EFFICACY OF BOOM SYSTEMS IN CONTROLLING RUNOFF UNDER CENTER PIVOTS AND LINEAR MOVE IRRIGATION SYSTEMS

P. Nakawuka, R. O. Okwany, T. R. Peters, K. Desta, S. H. Sadeghi

ABSTRACT. *Center pivot and linear move irrigation systems' design and operation are primarily limited by soil infiltration rates. Surface runoff can be a problem on some soils whose in-take rates are low. Additional design and management factors must be considered to prevent runoff in these systems. Boom systems have been suggested to decrease runoff by reducing the water application rate of center pivots and linear move systems. In this study, runoff from plots irrigated with typical in-line sprinklers was compared to runoff from plots irrigated with off-set boom systems. Both in-line sprinkler drops and the boom systems were fitted on the same linear move system. Sprinkler nozzle type and size was the same for both in-line drops and the off-set boom drops. Runoff was measured for five irrigation events applied on bare soil during three weeks in October 2013. Differences in runoff between the drop types were significant for the second, third, fourth, and fifth irrigation events. In-line drops generated between 3% and 24% more runoff than the boom systems during the test period. Runoff as a percentage of irrigation water applied increased with each irrigation event for both drop types. The increase however was higher for the in-line drops than for the boom systems. Increase in runoff with increase in sprinkler irrigation events was mainly attributed to soil surface sealing which resulted from sprinkler drop impact.*

Keywords. *Boom systems, Center pivots, In-line drops, Linear move systems, Runoff, Sprinkler irrigation.*

The use of mechanized sprinkler irrigation systems, particularly center pivots (or pivots) has rapidly increased in the United States. Surface irrigated area is being gradually converted to sprinkler irrigation, especially with pivots. Center pivots are used on 83% of sprinkler irrigated land (USDA, 2010). In 2007, center pivot and linear move irrigation systems accounted for 10.5 million ha or 46% of the total area (22.9 million ha) irrigated in the United States (USDA, 2010). The growth of mechanized sprinkler irrigation systems in the recent years, particularly pivots, may be due to the automation features being built into them that allow many types of crops to be irrigated with minimal labor input, cover large areas, and are able to operate on relatively rough topography (Wilmes et al., 1993; Kincaid, 2005). In addition, these systems can achieve high efficiencies and uniformities when designed and managed properly. However, the efficiency and uniformity of these systems can be considerably reduced by runoff resulting from high application rates; unfortunately, runoff is inherent with moving sprinkler systems (Kincaid et al., 1969; Thooyamani et al., 1987; Kincaid, 2005; Luz, 2011). Moving systems are designed to apply water over a given point in the field within a set limited amount of time. When the application rate exceeds both the soil infiltration rate and the soil surface storage, water begins flowing on the soil surface producing runoff (Mielke et al., 1992; Luz and Heermann, 2004).

Potential runoff is the major problem associated with moving sprinkler systems (Kincaid, 2005). Surface runoff is aggravated by pivots and linears operated at low pressures (Thooyamani et al., 1987; Wilmes et al., 1993). The problem worsens at the outer end of the lateral for center pivots where the application rate is higher than other points closer to the pivot center (Allen, 1990; King and Kincaid, 1997; Smith and North, 2009).

Runoff can be reduced by increasing the lateral speed on pivots or linears, thereby reducing irrigation depth applied during each pass. This, however, can be problematic for plants that need deeper application depths during irrigation. The major challenge in the design and operation of pivots and linears is the design of systems that apply sufficient water to meets plants' water requirements but with no or minimal surface runoff. The design should thus be able to limit water application rates to values less than the critical

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sum of the soil's infiltration rate and the surface storage capacity at all times and along all points on the laterals (Allen, 1990). Infiltration rate varies with soil type, soil surface cover, and the soil moisture conditions. Surface storage temporarily allows the water to pond until it completely infiltrates. 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 minimizing runoff potential is by reducing the water application rate while maintaining an irrigation depth appropriate for the needs of the plants. Booms (or offset booms or boombacks) on alternate sides of the center pivot or linear move system are one way for decreasing the water application rate (King and Kincaid, 1997). In boom systems, the sprinkler heads are offset 3 to 5 m alternately from both sides of the irrigating pipeline (lateral) as shown in figure 1. Booms lower water application rate by applying water to a larger area (that is, by increasing the sprinkler wetted area) thus allowing the soil to absorb the water at a slower rate. This improved infiltration allows for larger and sometimes less frequent irrigation thus reducing surface evaporation and, also, reducing diseases in some crops (Kincaid et al., 2000). Reducing the number of irrigation applications results in deeper movement of water into the soil, less wear-and-tear on the pivot's motors and gear boxes, and energy savings. The objective of this work was to compare runoff from booms versus typical in-line drops that have the sprinkler heads directly underneath the lateral.

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).

A 148-m long linear move irrigation system (Valley 8000 Series model, Valley, Neb.) was used for this experiment. Originally, the system had all its drops directly underneath the lateral. The system was modified to include alternating booms at positions shown in figure 2. The drops for the booms were moved 4.6 m from the lateral using lightweight galvanized steel tubing (BoomBacks made by IACO, Vancouver, Washington). All the drops across the linear move system (both in-line and booms) were located 3 m apart along the lateral with sprinkler heads located 1.5 m above the soil surface. The sprinkler head system used on both booms and in-line drops included a Nelson S3000 spinner with a yellow plate (Nelson Irrigation Corporation, Walla Walla, Washington), a sprinkler nozzle diameter of 4.37 mm (Nelson nozzle size 22) and a Nelson 103 kPa pressure regulator providing an application rate of 12.2 L min^{-1}. A pond near the experimental field was the source of water.

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

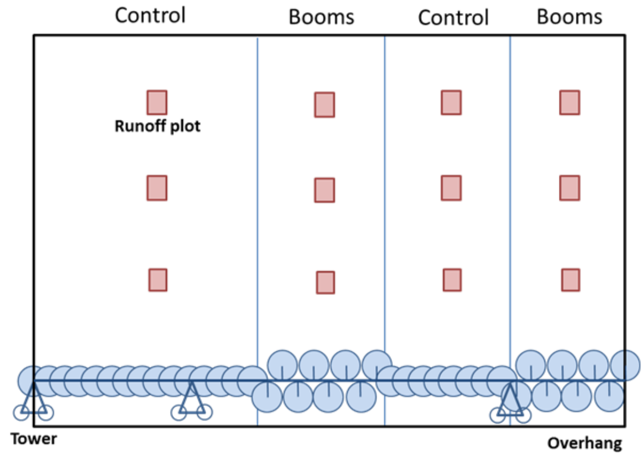

Figure 2. Runoff plot layout for field studies in 2013.

The field was previously planted with winter wheat. After the wheat was harvested and the stubble mowed, the field was plowed with a disk plow. The runoff 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 content of 21%, 68%, and 11%, respectively, and with a slope of about 0.5%. The soil has bulk density of 1.26 g/cm^3 and an organic matter content of 0.92%. This soil has a moderate infiltration rate (moderate runoff potential) when thoroughly wet (Web Soil Survey). Volumetric water contents at field capacity and at permanent wilting point were 22.7% and 7.1%, respectively.

Twelve runoff plots were installed in a three-row (parallel to the lateral) by four-column (perpendicular to the lateral) arrangement as shown in figure 2. Average distance between the plots in a column ranged between 5.0 to 7.5 m. There were two plots under each of the in-line and boom sprinkler systems in each row. The plots were positioned such that when the linear move system was directly over the plots, each plot was mid-way between two adjacent drops on the lateral. 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 had similar slopes. This also helped to minimize the variability between the plots' soil surface storage components of the infiltration-storage-runoff process. All irrigation applications for this experiment were on relatively smooth and bare soil conditions.

Runoff plots had a surface area 1.12 m^2 and were marked off by steel metal frames. The frames captured a representative sample of field runoff from each plot and also prevented run-on to the plot from the surrounding areas. The metal frames were 3 mm thick and 20.2 cm wide. The frames were oriented vertically and their bottom edges driven into the ground to a depth of about 9.5 cm. A PVC pipe, 5.1 cm in diameter and 12 cm long, was fitted through a hole on the down slope outlet end of the frame (fig. 3). The PVC pipe routed the plot 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 irrigation events were applied to the runoff plots with irrigation intervals varying between 1 to 4 days during the month of October. The dates the experiment were run and the application depths are recorded in table 1. The one-day irrigation interval didn't allow the soil profile to drain sufficiently before irrigations. The application depths were hence progressively decreased as the experiment progressed to prevent excessive runoff. Rainfall was minimal during the experimental period (1 mm of rainfall was received on 18 October 2013). Each runoff plot had two catch cans placed on the ground near the plot that were used to measure the depth of irrigation applied (fig. 3). Application depths for particular irrigation events were chosen to ensure that some measurable runoff occurred on the plots for each irrigation event.

The field was divided into two blocks with three runoff plots of each treatment in each block (fig. 2). In each block, each in-line-drop plot had a booms plot parallel to it, forming a pair of measurements whenever runoff data was collected. Differences in runoff between the two drop types were analyzed using a paired "t" test (Minitab, 2012) with six pairs of measurements for each irrigation event.

Figure 3. Runoff plot components.

RESULTS AND DISCUSSION

Irrigation events, including dates, application depths, and runoff are summarized in table 1. Runoff from the in-line drops ranged between 11% and 60% of the irrigation depth applied during the period of testing (fig. 4). The booms, on the other hand, 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 by using booms should minimize crop water stress by allowing more water to infiltrate into the soil and be used by the crop. This can 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. A boost in crop yields increases farm revenue, whereas a 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.

The percent runoff for both the in-line drops and the booms across the irrigation events (fig. 4) shows 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; infiltration differences may have been largely influenced by soil surface sealing which was a result of droplet impact on the bare soil. This could explain the increasing percent runoff in both treatments as the experiment progressed (fig. 4). Runoff percentages generally increased with increased number of irrigation events in both treatments; this result is consistent with the finding of King and Bjorneberg (2011). 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 surface sealing. 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 in-line drops and the booms. The first irrigation event produced the least runoff for both in-line 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 antecedent 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

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

Irrigation		Wind Speed	Application Depth	Runoff[a] (mm)		ANOVA	Difference in
Event	Date	(m/s)	(mm)	Control	Booms	Probability	Runoff[b] (%)
1	2/10/2013	1.40	31.8	3.36 a	2.40 a	0.153	3.0
2	9/10/2013	1.21	17.8	6.59 a	5.19 b	0.025	7.9
3	14/10/2013	1.61	15.5	6.43 a	4.16 b	0.000	14.6
4	16/10/2013	1.40	10.2	6.28 a	4.00 b	0.000	22.4
5	18/10/2013	1.43	10.4	6.18 a	3.66 b	0.001	24.2
Total			85.6	28.8 a	19.4 b	0.000	

[a] Values in rows with the same letters are not significantly different at a probability level of 5%.

[b] Difference in runoff between in-line drops and booms expressed as a percentage of irrigation applied per irrigation event.

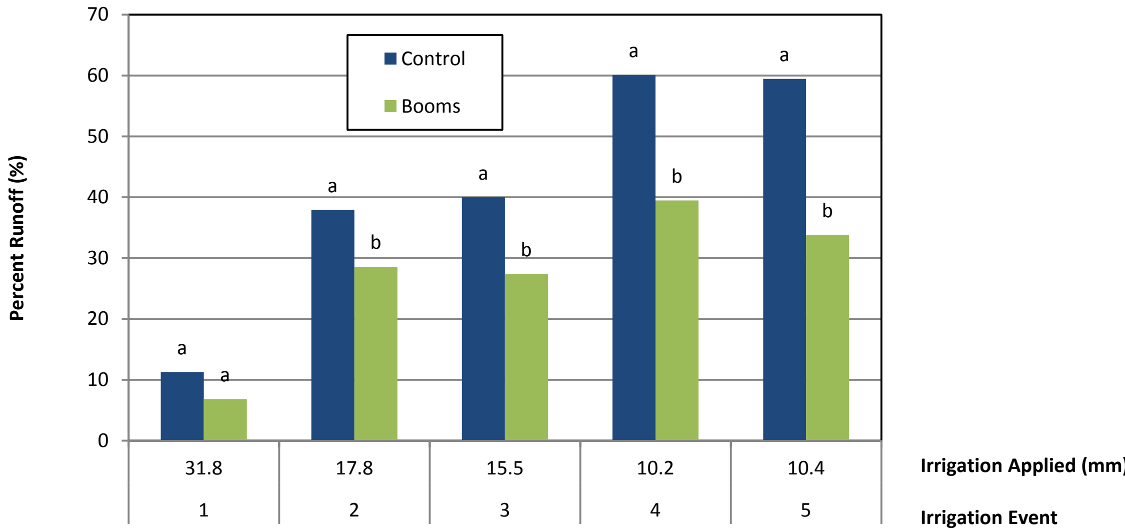

Figure 4. Percent runoff for the runoff tests for each irrigation event. Treatments with the same letter for a particular irrigation event are not significantly at a probability level of 5%.

before an irrigation event further increases the occurrence of runoff.

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 by increasing the wetted sprinkler area thus minimizing soil surface sealing and encouraging infiltration of water into the soil.

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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