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Runoff as Function of Forward Speed and Sprinklers' Type for Center Pivot System

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Abstract - **The effective features of center pivot sprinklers are well documented but few studies have been conducted to evaluate the effects that forward speed of center pivot and sprinklers' type on runoff of specific soil type. The objective of this study was to evaluate potential runoff from common commercial center pivot sprinklers on loamy soil under three forward speed of center pivot irrigation. A center pivot system was used on experimental runoff plots. Sprinklers used in the study were two fixed plate sprinklers (FPS1& FPS2) and two dynamic plate sprinklers (DPS1& DPS2). There were large differences in runoff rates between sprinkler types for the soil tested and experimental conditions. In general, sprinkler types that have fixed plates exhibited the highest runoff rates. The fixed plate sprinkler exhibited the highest overall runoff rates compared to multiple pads sprinkler. On the other hand, dynamic plate with 10 grooves exhibited the lowest rates for the three forward speed compared to the two sprinklers with fixed plate and also compared dynamic plate with 9 grooves.**

Keywords: Center Pivot, Forward Speed, Runoff, Fixed Plate Sprinklers & Dynamic Plate Sprinkler

1. INTRODUCTION

Center pivot irrigation system becomes popular with all producers who develop mega scale projects. Water applied rates along the last tower of the system, often exceed soil infiltration rates for medium- and fine -textured soils. This results in substantial runoff during irrigation events and spatial non- distribution uniformity in water applied. The primary emphasis for many center pivot sprinkler product developments and application studies has given a high uniformity which really is the main challenge for good water application at the last tower and the overhang of the pivot system. Over the past two decades' center pivot sprinkler manufacturers have developed sprinklers that minimize peak water application rates while sustaining high application uniformity. As a result, there are numerous center pivot sprinkler choices available for the producer but little quantitative information that relates these choices to infiltration, runoff, and erosion on a particular soil.

The effective features of center pivot sprinklers such as wetted diameter, application rate pattern shape, drop size and distribution uniformity have been reported in the scientific literatures (Kincaid D. C., 1996); (Faci, 2001); (DeBoer D. W., 2001); (Sourell, 2003); (Playán, 2004) and (Kincaid D. , 2005). Consequently, studies evaluating the effect operating characteristics of a particular sprinkler on of specific soil are limited.

Reference (Kincaid D. , 2002) declared that runoff under center pivot irrigation systems tends to be quite variable due to inconsistency in soil texture, roughness and slope. Moreover, the effect of small differences in the operating characteristics of variable sprinklers on infiltration, runoff and erosion is likely to be small as well.

The objective of this study is to evaluate potential runoff from common commercial center pivot sprinklers for loam soil under center pivot irrigation.

2. MATERIALS AND METHODS

A Center pivot consists of 7 spans 56-meter length plus 17-meter length overhang is used in this study. The pivot radius was 409 meter to irrigate 125 Feddan (52.5 hectares). The flow rate delivered to the pivot was 204 m^3/hr, so the application rate per unit of area was 3.89 m^3/hr/ha. The end pressure of the center pivot is adjusted to be 1.4 bar and the pivot point pressure is calculated considering the friction losses inside the pipeline using Hazen Williams equation.

Hazen Williams equation in SI units (Richard G. Allen, 2000):

$$\Delta P = 1.1101 X 10^{10} \left(\frac{Q}{C}\right)^{1.85} \frac{1}{D^{4.87}} \quad \ldots\ldots\ldots\ldots\ (1)$$

where
P = frictional pressure drop, kPa/m;
Q = flow rate, m^3/h;
D = pipe inside diameter, mm and
C = Hazen-Williams factor, dimensionless
Average application rate is computed using the following formula (Richard G. Allen, 2000):

$$I_a = 2 X 1000 X L_s X Q_p X \left(L_p + R_g\right)^{2} X L_d \quad \ldots\ldots\ (2)$$

where
Ia = average application rate (mm/hr.);
Ls = distance to sprinkler (m);
Qp= pivot flow rate (m^3 /hr);
Lp = length of pivot (m);
Rg = end gun radius (m) and
Ld = sprinkler throw diameter (m).
Depth of water applied by the center pivot at a specific forward speed of the last tower is calculated as follow (Richard G. Allen, 2000):

$$D = Q_p \text{ x } T_r \text{ x } 318.3\ (Lp + Rg)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

Where

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D = depth of water applied (mm);
Qp= pivot flowrate (m3 /hr);
Tr = hours per revolution (hrs.);
Lp = pivot length (m) and
Rg= end gun radius (m).

A new sprinkler nozzle chart is created specifically for this study to reveal the nozzle size in every outlet of each span based on number of spans, flow rate, end pressure, pivot point pressure, flow rate per each outlet along all towers and the overhang.

The outlet spacing in the pipe of the overhang was one meter between adjacent outlets. Sprinklers' clearance was 1.5 meter above the ground.

In order to deliver the required flow to the runoff boxes; nine sprinklers of each sprinkler under the study with its pressure regulators are installed in the overhang pipe.

The quantity of the selected sprinklers' nozzle sizes and its corresponding flow rates were; one nozzle (#40) rated at 2.4 m^3/hr, one nozzle (#41) rated at 2.6 m^3/hr, two nozzles (#43) rated at 2.8 m^3/hr, three nozzles (#44) rated as 2.9 m^3.hr and two nozzles (#45) rated at 3.1 m^3/hr. Sprinkler height was 1.5m above the surface of the runoff boxes. Sprinkler spacing along the overhang was 1m approximately.

Table (1) reveals the applicate depth per revolution versus different forward speed of the last span.

Table 1: Water Applicate depth per revolution

FULL CIRCLE		
Timer %	**Hrs/Rev**	**mm/Rev**
100	10.87	4.22
95	11.44	4.45
90	12.08	4.69
85	12.79	4.97
80	13.59	5.28
75	14.49	5.63
70	15.53	6.04
65	16.72	6.50
60	18.11	7.04
55	19.76	7.68
50	21.74	8.45
45	24.15	9.39
30	36.23	14.08
20	54.34	21.12

Forward speed of the last tower is adjusted in the control panel of the pivot to be 100%, 75% and 50% of the timer setting which means applying 4.22, 5,63 and 8.45 mm of water depth.

The last motor which installed at the last tower of the center pivot was running on 57 revolutions per minute at 50htz, gearbox reduction ratio was 52:1 and the tire size was 14.9X24. According to motor speed, gearbox reduction percentage and tire size, the forward speed of the last span and overhang were 3.95, 2.96 and 1.97 m/min at 100%, 75% and 50% of timer setting of the center pivot. The replicated soil plots have placed under the overhang of the center pivot to receive the application rate of the three forward speed when applied by the four different commercial sprinklers used in this study.

Elevated plots with 5% slope suggested by (King, 2007) are used in this study, Fig (1), to hold the runoff box used in evaluating the potential runoff for a specific sprinkler types versus last span's forward speed. The elevated plot dimensions were 1.2m width and 2.4m length with a nominal slope of 5% between the two ends of the boxes. Runoff box is installed on the top of the elevated plot to collect the potential runoff for a soil depth of 30cm used in this study. The horizontal down slope end of the metal frame of the runoff box has a horizontal lip for runoff to leave the box. 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 direct it into a collection bucket through a hole dug near the corner of the runoff box. The depth of water in the bucket was measured with a ruler to determine runoff volume. The bucket was covered to prevent water from sprinklers contributing to runoff water volume.

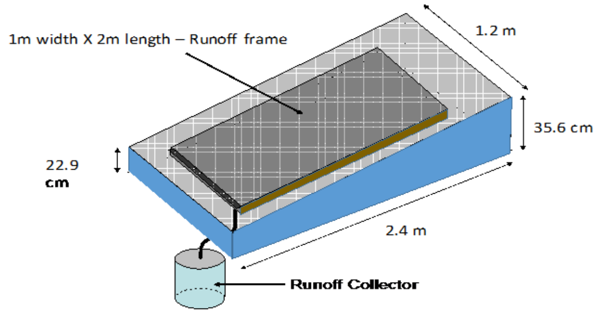

Fig. (1): Elevated boxes with Runoff plots, adapted from (King, 2007).

Sprinklers used in this study were 4 sprinklers; two of them with fixed plate sprinklers and the other two with dynamic plate sprinklers. The two sprinklers which have fixed plate were: Single Blue plate-(FPS1) and Multiple Pads (Blue & Black Plates) sprinklers (FPS2). The other two sprinklers with dynamic plate were standard black plate 10-grooves plate (DPS1), and standard 9-grooves plate (DPS2). Based on sprinklers' manufacturer's data, suitable pressure regulator has been selected per each sprinkler, so all sprinklers have been operated under 1,00 bar except 10-grooves plate (DPS1) which is operated under 0.7 bar, Table 2.

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Table 2. Sprinklers' operational features based on manufacturer's da

Sprinkler Name	Plate Type	Streams number	Operating Pressure, bar	Flow Rate, l/min	Wetted Radius, m
(FPS1)	Fixed	36	1	11.94 to 40.69	4 to 5.2
(FPS2)	Fixed	66	1	14.8 to 36	4.85 to 6.8
(DPS1)	Dynamic	9	1	20 to 43	8.5 to 9
(DPS2)	Dynamic	10	0.7	20 to 43	9 to 10

Four irrigations events were applied to the runoff plots with an irrigation intervals of 3 days to allow the soil surface to dry and soil profile to drain between irrigations. All irrigation applications were to bare soil conditions.

As concerns, soil texture and its particle analysis, Table 3 shows the soil texture used in this study.

Table 3. Particle size distribution of the soil used in this study.

Soil Texture	Sand, %	Silt, %	Clay, %
Loam	45	40	15

Sixteen runoff plots boxes were arranged in a four row by four columns under the overhang to receive the application rate of each sprinkler set. The metal frames were installed at a constant slope of 5% on the surface of each runoff plot box and the soil within the metal frames graded smooth. The rather steep slope and smoothed soil surface of the plots were selected to minimize the unknown and variable surface storage component of the infiltration-runoff process. Consequently, the runoff measured in this study represent maximum rates for worse conditions. Actual field runoff would be substantially less due to soil surface micro topography storage, sustained higher infiltration rates due to residue management and less slope. The runoff obtained in this study represent potential runoff for sloping conditions rather than actual field rates.

The four sprinkler configurations (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 to protect the soil surface and prevent water application when overhang passed over the plot area with a particular sprinkler treatment. All the tarps were installed and removed at the same time to minimize differences in soil drying between irrigation events, Fig. 2.

Fig. (2): Diagram showing experimental plot layout used to evaluate center pivot sprinkler runoff

3. RESULTS & DISCUSSION

As per the sprinklers' chart which is created specifically for this study; the irrigated area under the overhang was 15 acres (62,974 m^2) when pivot completes its full cycle in 10.87 hours as declared in Table 1.

Required flow to irrigate such area was 25.3 m^3/hr, while the actual flow delivered by nozzles sizes available at the overhang pipes was 25.5 m^3/hr with 1% deviation of the required flow.

Average application rate in mm/hr per each sprinkler under each span is calculated using equation 2 based on the data supplied by the manufacturer of each sprinkler. Fig. 3 reveals the average application rate under each span per each sprinkler.

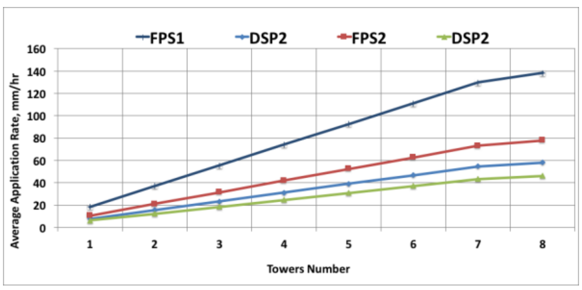

Fig. (3).: Average application rate under each span per each sprinkler.

Application depths for each irrigation event are increased from 4.22, 5.63 and 8.45mm per revolution while timer setting decreased from 100% to 75% and 50% respectively. Its accumulated depths during the four irrigation events are varied to be 16.88 to 22.52 and 33.8m with 100%, 75% and 50% timer setting respectively.

Percent runoff as in (King, 2007) (runoff volume / application volume x 100) for each sprinkler type with the first event and three forward speed at timer setting of 100%, 75% and 50% are shown in Fig. 4 through 7.

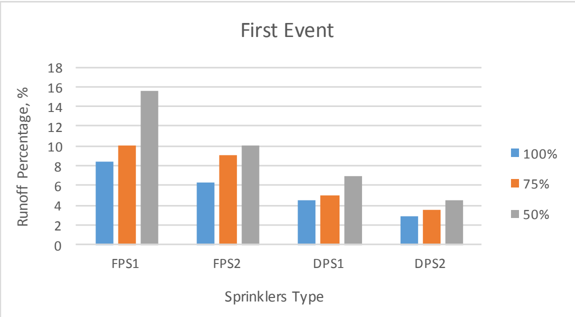

Fig. 4.: Runoff percentage during first irrigation event at three different timer setting

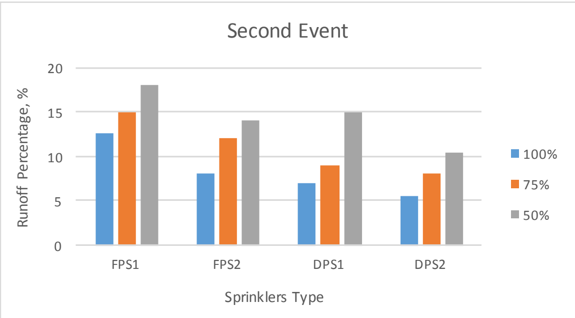

Fig. 5.: Runoff percentage during second irrigation event at three different timer setting

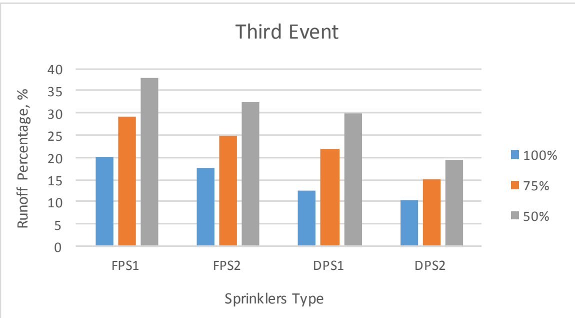

Fig. 6.: Runoff percentage during third irrigation event at three different timer setting

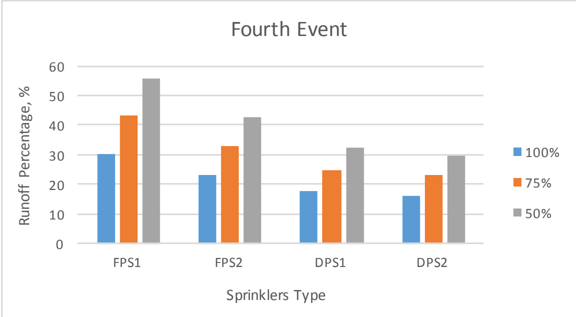

Fig. 7.: Runoff percentage during fourth irrigation event at three different timer setting

Runoff measurements were highly variable despite the controlled experimental conditions and small distances between plots, limiting detection of large differences in runoff among sprinkler types. In general, percent runoff increased with the number of irrigations. This result is attributed to reduced infiltration rates caused by soil surface sealing due to sprinkler droplet impact on the bare soil surface and inline with the findings of (Thompson, 1985), (DeBoer D. A.-J., 1988), (Agassi, 1994) and (Lersch, 2000)

However, during all irrigation events FPS1 sprinkler produced the highest runoff volumes. The peak application rate of FPS1 sprinkler was about 50% higher than the DPS1 or DPS2 sprinklers due to its smaller wetted diameter. The higher peak application rate of the FPS1 sprinkler is largely responsible for the high measured runoff despite the lower kinetic energy of the droplets due to there smaller size.

Percent runoff continued to increase from second event to fourth one indicating that soil surface sealing increased with continued irrigation due to increasing the application rate than the infiltration rate of the soil.

Fig 8 through 10 reveal the effect of three forward speeds at timer setting of 100%, 75% and 50%, on percent runoff occurred by different sprinklers during the four irrigation events.

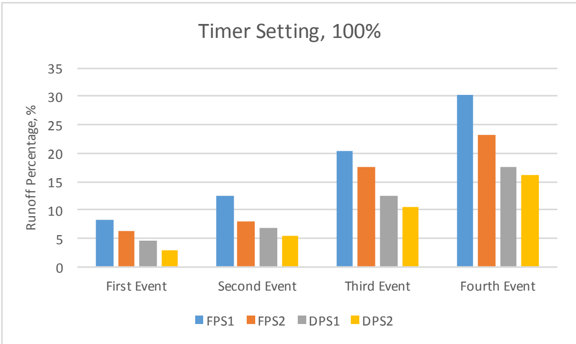

Fig. 8.: Runoff percentage at 100% timer setting during irrigation events

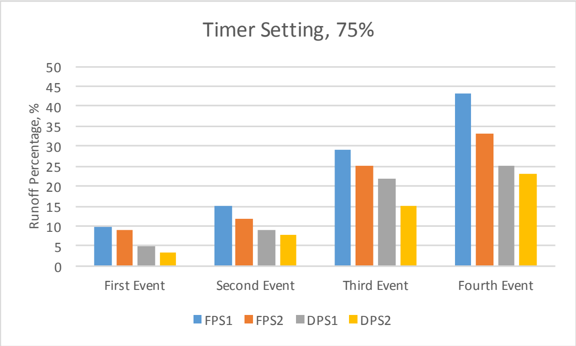

Fig. 9.: Runoff percentage at 75% timer setting during irrigation events

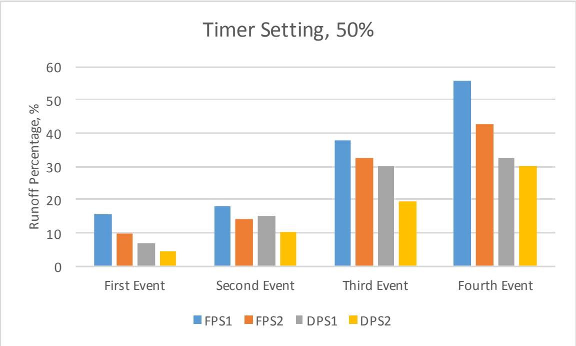

Fig. 10.: Runoff percentage at 50% timer setting during irrigation events

As shown in Fig. 8 through 10, percent runoff increased with all sprinklers when reducing the forward speed from 3.95 m/min (100% timer setting) to 2.96 m/min (75% timer setting) and 1.97 m/min (50% timer setting). That due to reducing forward speed of the last tower results in increasing the application depth from 4.22, 5,63 and 8.45 mm of water depth.

FPS1 sprinkler exhibited less than 10% runoff of applied water at the highest forward speed (100% timer setting) whilst exhibited more than 50% at the lowest forward speed (50% timer setting). On the other hand, DPS2 sprinkler showed less than 5% runoff of applied water at the highest forward speed (100% timer setting) compared to 30% runoff occurred at the lowest forward speed (50% timer setting). That means dynamic plate sprinklers (DPS) are exhibited 20% less runoff at the same forward speed and irrigation event compared to fixed plate sprinklers (FPS).

This result considers as an important indicator to the growers and pivots operators when select sprinklers package with the center pivots in order to minimize the runoff special during the summer when applying enough water to meet the peak consumptive use of the crop.

Percent runoff continued to increase for event three through four indicating that soil surface sealing increased with continued irrigation without reaching a maximum. By the fourth irrigation event a trend in runoff percentage differences between sprinkler types began to appear but additional testing is required to verify this result.

4. CONCLUSIONS

Potential runoff from four sprinklers were evaluated under three different timer setting of center pivot irrigation during applying four irrigation events on loamy soil.

There were large differences in runoff percentages between center pivot sprinkler types for the soils tested and experimental conditions. Overall, the FPS1 sprinkler exhibited the highest runoff and the DPS2 sprinkler exhibited the lowest rates for the four irrigation events. In general sprinkler types that have fixed plate exhibited the highest runoff percentages. Additional research is needed to examine the infiltration and runoff processes under the study conditions in more detail in order to explain the results.

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