FIELD TEST OF A CENTER PIVOT IRRIGATION SYSTEM

R. Sui, D. K. Fisher

ABSTRACT. *Uniformity of water distribution of a commercial variable rate center pivot irrigation system was evaluated. This four-span center pivot system was configured with 10 equal area sized water application zones along its 233 m long lateral. Two experiments were conducted to evaluate water application uniformity. In one test, a constant water application rate (100%) was applied in each zone, and in the other, variable application rates (0%, 30%, 50%, 70%, and 100%) were assigned to different zones. To measure 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 evaporative losses during the tests. Water caught in the collectors was measured, and the center pivot's coefficient of uniformity (CU_H) was calculated. Results showed a CU_H of 86.5% for the constant application rate test. In the variable rate test, average CU_H over the application rates of 30%, 50%, 70%, and 100% was 84.3% with the highest CU_H of 89.2% in the 100% application rate. Effect of application rate on CU_H was significant, with higher application rates providing higher CU_H values. The uniformity of a control zone could be influenced by the overlap of sprinkler coverage between the adjacent control zones.*

Keywords. *Center pivot irrigation system, Irrigation, Uniformity, Variable rate irrigation.*

Uncertainty in the amount and timing of precipitation is one of the most serious risks to crop production in the Mid-South United States. In recent years, producers in this region have become increasingly reliant on supplemental irrigation to ensure adequate yields and reduce risks of production losses due to water stress. Increasing groundwater withdrawals, however, are 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 critical issue. Compared to furrow-irrigation methods, sprinkler irrigation systems can significantly improve irrigation efficiency, and their use is increasing in the Mid-South region.

In most agricultural fields, soil characteristics and plant growth status vary considerably 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 groups of sprinklers.

Knowledge of the accuracy and uniformity of an irrigation system are essential for the success of precision irrigation management. Accuracy of the system denotes that the plants receive the desired amount of water at specific locations in the irrigated area. System uniformity means that the depth of water application is consistent throughout the spatially designated irrigated area. The American Society of Agricultural and Biological Engineers (ASABE) has established a standard method for uniformity testing of center pivot and lateral irrigation devices under constant application rates. However, there is currently no standard method for evaluating a VRI system capable of making site-specific water application for precision agriculture practices.

Some work has been reported on the evaluation of VRI system performance. King and Kincaid (2004) developed a variable flow rate sprinkler applicable to center pivot and lateral-move irrigation systems. Prototypes of this sprinkler were tested on a three-span linear-move irrigation system to evaluate water application uniformity (King et al., 2005), and the application uniformity was found to be equal to or greater than 90% with application rates varying from 36% to 100%. Perry et al. (2003) evaluated the performance of a prototype center pivot VRI system developed by researchers at the University of Georgia and the Farmscan

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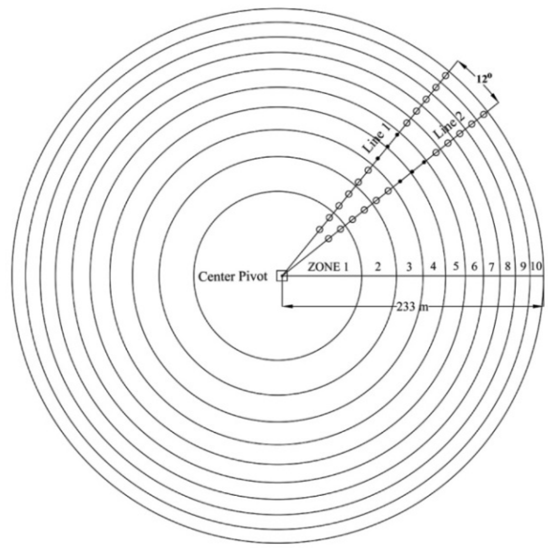

Figure 1. Control zone configuration of the center pivot variable rate irrigation system and the test line setup for the evaluation.

group (Perth, Western Australia). The uniformity coefficients of the system, with application rates of 20%, 80%, and 50%, were 86%, 94%, and 95%, respectively. In their test, three data points from the water collectors at the beginning of a control zone and three at the end of a control zone were excluded in the uniformity analysis. Stone et al. (2006) evaluated water delivery rates of a VRI system consisting of 13 segments along a 140 m pivot lateral. Comparing the measured water delivery to the designed parameters, they observed that the VRI system was able to deliver water to the control zones at rates very close to the design. Dukes and Perry (2006) reported their tests of uniformity along the length of a center pivot and a linear move irrigation system at four application rates ranging from 20% to 100%. Pneumatically actuated solenoid valves were used in the center pivot system, and electric solenoid valves in the linear move system, to pulse groups of sprinklers on and off to achieve variable water application rates. Two selected spans in each system were used in their tests, and results showed an overall average uniformity of 93% and 84% for the pivot and linear move systems, respectively. O'Shaughnessy et al. (2013) tested the uniformity of two center pivot VRI systems in a windy location with five application rates ranging from 30% to 100%. The test results showed that uniformity coefficients at different application rates varied from 84.4% to 90.8% with an average of 88.8%.

The objective of this study was to test the accuracy and uniformity of a commercially available variable rate center pivot irrigation system.

Materials and Methods

System Description

The center pivot VRI system used in this research consisted of a Valley Standard Pivot 8000 coupled with the Valley VRI zone control package (Valmont Irrigation, Valley, Neb.). The system was installed at a research farm of the USDA-ARS Crop Production Systems Research Unit at Stoneville, Mississippi in November 2011. The system was configured with a total length of 233.5 m, with four spans and drive units, and a flow rate of 79.5 m^3/h. Fixed-pad sprinklers (Senninger LDN, Clermont, Fla.) were installed with UP3 flat medium groove pads and 103 kPa pressure regulators. The distance from the sprinkler to the ground surface was approximately 1.83 m. Sprinkler spray radius varied in a range of 3.5 m to 6.7 m from the beginning at the center pivot to the end of the pivot lateral line. Sprinkler spacing was 2.74 m, and 85 sprinklers along the length of the pivot lateral were divided into 10 control zones to achieve an equal covered surface area of 1.71 ha in each zone (fig. 1).

During the test period, the inlet pressure was approximately 234 kPa for the constant application rate test, and 290 kPa for the variable application rate test. The pressure was measured using a pressure transducer installed on the riser pipe at the pivot point. The pressure transducer was connected to the pivot's control panel for pressure control, and provided safety settings to prevent operation of the pivot under unsafe pressures. The control system of the pivot had a "resync valve pressure" and, in case pressure reached this value, the control system would open half of the closed valves to alleviate the overpressure, and the system would then start to cycle as normal. There was also a high pressure shutoff point, and in case this maximum allowable pressure was reached, the system would shut down completely.

The Valley VRI zone control package included five VRI zone control units, a GPS receiver, and computer software. The control units were mounted on the top of the pivot towers. The GPS receiver was installed on the top of the last pivot tower farthest from the pivot center beside a control unit. Each VRI zone control unit controls the duty cycle of the sprinklers in two independent zones by turning electric solenoid valves on and off to achieve desired application depths in individual zones. The GPS receiver determines the pivot's position and location in the field for identification of control zones in real time. VRI prescriptions are created using the software provided with the VRI system and wirelessly uploaded to the system's control panel. Performance status of the system can be remotely monitored using a smart device such as a smart phone.

EXPERIMENT SETUP

The system was tested under both constant application rate and variable application rate conditions. New plastic cups with an 8.9 cm diameter opening and 12.7 cm depth were used as water collectors to measure the depth of water applied. Each water collector was taped onto a wooden stake which was inserted into the soil (fig. 2). The distance between the ground surface and the collector opening was approximately 20 cm. 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 water collectors was 12° (fig. 1). 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, 46 m in this case. Sprinkler spray radius varied in a range of 5.5 to 6.7 m from the nearest to the farthest ends of the test setup, respectively. In the constant application rate test, 78 water collectors were placed with a spacing of 2.44 m in each line. In the variable rate test, three additional water collectors were placed 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.

During the test period, 40 to 50 minutes were required to measure the water caught in all of the water collectors. Within this time period, water in each collector could evaporate, which might result in the measured amounts of water in each collector less than the true amount of water caught by the collector. To account for evaporation from collectors, three water collectors containing known amounts of water similar to the anticipated catch were placed at the test site at the beginning of the test period. Water remaining in these control collectors was measured at the end of the test and combined with the recorded time to determine evaporative losses occurring during the tests.

TEST PROCEDURES

The constant rate test was conducted on 15 March 2012 and the variable rate test on 26 March 2012. The pivot started at approximately 12° before reaching the first test line to allow the water pressure and application rate of the system to stabilize at the desired testing conditions. The application depth was set at 2.54 cm for the constant rate test. For the variable rate test, the 10 control zones were randomly assigned 5 different application rates; 0, 30%, 50%, 70%, and 100% (table 1). The 100% rate corresponded to an application depth of 2.54 cm.

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

Table 1. Configuration of control zones and application rate assignments.

Span No.	Zone No.	Rate (%)	No. of Collectors	Sprinklers Per Zone	Zone Width (m)
1&2	1	70	11	27	73.76
2	2	0	12	11	30.48
2&3	3	30	11	9	23.47
3	4	50	7	7	19.81
3&4	5	70	7	6	17.37
4	6	100	6	6	15.85
4	7	30	6	5	14.63
4	8	50	5	5	13.41
4	9	100	6	5	12.80
4&Overhang	10	0	7	4	11.89

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. The volume of water was then converted to the depth applied based on the dimensions of the water collector cups. During the tests, the air temperature was around 26°C, with wind speeds of approximately 3.58 m/s from the South during the constant rate test and 3.14 m/s from the South during the variable rate test.

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 = the Heermann and Hein uniformity coefficient;
N = the number of collectors;
I = the ith collector;
V_i = the volume of water collected in the ith collector;
S_i = the distance of the ith collector from the pivot point;
$\overline{V_p}$ = 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 were then computed.

For the variable application test, the uniformity coefficients and applied water depths in each control zone were calculated following the same procedure as described above.

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, N.C.) to compare the effect of application rate on uniformity of the pivot.

RESULTS AND DISCUSSION

CONSTANT RATE TEST

Measured water depths for the constant rate test are plotted in figure 3. The average uniformity coefficient of the pivot was 86.47% with a value of 86.45% in the first test line and 86.49% in the second test line. There were several large fluctuations in the depth values, caused mainly by the locations where the water collectors were placed. Some water collectors were located very close to a pivot tire or at the end of a test line. The mean of the depth applied was 2.67 cm, with a standard deviation of 0.46 cm. Compared with the desired depth of 2.54 cm, 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. Average uniformity coefficient over application rates of 30%, 50%, 70%, and 100% was 84.3%. The uniformity with these rates varied, but their difference was not significant. The uniformity with zero application rate, however, was significantly different from the other four application rates. The ANOVA test revealed that there was a significant effect of the application rate assigned to the control zone on the uniformity coefficient [F=115.97, p=0.0001]. The uniformity coefficient increased as the application rate increased, with the highest uniformity of 89.2% occurring in zone 9 with an application rate of 100%. Very low uniformity coefficients were observed in zones 2 and 10, in which the desired application rate was zero. The uniformities in zones 3 and 7, with application rates of 30%, were also noticeably lower than zones with higher rates. These low application rates resulting in poor uniformity were consistent with reports by other researchers (Perry et al., 2003; Dukes and Perry, 2006; O'Shaughnessy et al., 2013). However, it should be pointed out that a small portion of water applied by the sprinkler at each end of a control zone could reach to the adjacent control zone because the sprinkler spray radius is greater than the spacing between the zones. This overlap of sprinkler coverage affects uniformity of the zones, especially in the zones with zero application rate, such as zones 2 and 10 in this case. The VRI system in this study was very similar to that tested by O'Shaughnessy et al. (2013). We found the average uniformity coefficient with application rates from 30% to 100% to be 84.3% while that reported by O'Shaughnessy et al. (2013) was 88.8%, which is close to but slightly higher than what we obtained. This difference could partially be explained by the difference in the size of overlap of sprinkler coverage between zones. Sprinkler spray radius in our test ranged from 5.5 to 6.7 m, while spray radius varied from 3 to 4.6 m in their test. The larger the spray radius, the greater the overlap, and would affect amounts of water collected and reduce uniformities in the test. A system with wider zones would be expected to show higher uniformity coefficient in each zone because the effect of the overlap of sprinkler coverage between adjacent zones on the uniformity coefficient would be reduced.

Table 2. The uniformity coefficients under various application rates.

Rate (%)	0	30	50	70	100
[a]CU_H	-34.32[a]	77.63[b]	83.07[b]	87.82[b]	88.67[b]

[a] CU_H values with the same letter are not significantly different at the 0.05 level.

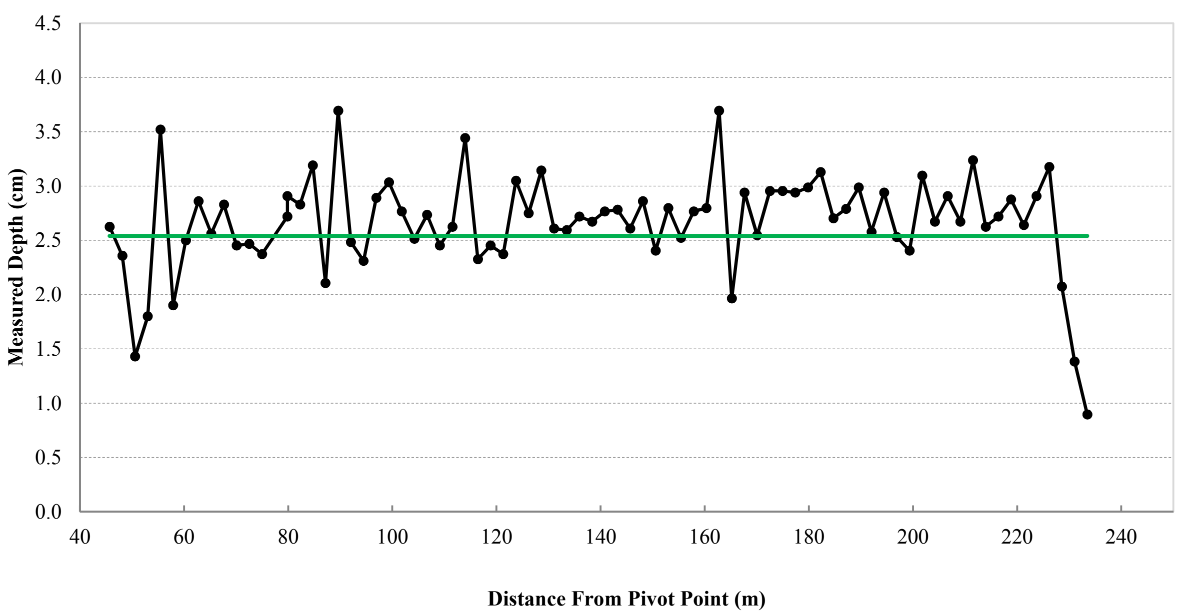

Figure 3. Water depth caught by the collectors in the constant rate test. The desired depth was 2.54 cm shown by the straight line.

Table 3. The uniformity coefficients in each control zone of the center pivot system.

Zone No.	Rate (%)	Desired Depth (cm)	Measured Depth (cm)	CU_H in Line 1 (%)	CU_H in Line 2 (%)	CU_H Average (%)
1	70	1.78	2.10	93.82	79.78	86.80
2	0	0.00	0.19	-18.36	-30.95	-24.65
3	30	0.76	0.80	78.58	86.09	82.33
4	50	1.27	1.35	86.18	84.49	85.34
5	70	1.78	1.83	85.51	92.19	88.85
6	100	2.54	2.52	91.01	85.20	88.10
7	30	0.76	1.31	75.54	70.29	72.92
8	50	1.27	1.55	91.68	69.93	80.80
9	100	2.54	2.43	94.00	84.48	89.24
10	0	0.00	0.33	-43.94	-44.03	-43.99

Another analysis was performed using the PROC MIXED procedure in the SAS software to evaluate the effect of application rate and distance of the zone from the pivot's center on uniformity. The results showed that application rate had a significant effect on uniformity ($F=46.53$, $p=0.0005$) while the effect of the distance from pivot center was not significant ($F=0.01$, $p=0.9134$).

Applied depths and desired depths in the variable-rate test are shown in figure 4. Application amounts followed the desired values as a general trend. The means of measured depths of water application for each zone are reported in table 3, and show that the lower the desired depth, the greater the difference between the desired and applied depths. Figure 5 shows a comparison of measured depth in each zone and the depth in the transition areas between two zones. Due to the overlap of sprinkler coverage in the transition area between zones, a gradual depth change between two adjacent zones with different application rates was consistently observed. This should be taken into consideration if VRI is used in studies with small field plots.

At present, there is no established standard for evaluating the performance of VRI systems. In this study, use of additional collectors in the areas between adjacent zones was included to obtain additional information from those areas. Data obtained from these additional collectors allowed us to more accurately assess the change of application rate between adjacent zones. The use of additional collectors in these areas is recommended as part of a standard procedure for VRI system testing. Based on our experience, we would also suggest eliminating zero application rates in a VRI test, and testing with additional target depths to provide a better understanding of the performance of the VRI system. Since more VRI systems are being adopted in agricultural research and production, establishment of a standard method for VRI system testing is needed.

Conclusion

Application of VRI technology has great potential for farmers to optimize crop yield and minimize environmental impact. A commercially available center pivot VRI system was evaluated under constant application rate and variable application rate conditions. 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 ranging from 0 to 100%. The system performed well in zone control, and in general, the applied water depths followed the desired rate pattern. Average uniformity coefficient over application rates of 30%, 50%, 70%, and 100% was 84.3%. The uniformity coefficients with these application rates were not significantly different. Effect of application rate on uniformity was significant. The

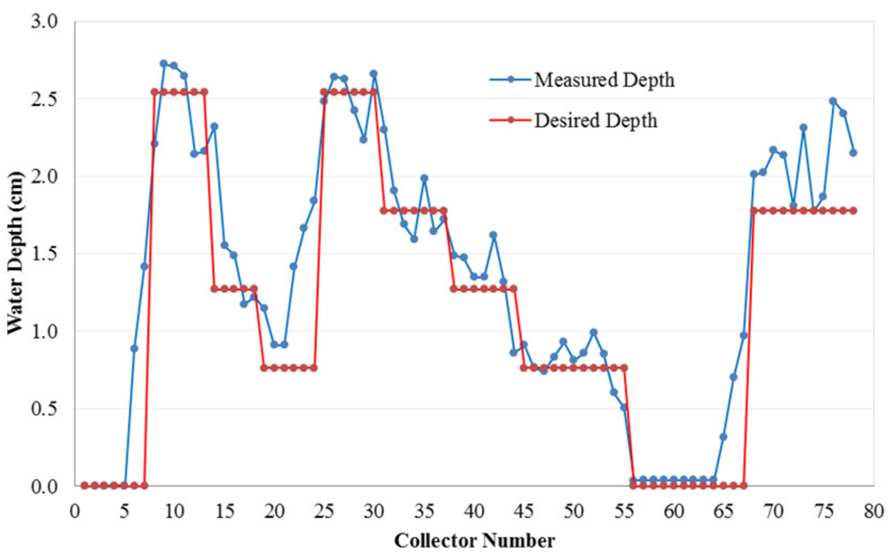

Figure 4. Desired water depth and measured water depth in the variable rate test.

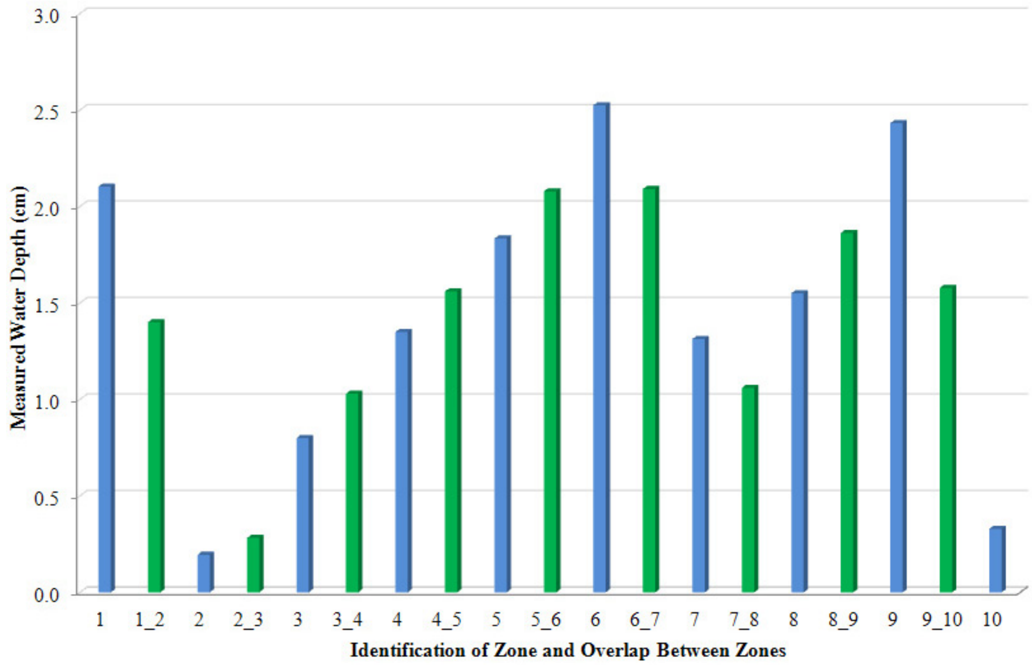

Figure 5. Applied water depth in each zone and in the overlap between control zones.

uniformity under higher application rates was greater than that for application rates 30% or less. The highest uniformity coefficient obtained in the VRI test was 89.2% in the zone with 100% application rate. Due to overlap of sprinkler coverage between the control zones, 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 VRI system performance are needed. Based on our experience, we suggest elimination of the zero application rate in uniformity testing of a VRI system. Additional water collectors should be used in the area between adjacent zones to collected data for observing the application rate transition between adjacent zones. A test with more target depth patterns could provide better understanding the performance of a VRI system.

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References

ASABE Standards. (2007). 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. St. Joseph, Mich.: ASABE.

Dukes, M. D., & Perry, C. (2006). Uniformity testing of variable-rate center pivot irrigation control systems. *Precision Agric., 7*(3), 205-218. http://dx.doi.org/10.1007/s11119-006-9020-y.

King, B. A., & Kincaid, D. C. (2004). A variable flow rate sprinkler for site-specific irrigation management. *Appl. Eng. Agric., 20*(6), 765-770. http://dx.doi.org/10.13031/2013.17724.

King, B. A., Wall, R. W., Kincaid, D. C., & Westermann, D. T. (2005). Field testing of a variable rate sprinkler and control system for site-specific water and nutrient application. *Appl. Eng. Agric., 21*(5), 847-853. http://dx.doi.org/10.13031/2013.19712.

LaRue, J., & Evans, R. (2012). Considerations for variable rate irrigation. *Proc. of the 24th Annual Central Plains Irrigation Conf.*, (pp. 111-116.). Colby, Kan.: CPIA.

O'Shaughnessy, S. A., Urrego, Y. F., Evett, S. R., Colaizzi, P. D., & Howell, T. A. (2013). Assessing application uniformity of a variable rate irrigation system in a windy location. *Appl. Eng. Agric., 29*(4), 497-510. doi: http://dx.doi.org/10.13031/aea.29.9931.

Perry, C., Pocknee, S., & Hansen, O. (2003). A variable rate pivot irrigation control system. In J. Stafford, & A. Werner (Ed.), *Proc. of the Fourth European Conf. on Precision Agriculture*, (pp. 539-544.). Wageningen, The Netherlands: Wageningen Academic Publishers.

Stone, K. C., Sadle, E. J., Millen, J. A., Evans, D. E., & Camp, C. R. (2006). Water flow rates from a site-specific irrigation system. *Appl. Eng. Agric., 22*(1), 73-78. http://dx.doi.org/10.13031/2013.20194.