Evaluation of a Center Pivot Variable Rate Irrigation System

Ruixiu Sui Daniel K. Fisher

USDA-ARS Crop Production Systems Research Unit, Stoneville, Mississippi

Abstrat: Uniformity of water distribution of a variable rate center pivot irrigation system was evaluated. This 4-span center-pivot system was configured with 10 water application zones along its 766 ft-long lateral. Two experiments were conducted for the uniformity tests. In one test, a constant water application rate (100%) was applied, and in the other, variable application rates (0%, 30%, 50%, 70%, and 100%) were assigned to each zone. To catch water applied, multiple water collectors were placed in two straight lines perpendicular to the pivot travel direction. Three control collectors with known amounts of water were placed at the test site to account for water evaporation losses during the tests. Water caught in the collectors was measured, and the center pivot coefficient of uniformity (CU_H) was calculated. Results showed a CU_H of 86.5% for the constant application rate test. The effect of application rate on CU_H was significant, with higher application rates providing higher CU_H values.

Keywords: Irrigation, variable rate application, center-pivot irrigation system, uniformity, precision agriculture

INTRODUCTION

Uncertainty in the amount and timing of precipitation is one of the most serious risks to crop producers in the Mid-South. In recent years, producers in this region have become increasingly reliant on supplemental irrigation to ensure adequate yields and reduce risks of production. Increasing groundwater withdrawal is resulting in a decline in aquifer levels across the region. For sustainable water use in agriculture, increasing water-use efficiency in agricultural production has become a serious issue. Compared to furrow-irrigation methods, sprinkler systems can significantly improve irrigation efficiency, and their use is increasing in the Mid-South.

In the most of agricultural fields, soil characteristics and plant growth status considerably vary within a field. Plants in one location may need more inputs, such as water or fertilizer, than the plants in another location in the field. Treating plants differently based on their needs is required for optimizing crop yield and quality. Precision agriculture technologies make it possible for farmers to adjust production inputs site-specifically to address the spatial variability in the field. Sprinkler irrigation systems equipped with variable rate irrigation (VRI) controllers are now commercially available. Currently two primary control methods are used to realize VRI; speed control and duty-cycle control (LaRue and Evans, 2012). The speed control method varies travel speed of the center pivot to accomplish the desired application depth, while the duty-cycle control changes the duty cycle of individual sprinklers or a group of sprinklers.

Currently there is no standard method for evaluating a VRI system capable of making site-specific water application for precision agriculture practices. Limited work has been reported on the evaluation of VRI performance yet. The accuracy and uniformity of the system are essential for the success of precision irrigation management.

The objective of this study was to evaluate the accuracy and uniformity of a center-pivot irrigation system equipped with a VRI zone control package.

MATERIALS AND METHODS

System description

The center pivot VRI system used in this research was a Valley Standard Pivot 8000 coupled with the Valley VRI zone control package (Valmont Irrigation, Valley, NE). The system was installed at a research farm of the USDA-ARS Crop Production Systems Research Unit at Stoneville, Mississippi in November 2011 (Figure 1). The system was configured with a total length of 766 ft, with 4 drive units and a flow rate of 350 gpm. Fixed-pad sprinklers (Senninger LDN, Clermont, FL) were employed with UP3 flat medium groove pads and 15 psi pressure regulators. The distance from the sprinkler to ground surface was 72 in. Sprinkler spacing was 108 in, and 86 sprinklers along the length of the pivot lateral were divided into 10 control zones based on covered surface area.

The Valley zone control package included 5 VRI zone control units, a GPS receiver, and software. The control units and the GPS receiver were mounted on the top of pivot towers. Each VRI zone control unit controls the duty cycle of the sprinklers in two independent zones by turning on/off electric solenoid valves to achieve desired application depths in individual zones. The GPS receiver determines the pivot position for identification of the control zone in real time. VRI prescriptions can be created using the software provided in the package and wirelessly loaded up to the system.

Experiment setup

The system was tested under both constant application rate and variable application rate conditions. New plastic cups with a 3.5-in diameter opening and 5-in depth were used as collectors to measure the depth of water applied. Each collector was taped onto a wood stake which was inserted into the soil (Figures 2 and 3). The distance between the ground surface and the collector opening was approximately 8 in. The collectors were uniformly spaced along two straight lines perpendicular to the direction of travel of the pivot. The angle between the two lines of collectors was 12 degrees. In accordance with ASABE Standard S436.1 (ASABE Standards, 2007), no collectors were placed within the inner 20% of the effective radius of the pivot, 145 ft in this case. In the constant application rate test, 78 collectors were placed with a spacing of 8 ft in each line. In the variable rate test, 3 more collectors were added between each control zone, for a total of 105 collectors in each line. Details of the control zones and desired application rates are presented in Table 1.

To make adjustments to the collected data to account for evaporation from collectors, three collectors containing known amounts of water similar to the anticipated catch were placed at the test site. Water remaining in the control collectors was measured at the end of the test and combined with the recorded time to determine evaporation occurring during the tests.

Test procedures

The constant rate test was conducted on March 15, 2012 and the variable rate test on March 26, 2012. The pivot started at approximately 12 degrees before reaching the 1st test line to allow the water pressure of the system to stabilize at the desired testing conditions.

The application depth was set at 1 in for constant rate test. For the variable rate test, the 10 control zones were randomly assigned to 5 different application rates; 0, 30%, 50%, 70%, and 100%. The 100% rate corresponded to an application depth of 1 in.

The volume of water collected in each collector was measured using a graduated cylinder immediately after the pivot passed the test line and no more water from the sprinklers reached the collector (Figure 4). The volume of water was then converted to the depth applied based on the dimensions of the collector cups.

During the tests, the air temperature was around 78 F. The wind speed was approximately 7-8 mph S.

Data analysis

The center pivot coefficient of uniformity was calculated using the formula of Heermann and Hein (ASABE Standards, 2007)

$$CU_H = 100\left[1 - \frac{\sum_{i=1}^{n} S_i \left| V_i - \overline{V}_p \right|}{\sum_{i=1}^{n} V_i S_i}\right]$$

where

CU_H is the Heermann and Hein uniformity coefficient;

n is the number of collectors;

i indicates the i^{th} collector;

V_i is the volume of water collected in the i^{th} collector;

S_i is the distance of the i^{th} collector from the pivot point;

$\overline{V_p}$ is the weighted average of the volume of water caught.

$\overline{V_p}$ was determined as

$$\overline{V}_p = \frac{\sum_{i=1}^{n} V_i S_i}{\sum_{i-1}^{n} S_i}$$

The mean of the applied depth and its difference from the desired depth was then computed.

For the variable application test, applied water depths in various control zones were calculated following the same procedure. Applied amounts in the area between control zones were also determined for comparison with the applied depths in the adjacent zones. An ANOVA was performed with SAS software (SAS Institute Inc., Cary, NC) to compare the effect of the application rate on the uniformity of the pivot.

RESULTS AND DISCUSSION

Constant rate test

The water depths measured by the collectors are plotted in Figure 5. The average uniformity coefficient of the pivot was 86.47% with a value of 86.45% in the 1^{st} test line and 86.49% in the 2^{nd} test line. There were several large fluctuations in the depth values, caused mainly by the locations where the collectors were placed. Some collectors were located very close to a pivot tire or at the end of a test line. The mean of the depth applied was 1.05 in, with a standard deviation of 0.18 in. Compared with the desired depth of 1 in, the difference between the amount applied and the desired depth was 5%.

Variable rate test

The uniformity test results for the variable rate test are shown in Tables 2 and 3. The ANOVA test revealed that there was a significant effect of the application rate assigned to the control zone on the uniformity coefficient [$F(4, 9)=115.97$, $p=0.0001$]. Very low uniformity coefficients were observed in zones 2 and 10, which had zero application rates. The uniformities in zones 3 and 7, which had an application rate of 30%, were also noticeably lower than the other zones. This indicated that low application rates could possibly introduce poor uniformity. This result was consistent with that reported by other researchers (Perry et al., 2003)

Applied depths and desired depths are plotted in Figure 6. Application amounts followed the desired values as a general trend. The means of applied depths for each zone are reported in Table 2, and again show that the lower the desired depth was, the greater the difference between the desired depth and the applied occurred. Figure 7 shows a comparison of measured depth in the zone and the depth in the adjacent areas between two zones. A gradual depth change between two zones with different application rates was consistently observed.

SUMMARY

Application of VRI technologies has great potential for farmers to optimize crop yield and minimize environmental impact. A center pivot VRI system was evaluated with both constant application rate and variable application rate. Under a constant application rate, a uniformity coefficient of 86.5% was observed, and the difference between the desired application amount and actual amount applied was 5%. A variable rate application test was conducted with five different application rates between 0 and 100%. The system performed well in zone control, and in general, the applied water depths followed the desired rate pattern. However, the effect of application rate on uniformity was significant. The uniformity under higher application rates was greater than that for application rates 30% or less. The variation in application rates between adjacent control zones was a gradual process instead of an ideally rapid change. This study was preliminary and more comprehensive evaluations on the VRI system performance are needed.

Disclaimer

The mention of trade names of commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

REFERENCE

ASABE Standards. 2007. Standard Number S436.1: Test procedure for determining the uniformity of water distribution of center pivot and lateral move irrigation machines equipped with spray or sprinkler nozzles. ASABE, St. Joseph, MI, USA.

LaRue, J. and R. Evans. 2012. Considerations for variable rate irrigation. Proceedings of the 24th Annual Central Plains Irrigation Conference, pp.111-116 Colby, Kansas, February 21-22, 2012.

Perry, C., S. Pocknee, and O. Hansen. 2003. A variable rate pivot irrigation control system. The 4th European Conference on Precision Agriculture, Berlin, Germany, 15-19 June, 2003.

Table 1. Configuration of control zones and application rate assignments

Span No.	Zone No.	Rate (%)	No. of Collectors	Drops Per Zone
1&2	1	70	11	27
2	2	0	12	11
2&3	3	30	11	9
3	4	50	7	7
3&4	5	70	7	6
4	6	100	6	6
4	7	30	6	5
4	8	50	5	5
4	9	100	6	5
4&Overhang	10	0	7	4

Table 2. The uniformity coefficients in various control zones of the center pivot system.

Zone No.	Desired Depth (in)	Measured Depth (in)	CU_H in line 1 (%)	CU_H in line 2 (%)	CU_H average (%)
1	0.70	0.83	93.82	79.78	86.80
2	0.00	0.08	-18.36	-30.95	-24.65
3	0.30	0.31	78.58	86.09	82.33
4	0.50	0.53	86.18	84.49	85.34
5	0.70	0.72	85.51	92.19	88.85
6	1.00	0.99	91.01	85.20	88.10
7	0.30	0.52	75.54	70.29	72.92
8	0.50	0.61	91.68	69.93	80.80
9	1.00	0.96	94.00	84.48	89.24
10	0.00	0.13	-43.94	-44.03	-43.99

Table 3. The uniformity coefficients under various application rates. (*CU_H averages with the same character are not significantly different at 0.05 level.)

Rate (%)	CU_H in line 1 (%)		CU_H in line 2 (%)		CU_H average (%)*
	rep 1	rep 2	rep 1	rep 2	
0	-43.94	-18.36	-44.03	-30.95	-34.32[a]
30	75.54	78.58	70.29	86.09	77.63[b]
50	91.68	86.18	69.93	84.49	83.07[b]
70	85.51	93.82	92.19	79.78	87.82[b]
100	94.00	91.01	84.48	85.20	88.67[b]

Figure 1. Four-span Valley 8000 center-pivot variable-rate irrigation system.

Figure 2. Water collectors lined up to catch water applied.

Figure 3. Plastic cup to be used as the water collector.

Figure 4. Water was collected and measured using a graduated cylinder.

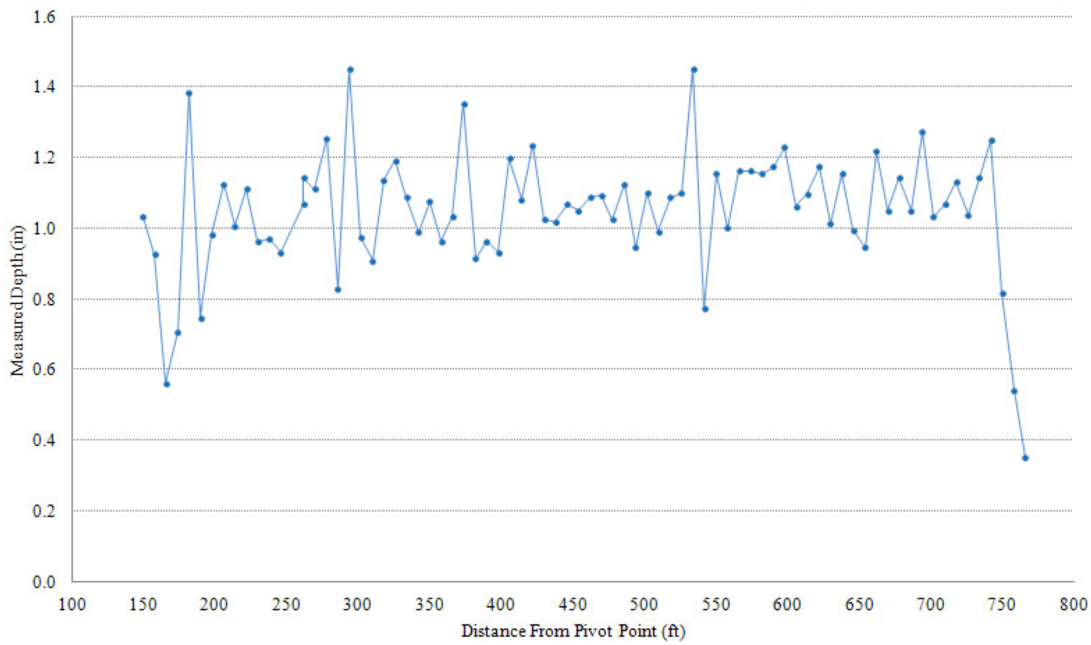

Figure 5. Water depth caught by the collectors in the constant rate test. The desired depth was 2.54 cm.

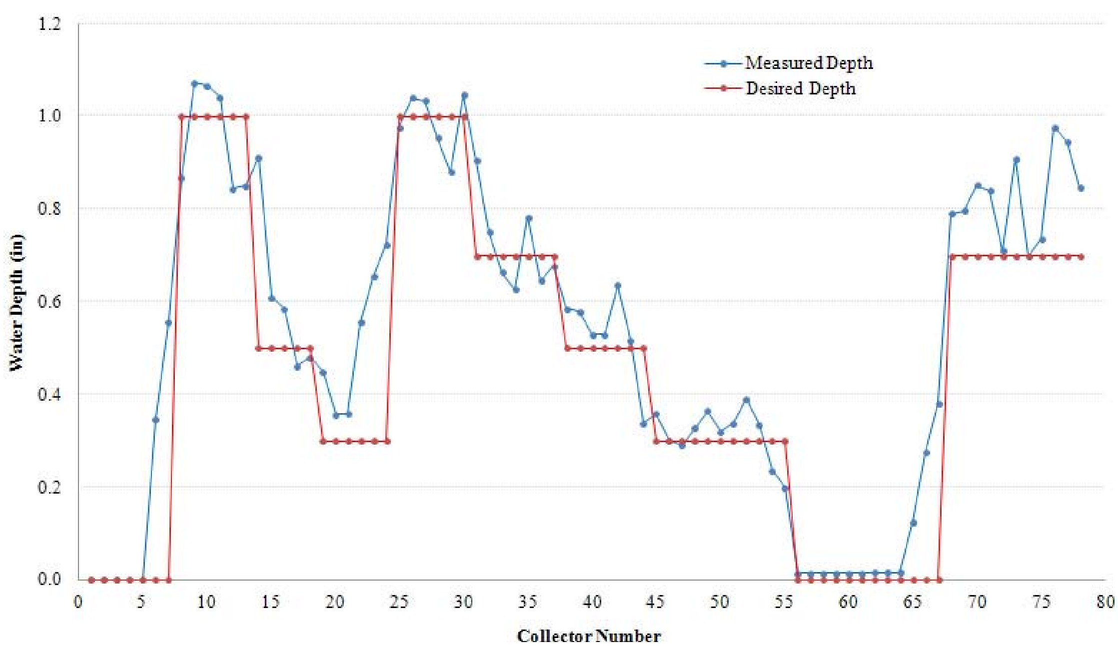

Figure 6. Desired water depth and measured water depth in the variable rate test.

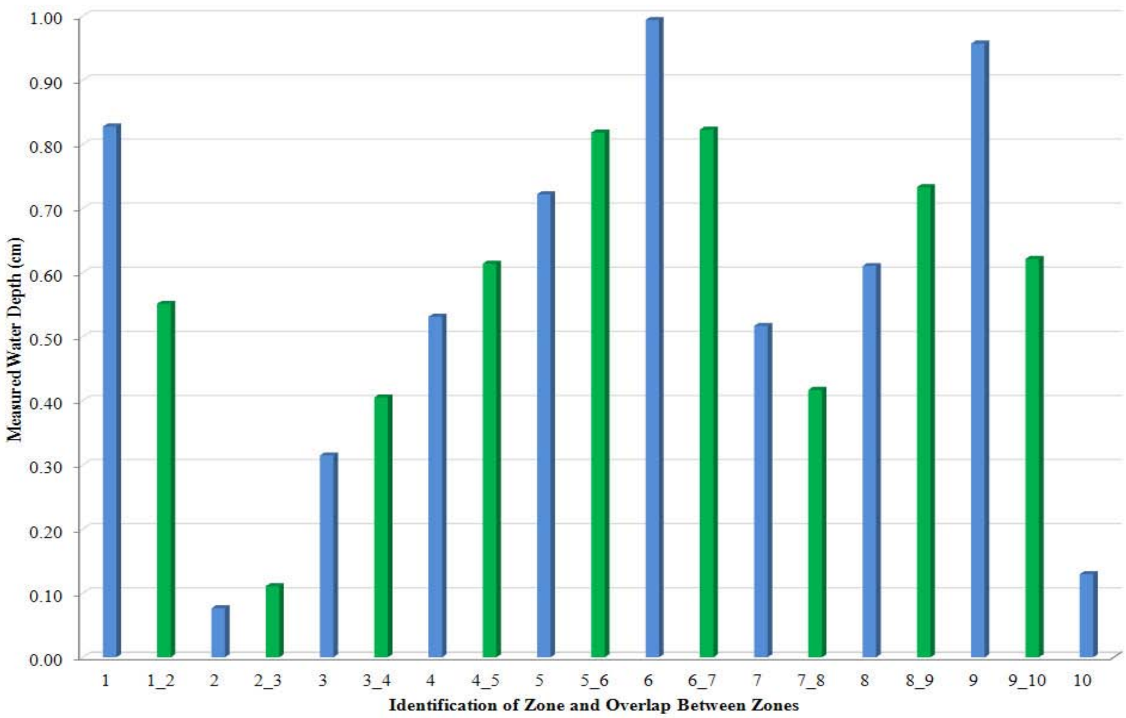

Figure 7. Applied water depth in control zones and in the overlap between control zones.