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Effects of Travel Speed and Collector on Evaluation of the Water Application Uniformity of a Center Pivot Irrigation System

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Abstract: Water application uniformity is an important performance parameter when designing and operating an irrigation system. Performance tests of a center pivot irrigation system equipped with fixed and rotated spray plate sprinklers (FSPS and RSPS, respectively) were conducted at five travel speeds. The effects of travel speed, collector size, and setting height on water application uniformity were evaluated using Heermann and Hein's coefficient of uniformity (CU_H). The CU_H was 12.7% higher for the RSPS than the FSPS and decreased as the travel speed increased. Collector size and setting height affected CU_H, and CU_H was higher when the collector had a large opening cross-section compared to the collector with a small opening cross-section. CU_H was higher when the collector with a low setting height compared to when it a high setting height for the FSPS. However, collector setting height had no effect on CU_H for the RSPS. The weighted average water application depth (D_w) decreased as the travel speed increased. Collector size had no significant effect on D_w, but D_w with a low collector setting height was larger than the values with a high collector setting height. The water application rate increased as distance from the pivot point increased and was higher for the FSPS than the RSPS. The results will improve the selection of travel speed and collector when the water application uniformity of a center pivot irrigation system is evaluated.

Keywords: center pivot irrigation; sprinkler; travel speed; collector; water application uniformity

1. Introduction

A variety of sprinkler irrigation systems are widely available for use, such as center pivot, lateral move, solid set, side roll, traveler, and hand move systems. Among these irrigation systems, center pivot irrigation systems have been shown to be water and labor efficient, and can easily irrigate relatively flat and wide areas of land [1–4]. Water application uniformity is important when designing and operating a sprinkler irrigation system [5]. Poor water distribution by center pivot systems can lead to surface water ponding, runoff, and leaching of agricultural chemicals into the groundwater [6–9]. The significant influence of water application uniformity on crop production [10] means that uniform water application should be taken into account when using center pivot irrigation systems.

Center pivot irrigation systems are increasingly equipped with low-pressure sprinklers to reduce energy consumption [11,12]. Currently, fixed and rotated spray plate sprinklers (FSPS and RSPS, respectively) are the two most popular types [13–15]. Some studies have evaluated the water application uniformity of the center pivot irrigation system and the effects that various factors have on it. Yan et al. [16] analyzed the effect of the percent timer parameters on the water application distribution of a center pivot irrigation system equipped with FSPS. Ouazaa et al. [17] analyzed the effect of different tower movement dynamics and wind speeds on the water application uniformity of center pivot irrigation systems and found that the sprinkler packages had a strong effect on irrigation performance. Abd El-Wahed et al. [18] evaluated the effect of operating pressure, sprinkler spacing, and height of sprinkler above the ground surface on the water application uniformity of a center pivot irrigation system. Their results showed that the water distribution uniformity increased when the height of the sprinkler above the ground surface was increased because the increased height gave a larger wetted diameter for the same nozzle. Ortiz et al. [10] compared RSPS and FSPS placed at two heights above the ground and found that the RSPS had higher water application uniformities. However, the FSPS and RSPS were simultaneously installed at the system spans. To date, there have been few studies on evaluation of sprinkler type effects on water application uniformity across an entire system.

The effects of travel speed on the water application uniformity of center pivot or lateral move irrigation systems have been reported. However, these studies produced different research results, including no effect [19], a positive effect [20], and a negative effect [21]. Therefore, there needs to be more research on the effect of travel speed on water application uniformity.

The collector also affects evaluation of the water application uniformity of center pivot irrigation systems. Rogers et al. [22] investigated the effect of collector size and spacing on center pivot uniformity evaluations. The results showed that water application uniformity appeared to be relatively insensitive to collector spacing, but uniformity variability and inconsistency was related to collector size. However, the setting height of the collector varied in different studies. Therefore, further research is needed on the effect of collector setting height on water application uniformity.

The objectives of this study were (1) to evaluate the water application uniformity of a center pivot irrigation system equipped with two types of low-pressure sprinklers, and (2) to investigate the effect of travel speed, collector size, and setting height on water application uniformity. The results from these evaluations of water application uniformity in a center pivot irrigation system should help to improve the selection of suitable travel speeds and collectors.

2. Materials and Methods

2.1. Experiment Sites and System Descriptions

Field tests on a center pivot irrigation system equipped with 31 sprinklers were carried out at Tongzhou Experimental Station, China Agricultural University. The experimental site was in flat terrain located at 39°41′59.38″ N, 116°41′0.94″ E and had an elevation of 21 m. The center pivot irrigation system had two spans and an overhang as shown in Figure 1. The lateral pipe was 168 mm in diameter and the irrigation water was supplied at a constant pressure of 200 kPa. The FSPS analyzed in this study was a D3000 Sprayhead equipped with the blue deflector plate, and the RSPS was a R3000 Rotator equipped with the brown deflector plate. These sprinklers were set approximately 1.6 m above the ground surface and with a spacing of 2.88 m. Nozzle numbers for the different sizes ranged from #9 to #33 out of the 42 size numbers listed in the 3000 Series 3TN Nozzle System catalog. The sprinklers and the nozzles were manufactured by Nelson Irrigation Corporation (Walla Walla, WA, USA, mention of trademarks does not imply an endorsement). The 31 pressure regulators (103 kPa) were able to maintain a constant sprinkler inlet pressure. The main technical parameters of the system are shown in Table 1, and the nozzle number and sprinkler discharge along the lateral pipe of the investigated system are shown in Figure 2.

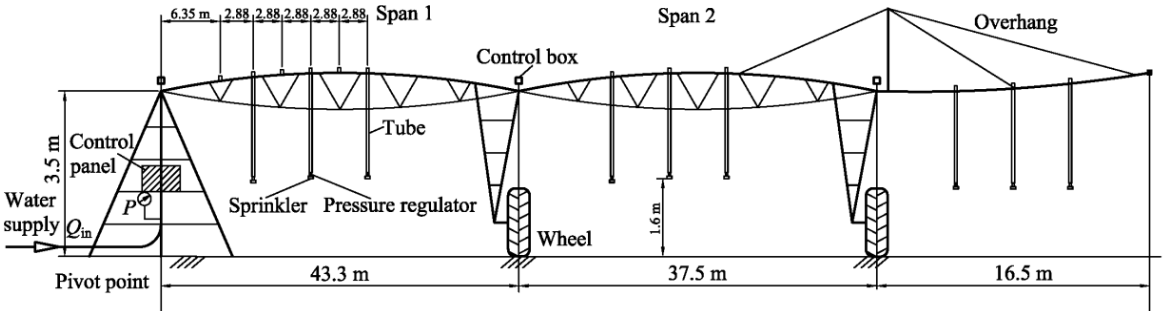


Figure 1. Structural components of the investigated center pivot irrigation system.

Table 1. Technical parameters of the center pivot irrigation system.

Item	Value	Item	Value
Pivot length (m)	97.3	Motor input speed (rpm)	1425
Area irrigated (hm^2)	3.0	Motor reducer gear ratio	40:1
System design discharge ($m^3\ h^{-1}$)	25	Wheel reducer gear ratio	50:1
System design pressure (kPa)	200	Outermost tower velocity ($m\ min^{-1}$)	2.78
Tire specification	14.9–24	Minimum hours per revolution (h)	3.04
Dynamic radius of tire (m)	0.609	Minimum application depth per revolution (mm)	2.56

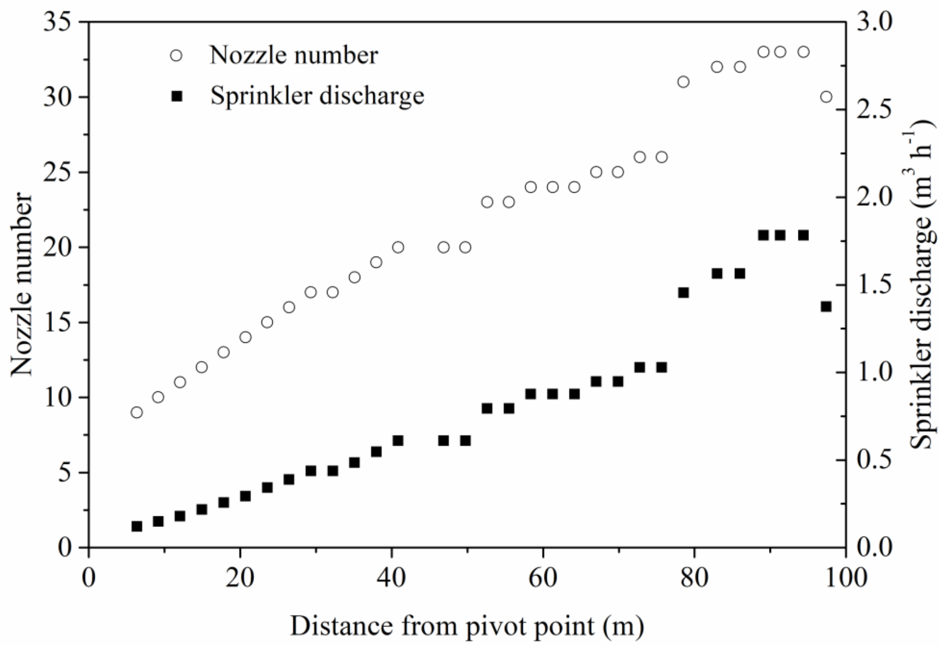


Figure 2. Nozzle number and sprinkler discharge along the lateral pipe of the center pivot irrigation system.

2.2. Experimental Setup and Test Procedures

The water application uniformity tests were conducted on the center pivot irrigation system in October 2015 after the maize had been harvested and were in accordance with the ANSI/ASAE S436.1 [23] and ISO 11545 [24] standards. A schematic illustration of the experimental apparatus is shown in Figure 3a. The collectors were 240 mm in height and had an opening diameter of 215 mm. They were uniformly spaced 3 m apart along two radial straight lines and the distance between the distal ends of the two lines was 16.5 m. The operating pressure and discharge of the system were separately measured using a pressure gauge at the pivot pipe and an ultrasonic flowmeter at the water inlet pipe that was connected to the pivot pipe. The water application depth was adjusted by controlling the travel speed, which was governed by a percent timer [16]. There were five percent timer settings (*PTS*s), which were 20%, 40%, 60%, 80%, and 100%. Water application uniformity tests with *PTS*s = 20%, 40%, and 60%, were conducted in test area I and the water application uniformity tests with *PTS*s = 80% and 100% were conducted in test area II. The whole field was relatively flat, and the slope was almost zero in test areas I and II. Wind speed and direction were measured every 15 min by a three-cup anemometer with a DEM6 (Zhonghuan TIG Meteorological Instruments Co., Ltd., Tianjin, China). The water collected in the collectors was weighed on an electrical scale with an accuracy of 0.1 g, and then the applied water volume was converted to the applied water depth by dividing it by the cross-sectional area of the collector. The effects of collector size and setting height on water application uniformity were evaluated using two different collectors and two height settings on Line 1: (1) collector I (215 mm opening diameter, 240 mm in height) was directly placed on the ground surface, and the vertical distance between the sprinkler and the opening of the collector was approximately 1.36 m; (2) collector II (89 mm opening diameter, 160 mm in height) was supported approximately 240 mm above the ground surface by iron brackets, and the vertical distance between the sprinkler and the opening of the collector was approximately 1.36 m; and (3) collector III (89 mm opening diameter, 160 mm in height) was supported approximately 1100 mm above the ground surface by iron brackets, and the vertical distance between the sprinkler and the opening of the collector was approximately 0.5 m (Figure 4). In each test scheme, the time that the four type I collectors received water at particular radial positions (15, 30, 60, and 90 m) was recorded by a stopwatch. The applied water depth was converted to application rate (R_a) by dividing it by the time at which the collector received water [25,26]. The main environmental parameters of the tests are shown in Table 2.

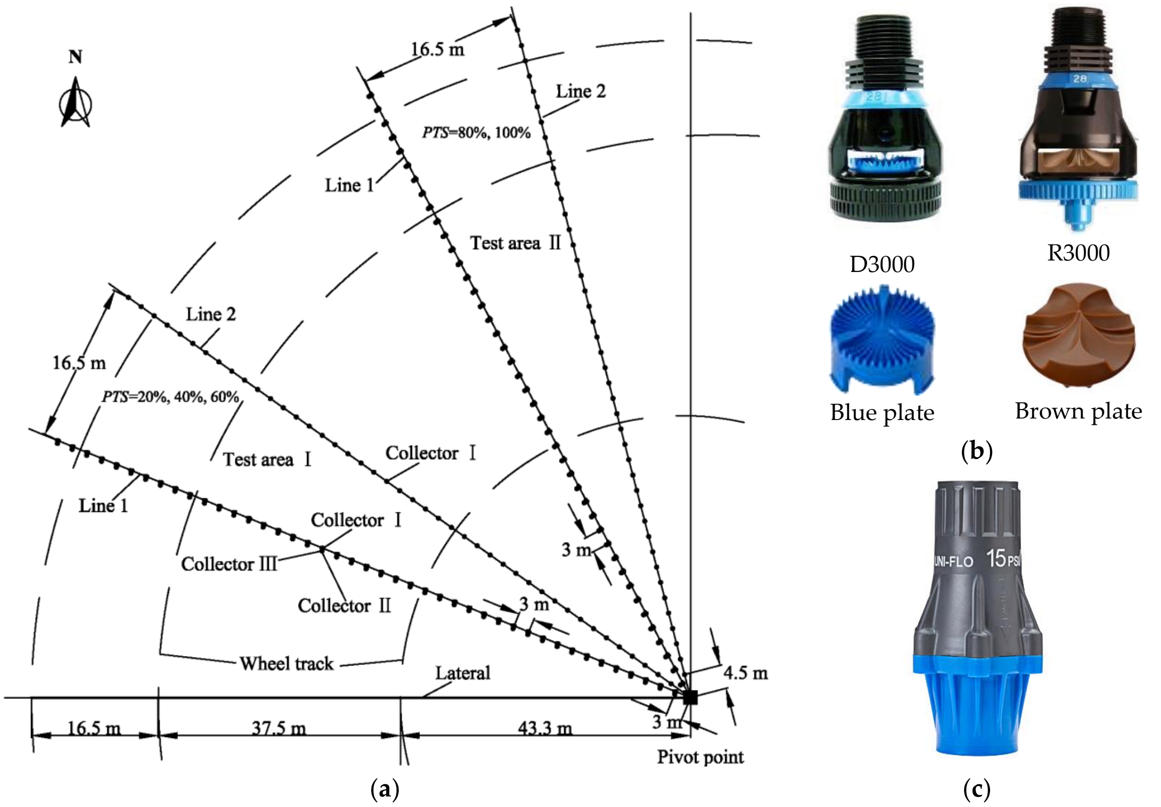
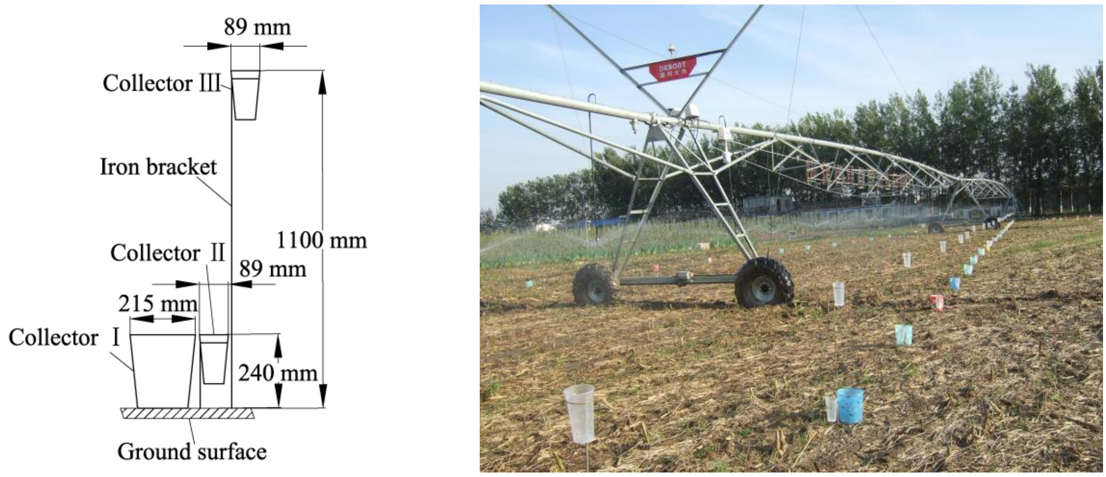


Figure 3. Schematic diagram of the experimental apparatus used to evaluate the performance of the center pivot irrigation system: (**a**) schematic diagram of the experiment; (**b**) FSPS with blue fixed spray-plates (D3000) and RSPS with brown rotated spray-plates (R3000); and (**c**) pressure regulator (103 kPa).



(**a**) (**b**)

Figure 4. Layout of the collectors during the performance evaluation of the center pivot irrigation system: (**a**) collector size and setting height on Line 1; (**b**) photograph of the experimental setup.

Table 2. Main environmental parameters of the field tests.

Sprinkler	***PTS* (%)**	**Average Air Temperature (°C)**	**Average Relative Humidity (%)**	**Average Wind Speed (m/s)**	**Prevailing Wind Direction**
	20	25.0	25.0	0.8	Southwest
	40	24.7	32.0	0.3	West
FSPS	60	22.5	38.0	0	-
	80	25.0	27.0	0.4	Southwest
	100	16.0	61.0	0.4	Southeast
	20	23.4	43.5	0.5	East
	40	23.0	47.5	0.1	Northeast
RSPS	60	24.0	37.7	0.2	Southeast
	80	25.0	33.7	1.3	South
	100	25.0	30.0	0.2	East

2.3. Data Analysis

The coefficient of uniformity for the center pivot irrigation system was calculated by a modified version of Heermann and Hein's formula [23,27] (Equation (1)):

$$CU_H = 100\left[1 - \frac{\sum_{i=1}^{N} |D_i - D_\mathrm{w}| S_i}{\sum_{i=1}^{N} D_i S_i}\right] \tag{1}$$

where CU_H is Heermann and Hein's coefficient of uniformity (%), N is the number of collectors used in the data analysis, i is a number used to identify a particular collector, normally beginning with the collector located nearest the pivot point (i = 1) and ending with i = N for the collector furthest from the pivot point, D_i is the application depth of the water collected in the ith collector (mm), S_i is the distance of the ith collector from the pivot point (m), and D_w is the weighted average application depth of water collected (mm), calculated as Equation (2):

$$D_\mathrm{w} = \sum_{i=1}^{N} D_i S_i / \sum_{i=1}^{N} S_i \tag{2}$$

The differences in CU_H and D_w of the center pivot irrigation system with two types of sprinklers at different travel speeds and under different collectors were tested using one-way analysis of variance (ANOVA; assessed as significant at the $P < 0.05$ level). The statistical data analyses and graphs were prepared with SPSS 23.0 analytical software (IBM Corp., Armonk, NY, USA) and OriginPro 2016 software (OriginLab, Northampton, MA, USA).

3. Results and Discussion

3.1. Effect of Travel Speed on Water Distribution and Application Uniformity

The travel speed of the center pivot has important effects on water distribution and application uniformity. There are different viewpoints and research results about the effect of travel speed on water application uniformity, including no effect [19], a positive effect [20], and a negative effect [21]. In this study, the relationship between water application depth and distance from the pivot point for collector type I is shown in Figure 5 for the FSPS and RSPS at the five travel speeds. It was clear that there were different water application depths along the radius between the two types of sprinklers for the various *PTS*s. Among them, the D_w values of the five *PTS*s (20%, 40%, 60%, 80%, and 100%) for the FSPS were 10.1 mm, 5.6 mm, 3.7 mm, 2.7 mm, and 2.3 mm, respectively, whereas they were 10.8 mm, 5.7 mm, 3.8 mm, 2.6 mm, and 2.1 mm for the RSPS, respectively. These findings indicated that the water application depth gradually decreased as the *PTS* increased for both sprinkler types, which was similar to previous findings by Dogan et al. [19]. The water application depths of the FSPS and RSPS were similar, and the differences between the two sprinkler types did not exceed 0.7 mm for any of the five *PTS*s. Therefore, sprinkler type had little impact on the water application depth.

The effect of travel speed on the water application uniformity of the center pivot irrigation system was investigated further. Table 3 shows CU_H values of the system with the two types of sprinklers for collector I at the five travel speeds. Overall, the RSPS had better CU_H values than the FSPS, and the CU_H values decreased with *PTS* for both the sprinklers. These results were in good agreement with those reported by Hills, et al. [21]. For example, the CU_H values corresponding to the five *PTS*s (20%, 40%, 60%, 80%, and 100%) were 72.8%, 73.1%, 67.4%, 70.1%, and 65.0% (69.7% on average) for the FSPS, respectively. However, the values changed to 80.3%, 80.1%, 79.5%, 75.6%, and 77.0% (78.5% on average) when switching from the FSPS to the RSPS, respectively. The CU_H values for the RSPS at the five *PTS*s were 8.8 percentage points higher on average than the FSPS values, and the RSPS produced smaller magnitude changes when the different *PTS*s were applied than the FSPS (3.3 versus 7.8 percentage points on average, respectively). This might be due to the fact that the rotary spraying characteristics of the RSPS meant that the water overlap between adjacent sprinklers was greater. Taken together, the results showed that the *PTS* influence on the D_w and CU_H values cannot be ignored. A lower *PTS* led to higher D_w and CU_H values, and vice versa. This means that it is critically important to determine the most appropriate *PTS* when operating a center pivot irrigation system. Although the two sprinkler types had similar D_w values at the same *PTS*, the CU_H improvement was better with the RSPS than with the FSPS. Therefore, the RSPS are more appropriate for center pivot irrigation systems when high water application uniformity is needed.

Figure 6 shows the CU_H fitting equations for the two sprinkler types at the different *PTS*s for collector I. Notably, the CU_H and *PTS* values for both the FSPS and RSPS had a good linear function relationship, as shown in the following Equations (3) and (4):

$$\text{For the FSPS}: \quad CU_H = -0.094\,PTS + 75.313 \quad \left(R^2 = 0.718\right) \tag{3}$$

$$\text{For the RSPS}: \quad CU_H = -0.056\,PTS + 81.873 \quad \left(R^2 = 0.715\right) \tag{4}$$

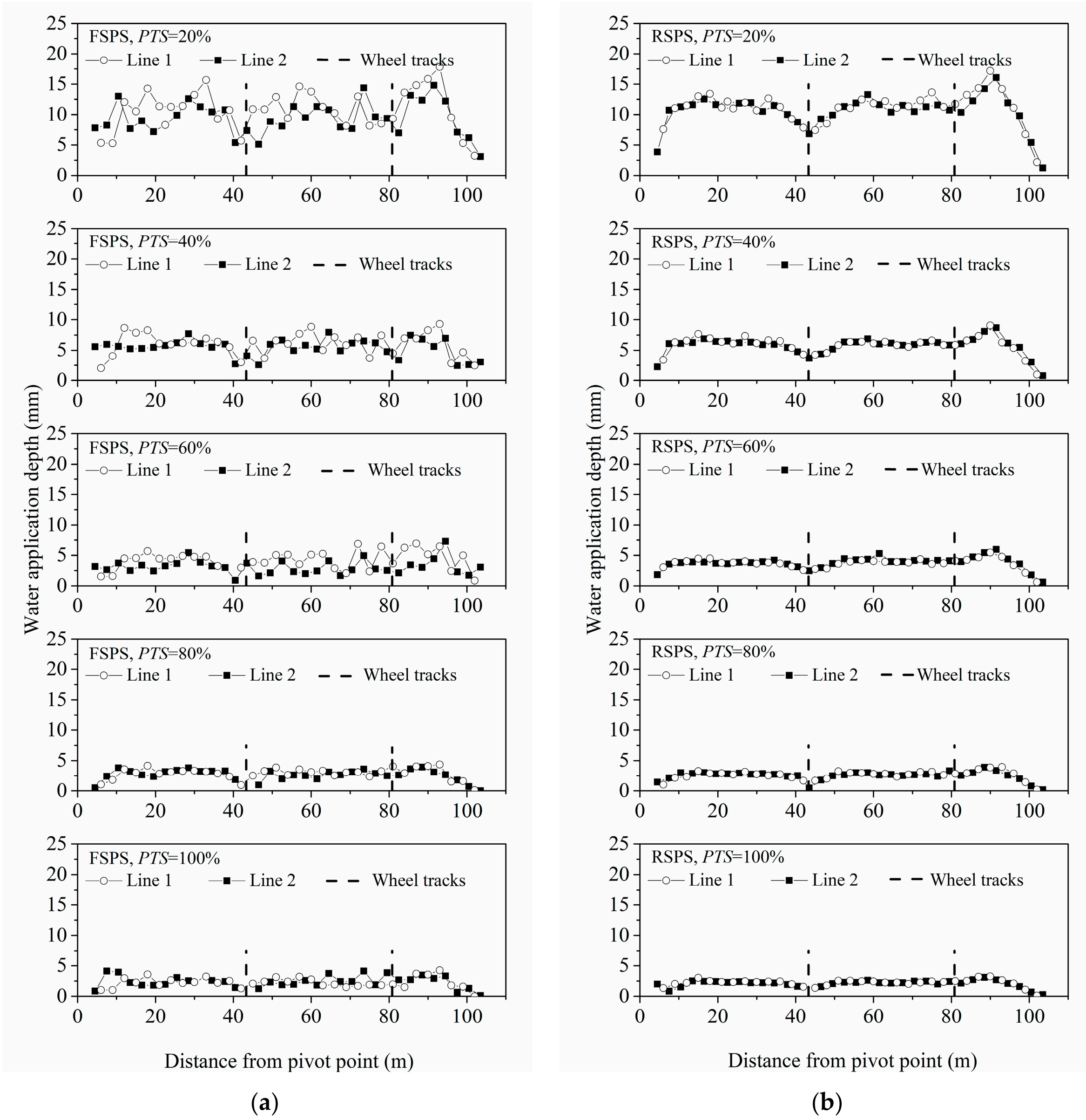


Figure 5. Water application depth versus distance from the pivot point for collector I: (**a**) FSPS, *PTS* = 20%–100%; (**b**) RSPS, *PTS* = 20%–100%.

Table 3. Water application uniformities of the center pivot irrigation system with FSPS and RSPS for collector I at the five travel speeds.

Sprinkler	*PTS* (%)	CU_H (%)		
		Line 1	**Line 2**	**Overall**
FSPS	20	72.5	73.2	72.8
	40	72.8	73.5	73.1
	60	67.1	67.9	67.4
	80	70.8	69.2	70.1
	100	65.7	64.3	65.0
	Mean	69.8	69.6	69.7
RSPS	20	80.6	80.0	80.3
	40	80.4	79.9	80.1
	60	80.0	79.0	79.5
	80	76.6	74.5	75.6
	100	77.4	76.5	77.0
	Mean	79.0	78.0	78.5

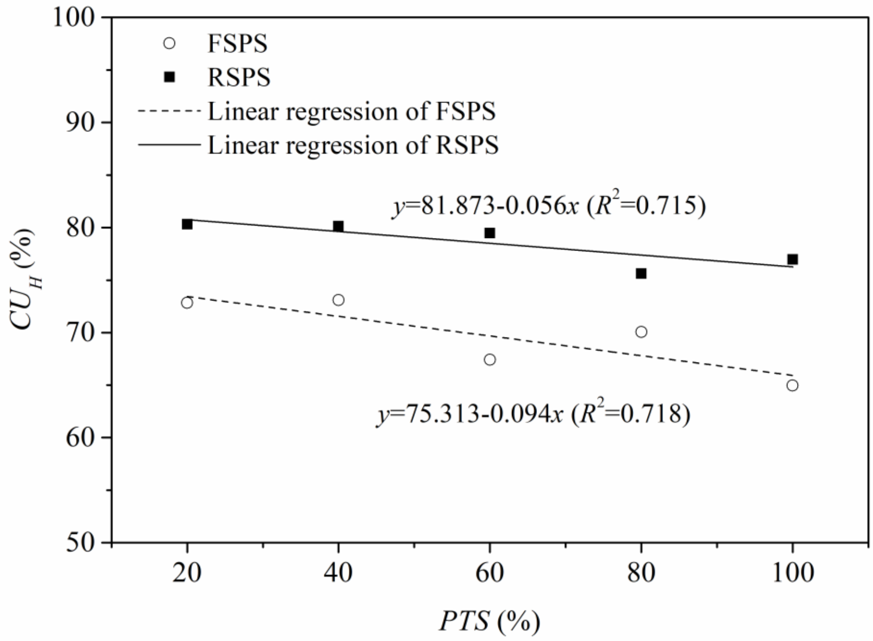
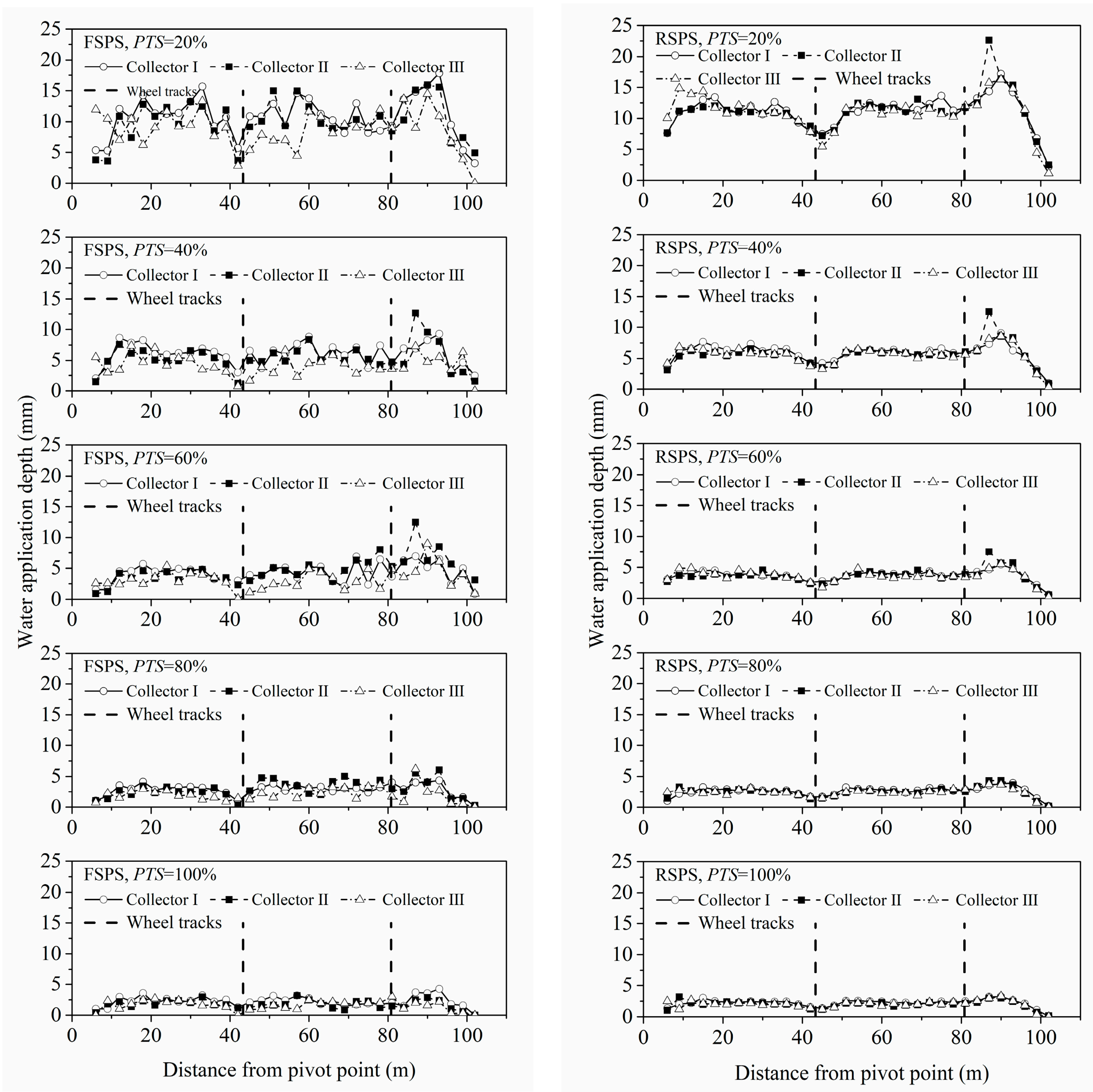


Figure 6. Relationship between water application uniformity and the travel speed in the center pivot irrigation system with FSPS and RSPS for collector I.

3.2. *Effect of Collector Size and Setting Height on Water Distribution and Application Uniformity*

Collector size and setting height are related to the water application depths at the different measuring points, which in turn affect the water application uniformities of center pivot irrigation systems. Figure 7 shows the relationship between water application depth and distance from the pivot point for FSPS and RSPS at the five travel speeds and for the three types of collector. Overall, collectors I and II (low collectors placed directly on the ground and 240 mm above the ground, respectively) had the larger D_w values among the three collector types, followed by collector III (high collector placed 1100 mm above the ground) regardless of the sprinkler type or travel speed. Taking the FSPS as an example, the mean D_w values at the five travel speeds averaged 5.3 mm, 5.2 mm, and 3.9 mm for collectors I, II, and III, respectively (Table 4). These results indicated that the D_w value was not obviously related to the collector size but was inversely proportional to the setting height.



(**a**) (**b**)

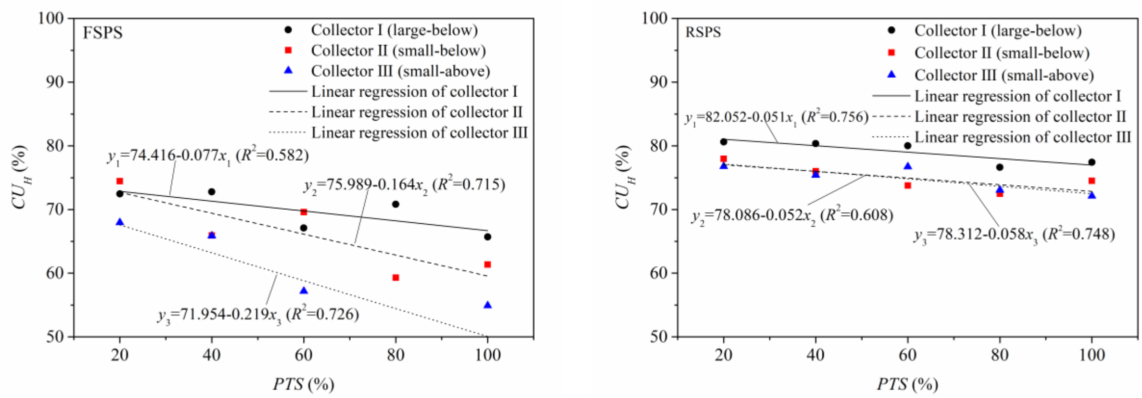
Figure 7. Water application depth versus distance from the pivot point for the three types of collectors: (**a**) FSPS, *PTS* = 20%–100%; (**b**) RSPS, *PTS* = 20%–100%.

In addition, from the perspective of water application uniformity versus travel speed (Figure 8), the overall CU_H values for the large size collectors and the low setting height collectors were above those recorded for the small size collectors and the high setting height collectors, except for individual cases caused by environmental factors. For the FSPS, the mean CU_H value of collector I at the five *PTS*s were 3.6 and 10.9 percentage points higher than the values for collectors II and III, respectively, whereas they were 4.1 and 4.2 percentage points higher for the RSPS, respectively. One possible explanation for this result is that large size and low setting height collectors could more fully achieve water overlap between adjacent sprinklers along the lateral pipe compared to the small size and high height setting collectors, which resulted in higher irrigation uniformity.

Further analysis indicated that the two linear regression lines (dashed line and dotted line) for the RSPS almost overlapped (Figure 8b), which showed that the CU_H values at the various *PTS*s for collector II were relatively close to the values for collector III because the average difference between the two collector types was only 0.1 percentage points. This occurred because the water from the RSPS had been sufficiently atomized when the jet left the spray plate, which meant that the setting height of the collector had no obvious effect on CU_H. In summary, the RSPS had good CU_H values for the different collector conditions and played a positive role in reducing the influence of collector setting height on CU_H. The highest water application uniformity was achieved using large size collectors and the greatest water application depth was obtained using low height collectors, and vice versa. This provides a basis for the reasonable selection of collectors in future studies on the performance of center pivot irrigation systems.

Table 4. Weighted average water application depths for the three types of collectors at the five travel speeds.

Sprinkler	*PTS* (%)	D_w (mm)		
		Collector I	**Collector II**	**Collector III**
	20	10.9	10.4	8.5
	40	6.0	5.6	4.1
FSPS	60	4.4	5.3	3.5
	80	2.9	3.1	2.1
	100	2.2	1.7	1.5
	Mean	5.3	5.2	3.9
	20	11.2	11.4	10.7
	40	5.8	5.8	5.4
RSPS	60	3.7	3.7	3.4
	80	2.7	2.5	2.4
	100	2.2	1.9	2.0
	Mean	5.1	5.1	4.8



(**a**) (**b**)

Figure 8. Effects of collector size and setting height on the water application uniformities produced by the two sprinkler types at the five different travel speeds: (**a**) FSPS; (**b**) RSPS. Note: subscripts (1, 2, and 3) in the linear regression equations correspond to the different collector levels (I, II and III).

3.3. Analysis of Variance Results for the Effect of Various Factors on Water Application Uniformity

The effects of various factors (travel speed, collector size, setting height, and sprinkler type) on water application depth and uniformity were further investigated by undertaking an ANOVA of the effect of each factor on the CU_H and D_w values (Tables 5 and 6, respectively). The interaction among various factors was not considered. The results showed that sprinkler type was the only one of these four factors that had a significant effect on CU_H (P = 0.000), followed by insignificant collector size (P = 0.164) and setting height (P = 0.338) effects. Travel speed had the smallest effect (P = 0.352) (Table 5). In contrast, although travel speed only had a minor effect on the CU_H, its impact on D_w was significant (P = 0.000) (Table 6). These findings revealed that travel speed and sprinkler type have critically important effects on the water application depth and uniformity of center pivot irrigation systems. Therefore, it is important to set an appropriate travel speed for center pivot irrigation systems. This speed is related to crop growth and to the utilization coefficient for irrigation water. Furthermore, RSPS are recommended when using center pivot irrigation systems because they produce better water application uniformities

Table 5. Analysis of variance results for the effect of various factors on CU_H.

Factor	Sum of Square of Deviation	Degree of Freedom	Mean Square Deviation	*F* Value	*P* Value
Travel speed	287.679	4	71.920	1.159	0.352
Collector size	73.728	1	73.728	2.102	0.164
Collector setting height	69.192	1	69.192	0.969	0.338
Sprinkler type	964.467	1	964.467	30.885	0.000

Table 6. Analysis of variance results for the effect of various factors on D_{w}.

Factor	Sum of Square of Deviation	Degree of Freedom	Mean Square Deviation	*F* Value	*P* Value
Travel speed	280.640	4	70.160	151.468	0.000
Collector size	0.018	1	0.018	0.002	0.969
Collector setting height	3.042	1	3.042	0.295	0.594
Sprinkler type	0.225	1	0.225	0.022	0.884

3.4. Water Application Rate

The R_{a} values at the four typical radial positions (15, 30, 60, and 90 m) in the system equipped with the FSPS and RSPS are shown in Figure 9 at *PTS* = 20% and 40%. The R_{a} generally rose as the distance from the pivot point increased. There was a linear relationship between the water application rate and the distance from the pivot point, as shown in the following equations:

$$\text{For the FSPS at PTS} = 20\% : R_a = 0.49\ S_i + 2.92 \qquad \left(R^2 = 0.999\right) \tag{5}$$

$$\text{For the RSPS at PTS} = 20\% : R_a = 0.44\ S_i - 1.91 \qquad \left(R^2 = 0.929\right) \tag{6}$$

$$\text{For the FSPS at PTS} = 40\% : R_a = 0.48\ S_i + 5.83 \qquad \left(R^2 = 0.958\right) \tag{7}$$

$$\text{For the RSPS at PTS} = 40\% : R_a = 0.42\ S_i - 0.02 \qquad \left(R^2 = 0.873\right) \tag{8}$$

In theory, travel speed has no effect on R_{a} [28]. The linear regression Equations (5) and (7) between R_{a} and S_i for FSPS at *PTS* = 20% and 40% were similar with comparable slope values, which agreed with the theoretical analysis. The same result was obtained for RSPS (linear regression Equations (6) and (8).

Further analysis indicated that the R_{a} values for FSPS along the lateral pipe were higher than the values for RSPS (Figure 9), which showed that the FSPS had relatively poor R_{a} values along the lateral pipe of the center pivot irrigation system. Surface runoff is more likely to occur when FSPS are used if the radial position R_{a} values significantly exceed the soil infiltration rate. Therefore, measures need to be taken to reduce or control surface runoff, such as installing a boomback system [29] or a control apparatus to adjust the sprinkler height [30]. Alternatively, an appropriate polyacrylamide compound could be applied [31].

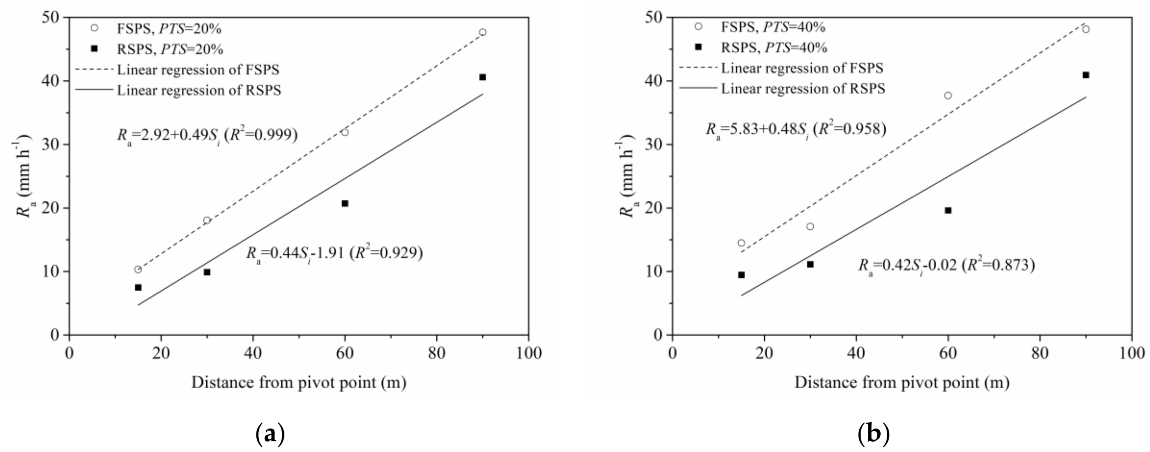


Figure 9. Water application rates at the four radial positions (15, 30, 60, and 90 m) in the center pivot irrigation system with FSPS and RSPS at two travel speeds: (**a**) *PTS* = 20%; (**b**) *PTS* = 40%.

4. Conclusions

This study investigated the effect of travel speed, collector size, and setting height on the water distribution and application uniformity of a center pivot irrigation system equipped with FSPS and RSPS. The D_w and CU_H values gradually decreased as the travel speed increased for both sprinkler types. The CU_H was higher for RSPS than for FSPS and the RSPS proved more appropriate for center pivot irrigation systems when high water application uniformity is needed.

The collector size and setting height affected the water application uniformity evaluation. Generally, collector size had no obvious effect on D_w. However, the D_w values for collectors with a high setting height were lower than the values for collectors with a low setting height. The results for both types of sprinklers showed that CU_H was higher when the collector had a large opening cross-section compared to the collector with a small opening cross-section. In the case of FSPS, CU_H was higher when the collector with a low setting height compared to when it a high setting height. However, the setting height of the collector had no effect on CU_H when RSPS were used.

From the ANOVA results, the sprinkler type was the only one of these four factors that had a significant effect on the CU_H, followed by the collector size and setting height, and the travel speed had the smallest effect. In contrast, although travel speed only had a minor effect on the CU_H, its impact on the D_w was significant. These findings revealed that it important to set an appropriate travel speed and to select a proper sprinkler type for center pivot irrigation systems.

Travel speed had no effect on R_a. However, the R_a values generally rose as the distance from the pivot point increased and were higher for the FSPS than for the RSPS. Furthermore, when the R_a values at a radial position significantly exceeds the soil infiltration rate, then surface runoff is more likely to occur if FSPS are used.

There are some limitations in this study. The water collected in the collectors was not weighed timely during the tests, which might lead to the measurement errors due to water evaporation. Both the collector size and setting height were set as two levels, which might not be sufficient to compare their effects on the water application uniformity. Moreover, the tested center pivot irrigation system had only two spans, with a full length of 97.3 m, which resulted in the difficulty of nozzle configuration and lower CU_H values.

Some research scopes need to be investigated in the future. More influencing factors, including wind speed, air temperature, relative humidity, and terrain slope, should be taken into account on the water application uniformity of a center pivot irrigation system. Moreover, more sprinkler types need to be compared to evaluate the water application uniformity according to different crop canopies and heights. Finally, optimal sprinkler package configurations are suggested to meet the requirements of water application uniformity at different climate conditions, crop growth periods and terrain slopes.

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