil moisture conditions. Surface storage temporarily allows the water to pond until it infiltrates completely. Soil surface storage capacity is the ability of a soil to hold a particular depth of water ponding on its surface depressions without letting it flow. Soil surface storage capacity depends on the field slope, soil surface conditions and the type of crop grown on that field. Runoff can be prevented or reduced by increasing the amount of soil surface storage (Neibling et al., 2009).

Another way of trying to reduce runoff potential is by reducing the water application rate while maintaining an irrigation depth appropriate for the needs of the plants. Booms (offset-booms, or boombacks) are one way of decreasing the water application rate. In boom systems, the sprinkler heads are offset 10-20 ft (3 to 6 meters) from the irrigation tower's frame (Figure 1). Booms lower water application rate by applying water to a larger area (that is, by increasing the sprinkler wetted area) thereby allowing the soil to absorb the water at a slower rate, thus allowing larger application depths. This allows for less frequent irrigations and thus reducing surface evaporation and also reduces diseases in some crops (Kincaid et al., 2000). Less frequent irrigations of more water per pass also result in deeper root zones, less wear-and-tear on the pivot's motors and gear boxes, and power savings. Booms on alternate sides of the center pivot or linear move system can reduce the application rate of low-pressure spray sprinklers (King and Kincaid, 1997). The objective of this work was to compare runoff from booms with typical in-line drops that have the sprinkler heads in-line and directly underneath the irrigation tower's frame.

Materials and Methods

The research was conducted at the Washington State University (WSU) Irrigated Agriculture Research and Extension Center (IAREC) located near Prosser, Washington (latitude 46° 15' N, longitude 119° 44' W), USA.

A linear move irrigation system, Valley 8000 Series model, 148 m long was used for this experiment. Originally the system had all of its drops directly underneath the tower frame. The system was modified to include alternating booms in two groups as shown in Figure 2. The drops for the booms were moved 15 ft (4.6 m) from the irrigation tower's frame using light-weight galvanized steel tubing (BoomBacks made by IACO, Vancouver, WA). All the drops across the linear move system (both in-line and booms) were located approximately 9 ft (3 m) apart along the tower frame and 5 ft (1.5 m) above the soil surface. The sprinkler type used on both booms and in-line drops included a Nelson S3000 spinner with a yellow plate (Nelson Irrigation Corporation, Walla Walla, Washington, USA), a sprinkler nozzle diameter of 11/64ths (4.37 mm; Nelson nozzle size # 22) and a Nelson 15 psi (103-kPa) pressure regulator to give an application rate of 3.2 gpm (12.2 L min^{-1}). A pond nearby the experimental field was the source of water. The pond received surface water diverted from the Yakima River.

Figure 1. A part of the linear move system fitted with booms for the sprinkler runoff tests in 2013.

The experimental field was formerly a wheat field. After the wheat was mowed, the field was plowed with a disk plow. The runoff area plots were prepared manually using a shovel and a rake towards the end of the month of September 2013. The field contains Warden silt loam soil with average sand, silt and clay of 21, 68 and 11% respectively and with a slope of about 0.5%. Twelve runoff plots were installed in a three row by four column arrangement as shown in Figure 2. Average distance between the plots in a column ranged between 16 and 25 ft (5 to 7.5 m). There were two plot locations under regular drops and two locations under booms in each row. The plot locations were such that when the linear move system was directly over the plots, each plot was mid-way between two adjacent drops on the irrigation tower frame. Before the runoff plots were demarcated by metal frames, the areas where the plots were to be located underwent some preparations. First, the locations were raked back and forth to remove wheat straw that was covering the field surface after the field was plowed. The areas were then dug up with a shovel; the soil was dug up and turned over. This was to help loosen up the subsoil and to also break up clods of the earth. The plot areas were then raked back and forth again to further remove any straw that might have been remaining on the surface and to also make sure that all the plots were at the same slope and soil surface condition. This helped to minimize the variability between the plots' infiltration and soil surface storage components of the infiltration-storage-runoff process. All irrigation applications for this experiment were on relatively smooth and bare soil conditions.

Metal steel frames of area 12 ft^2 (1.12 m^2) were used to capture a representative sample field runoff and to prevent plot run-on from the surrounding areas. The metal frames were 1/8 inch (3 mm) thick and 8 in (20.2 cm) wide. The frames were oriented vertically and their bottom edges driven into the ground to a depth of about 3.5 in (9.5 cm). A PVC pipe, 2 inches (5.1 cm) in diameter and 5 inches (12 cm) long was fitted through a hole on the down slope outlet end of the frame (Figure 3). The cracks were sealed by using duck tape to widen the pipe just so that it had a pressure fit. The PVC pipe routed the runoff into a clear plastic bag tightly tied on to the PVC pipe. A hole was dug into the soil near the outlet of the plot for the bag to sit when collecting runoff from the plot. The volume of the runoff that collected in the bag was measured using a graduated cylinder, and the depth of runoff and percent runoff (that is, depth of runoff / depth of irrigation applied × 100) was determined for each plot.

Five irrigations were applied to the runoff plots with irrigation intervals varying between 1 to 4 days during the month of October. The dates that the experiment was run and the application depths are recorded in Table 1. The one day irrigation interval didn't let the soil profile drain sufficiently before irrigations. The application depths were hence progressively decreased as the experiment progressed to prevent excessive runoff. Application depths for particular irrigation events were chosen to ensure that measurable runoff occurred on the plots for each irrigation event. Rainfall was minimal during the experimental period; less than 0.04 inches (1 mm) of rainfall was received on 10/8/2013. Each runoff plot had two catch cans placed on the ground near the plot that were used to measure the volume of water applied (Figure 3).

A block design with two blocks, two treatments and three replications per treatment was used for this experiment and solved using Minitab 16.2.3 GLM procedure (Minitab, 2012). Tukey's Studentized range test was used for treatment mean comparisons of runoff and runoff percentage at a 0.05 probability level.

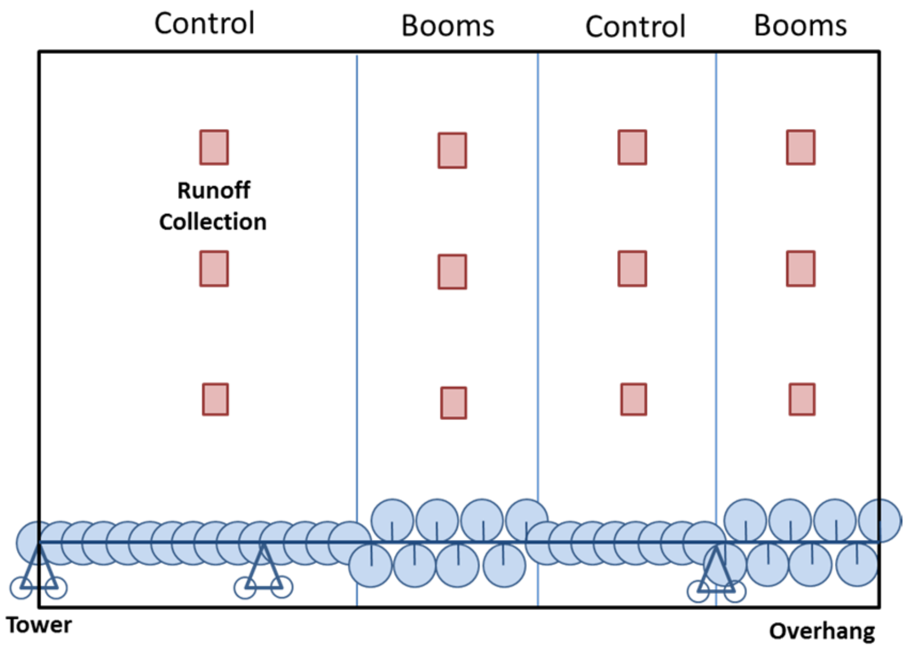

Figure 2. Runoff plot layout for field studies in 2013.


Figure 3. Runoff plot components.

Results and Discussion

Runoff from irrigation events was determined during the month of October of 2013. The irrigation events, including dates, application depths and runoff are summarized in Table 1. Runoff from the in-line drops ranged between 11.2% and 60.1% of the irrigation depth applied during the period of testing (Figure 4). The booms generated runoff ranging between 6.9% and 39.5% of the irrigation depth applied. In-line (control) drops generated greater runoff than the booms in all the irrigation events; the runoff differences between in-line drops and the booms ranged from 3% to 24% of the irrigation depth applied.

The differences in runoff from in-line drops and booms were significant for 2nd, 3rd, 4th and 5th irrigation events. On a field level, this reduction in runoff through using booms will minimize crop water stress by allowing more water to infiltrate into the soil and be used by the crop. This will boost crop yields and also improve the efficiency of the irrigation system. Also, with less runoff and more infiltration, pumping costs are reduced since less passes of the center pivot or linear move system will be required to sufficiently irrigate the crop during the growing season. A boost in crop yields increases farm revenue while reduction in pumping costs reduces crop production costs. Increase farm revenue and savings in water and pumping costs due to booms may be more than enough to compensate for the increased equipment costs due purchase, installation and management of booms.

Table 1. Date, wind speed, and average irrigation and runoff for each irrigation event and for each drop type.

Irrigation		Wind	Application	Runoff (in)		ANOVA	Difference in
Event	**Date**	**speed (mph)**	**depth (in)**	**Control**	**Booms**	**probability**	**runoff** (%)**
1	10/2/2013	3.13	1.25	0.13 a*	0.09 a	0.28	3.0
2	10/9/2013	2.71	0.70	0.26 a	0.20 b	0.03	7.9
3	10/14/2013	3.60	0.61	0.25 a	0.16 b	0.00	14.6
4	10/16/2013	3.13	0.40	0.25 a	0.16 b	0.02	22.4
5	10/18/2013	3.20	0.41	0.24 a	0.14 b	0.02	24.2
Total			**3.37**	**1.14 a**	**0.76 b**	**0.003**	

***** Values in rows with the same letters are not significantly different at a significance level of 5%.
** Difference in runoff between in-line drops and booms expressed as a percentage of irrigation applied per irrigation event.

The runoff trends (Figure 4) for both the in-line drops and the booms show similarity in runoff patterns as affected by the antecedent soil moisture content, time between irrigation events and soil surface sealing. The soil surface layer in both treatments was equally dried by evaporation and infiltration differences may have been largely influenced by soil surface sealing which was as a result of droplet impact on to the bare soil. This could explain the increasing percent runoff in both treatments as the number of irrigations increased (Figure 4). Runoff percentages generally increased with increased number of irrigations in both treatments. However, the increase was steeper with in-line drops than with booms. This suggests that boom systems may preserve the soil structure and reduce soil compaction. Booms thus may be a way of minimizing the increase of runoff that might occur throughout the season for in-row crops like potatoes.

Four out of the five irrigation events produced significantly different runoff percentages between the regular drops and the booms. The first irrigation event produced the least runoff for both regular drops and the booms due to minimal surface sealing as the plots had just been established and also because the runoff plots' soil moisture content was lowest prior to the first irrigation event. As the initial soil water content increases, infiltration decreases. The application intervals for this experiment ranged between 1 to 4 days. Not allowing the soil profile to sufficiently drain before an irrigation event further increases the occurrence of runoff.

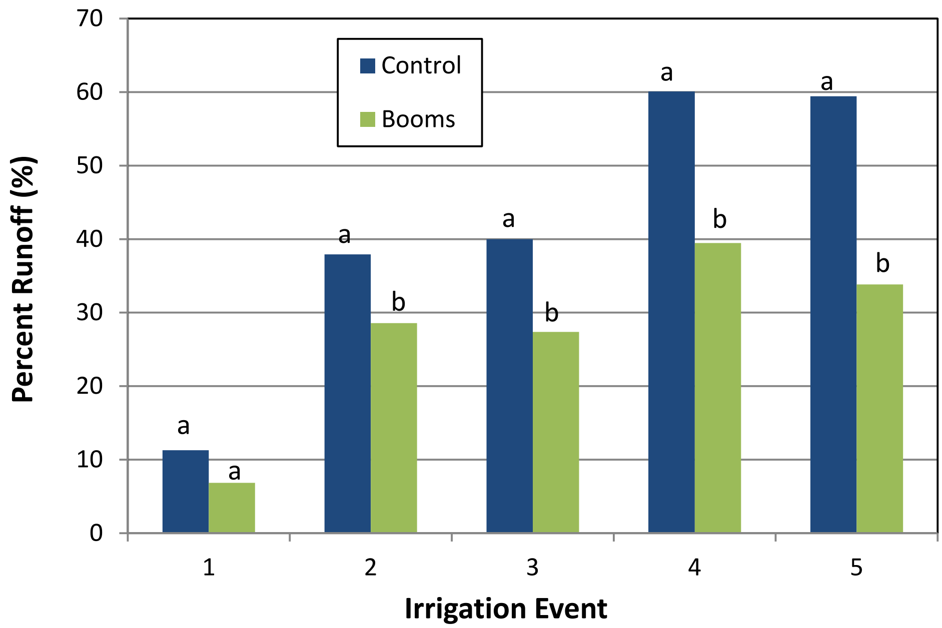

Figure 4. Runoff percentage (that is, measured runoff expressed as a percentage of measured applied water) for the runoff tests for each irrigation event. Treatments with the same letter for a particular irrigation event are not significantly at a significance level of 5%.

Conclusions

This study compared runoff from in-line drops with boom systems. The highest runoff occurred with in-line drops in all the irrigation events. In-line drops produced between 3% to 24% more runoff than the booms. This study shows how the use of boom systems is an effective way of lowering the water application rate through increasing the wetted sprinkler area thus minimizing soil compaction and encouraging infiltration of water into the soil. It appears that the more difficult it is to get water into the soil, the greater the benefit is from using booms.

Runoff from a particular area in a field depends on the slope, the initial soil water content and the roughness of the soil surface. In the application of mechanized sprinkler systems, care must be taken to match water application rates to infiltration rates of the soil under sprinkler conditions, and to the soil surface conditions in order to minimize runoff. Minimizing runoff will result in water savings, savings in pumping costs and minimize crop water stress.

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