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# Variable Water Application Depths from a Centre Pivot Irrigation Control System

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**ABSTRACT:** Current commercially available centre pivot (CP), linear-move and other sprinkler irrigation systems are normally capable and manage to apply relatively uniform controlled amounts of water, whereas the need for irrigation may differ between different zones of a particular field due to spatial soil variability. The 2nd span of CP including 15 nozzles was modified for site-specific irrigation using solenoid valves (SV), programmable logic control (PLC) and EIB-Bus communication protocol to evaluate the validation of site-specific irrigation control system and system modification and to examine water application uniformity. The PLC and the SV functioning were (open and close) were able to able to vary the amount of water proportionate to pulsing level and directly proportional to the fraction of time the valve was opened. There were no apparent problems with the pulsing water delivery system as in field tests were conducted. Except for 10 % pulsing level, measured irrigation depths were within 10 % of the target application rate. Error application of irrigation depth under low pulsing level of 10 % was found due to SV closing delay. Neither pulsing level of SV nor system movement speed had a significant effect and discernable impact on overall application uniformity.

**Key words:** Site-specific, Variable rate, Centre pivot, Irrigation, Application uniformity

## INTRODUCTION

Current commercially available centre pivot (CP), linear-move and other sprinkler irrigation systems are normally capable and manage to apply relatively uniform controlled amounts of water and injected chemicals laterally along the system. Thus over and/or deficit irrigation in some portions of the field will be unavoidable due to spatial soil variability. Modernized irrigation systems with advanced technology have developed by industrialized countries in the past 50 years (Sourell and Sommer, 2002; Maohua, 2001; Faci et al., 2001). Self-propelled commercial travelling irrigation systems, such as centre pivot (CP) and moving lateral, are particularly amenable to site-specific approaches because of their current level of automation and large area coverage with a single pipe lateral. However technology for varying water application along the mainline of self-propelled sprinklers is not commercially available. But several technologies have been developed by researchers to variably apply water with self propelled sprinkler systems. The last idea for VRI is Pulse concept by using solenoid valves to control single sprinkler or manifold (Fraisse et al. 1992, 1995; Giles et al. 1996; King et al. 1999; Sadler et al. 1996; Evans et al. 1996; Eberlein et al. 2000; King and Wall, 2001; AL-Karadsheh et al., 2002; Moore et al, 2005). In each case, spatially-variable water application was flexible and successfully achieved, and relatively, the water depth measured reached the target depths on a limited scale. It is important to ensure that the pulsing technique produces the desired amount of irrigation under different pulsing levels. Moreover, while a high standard coefficient of water distribution uniformity (CU) of an irrigation system is required, the effect of the overall CU by the ON and OFF cycling of sprinklers to achieve variable application rates must be evaluated, especially with due attention to limitation of literature in this case. Dukes and Perry (2006) found that in spite of some delay because of the time required for the valve mechanism to function for VRI during valve opening and closing, a high average overall CU of 93 % and 84 % were obtained by modified VRI centre pivots and linear moves, respectively. Also, preliminary testing indicated that variable-rate irrigation cycling had no effect on CU (Perry and Dukes 2004), however, this was limited to partial testing across cycling rate and movement speed for both the centre pivot and linear move systems. Perry et al. (2002) obtained 88 % CU by variable rate pivot irrigation control system. Also King and Wall (2001) obtained a range of CU from 87 to 92% for relative application rates of 33 to 100% and mean water application depths within 10% of the target depths. Therefore, the objectives of this study were 1) to evaluate the validation of site-specific irrigation control system and system modification and to determine if the actual applications were within design specifications and 2) to examine water application uniformity for several different levels of VRI control at three different speeds of system movement under low wind and low evaporation conditions.

## MATERIAL AND METHODS

**Irrigation System:** A two-span of 90 m total length and with an overhang commercial centre pivot system located at the Federal Agricultural Research Centre (FAL), Institute of Production Engineering and Building Research, Braunschweig, Germany, was modified for VRI. The irrigation system included “NELSON R3000” rotator nozzles (U4-8°, blue plate). The irrigation system could be operated in forward or reverse, with and without applying water, which is pumped from an underlying network.

**Irrigation System Modification:** The 2$^{nd}$ span of CP, including 15 nozzles, was controlled for variable-rate water application with a pulsing technique of “Baureihe 82340/82440” solenoid valve (SV) from the Buschjost company (www.buschjost.de) and PLC at control unit installed on CP at 3 m distance of pivot point. In this study, every four solenoid valves were wired together in one box with an EIB-Bus communication protocol (Europäischer Installationsbus) and connected to a control unit installed 3 m from a pivot point that opened and closed. But solenoid valves were individually controlled based on data- base values and the location in the field (using a position encoder). EIB-BUS is a free-cost and simple communication protocol that can control many SVs together with one cable. All electrical output devices including SV, position encoder, etc,. were controlled by a prototype PLC and EIB-Bus communication which were developed by the office for control technique and switching (www.schudzich.de). The control unit was mounted on the CP about 3 m from pivot point. Spatial location of each depth was to be determined by the system operating parameters: angle of rotation and location along the truss using position encoders. The integrative PLC had an on-board PC as data logger, which can read a saved data file, allows changes in the system information, and can convert the map of control to on/off setting in the directly-addressable solenoid control registers of the PLC. The application rate was varied based on pulsed ON for a fraction of 100 seconds, directly proportional to the desired fraction of the uniform (100 %) application rate. For example for pulsing level of 70 %, SV were opened 70 seconds and closed 30 seconds during each 100 seconds (one second for 1 % pulsing level). Three hypothetical irrigation management zones ($IMZ_1$, $IMZ_2$, and $IMZ_3$) were considered along the length of CP. Thus three different pulsing levels of SV could simultaneously be considered for 15 NELSON sprinklers to irrigate these three IMZs. Therefore IMZ1 was irrigated with the first three sprinklers (1, 2, and 3), $IMZ_2$ was irrigated with Sprinklers 4, 5, 6, 7, and 8 and $IMZ_3$ was irrigated with Sprinklers 9, 10, 11, 12, 13, 14, and 15. $IMZ_1$, $IMZ_2$, and $IMZ_3$ had about 9, 13, and 19 m width along the length of CP. Because of some economic reasons, only the 2nd span of CP was modified for VRI.

**Field tests of PLC validation and CU performance:** Tests of water distribution were conducted using catch-cups along the length of CP to validate the PLC, system modifications, and CU under SV pulsing. Seven pulsing levels and three CP speed levels were considered to investigate the feasibility of using pulsing techniques to produce the desired amount of irrigation under different pulsing levels. The tests were run while the machine was operating under 15 and 30 % of CP speed and programmed on three different pulsing setting of 10-40-70 %, 30-60-90 % and 100-100-100 %. Irrigation target depths were defined based on 100 % pulsing level and fraction of time the valve are opened. Therefore error of measured irrigation depth at different pulsing levels was measured relative to target irrigation depth.

Uniformity tests were currently being conducted to ensure that the irrigation system is applying an even distribution of water over the entire span of the CP lateral. With due attention to the short width of $IMZ_1$ along the length of CP and also overlapping of sprinkler from neighbour zones with different irrigation rates (effect of border area or where irrigation zone receives water from sprinkler which are installed inside neighbour irrigation zones by overlapping), it was not practically possible to calculate CU inside $IMZ_1$. Therefore CU was calculated only for $IMZ_2$ and $IMZ_3$ without considering transition zones (overlapping area) and also for all three zones when all sprinklers were operating under 100 % pulsing level CU tests were conducted based on ASAE standards (2003) by using the Heermann et al., formula (1992):

$$CU_{HH} = 100\left[1 - \frac{\sum_{i=1}^{n} S_i\left|V_i - \overline{V}_m\right|}{\sum_{i=1}^{n} V_i S_i}\right] \qquad (1)$$

where $CU_{HH}$ is the Heermann et al., uniformity coefficient, n is the number of collectors used in data analysis, i is a number assigned to identify a particular collector beginning with i = 1 for the catch cup located nearest to pivot point and ending with i = n for the most remote catch cup from the pivot point, Vi is the volume (or alternately the mass or depth) of water collected in the $i^{th}$ catch cup, $S_i$ is the distance of the $i^{th}$ catch cup, and $\overline{V}_m$ is the weighted average of the volume of water caught by all collectors. The tests were conducted during the early morning hours to minimize wind draft. Water was collected in a two rows of 38 catch-cups placed 40 cm from the ground and spaced 1 m between catch-cups with two replications as shown in Figure 1.

**RESEARCH RESULTS**

The PLC and the solenoid valve functioning (open and close) were able to pulse the water on and off for any given application rate at a programmable pulsing level from 0 to 100 % of 100 seconds pulsing interval and under 15, 20 and 30 % of given CP speeds. Figure 2 shows the pulsing effect on nozzle irrigation depth with a relative comparison between measured and target application depths for three different sets of time. Generally measured irrigation depths reached the target depths. Although measured irrigation depth at 10 % pulsing level of 15, 20 and 30 % CP speeds showed significant measured irrigation depth error higher than 10 % relative to target irrigation depths, generally measured irrigation depths were within 10 % of the target application rate.

Measurements indicated some deviations at the border of IMZ with less/more irrigation depth than the target depths. The error is considered very small when compared to typical sizes of irrigation zones and when considering that at the border area there will be a blending of water application rate. This is

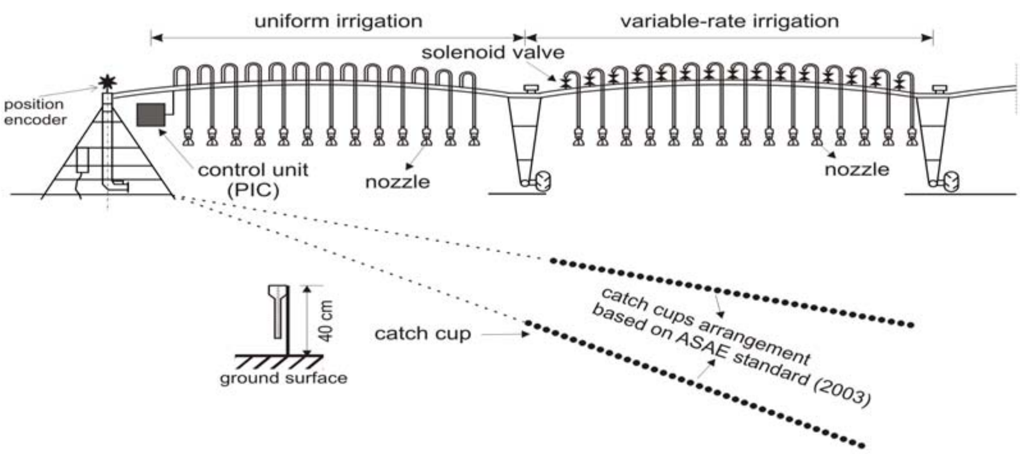


**Figure 1. Modified centre pivot for site-specific irrigation and catch-cups arrangement for PLC validation and CU test**

because the sprinklers used in the package had a relatively large wetted radius, which indicates the importance of using sprinklers with smaller wetted radius to reach depths much closer to the target depths. Moreover the selection of the proper sprinkler packages also has an effect on the size of the management unit in the application map, which depends mainly on the ability to measure and manage it (Blackmore, 1994). Therefore, as suggested by Omary and Sumner (2001), the throw radius of the spray nozzle should not be larger than three times the spacing between the spray nozzles. The contrasts between the target and measured depths at the borders area are decreased and increased when the required change in water depth is small or big, respectively. This indicates that this variable rate irrigation system is appropriate for applying variable target amounts step-wise, otherwise some deviations in the applied amount are expected.

In site-specific irrigation, the distribution uniformity within each IMZ must be as uniform as possible. The coefficient of uniformity for conventional CP irrigation systems ranges from 0.85 to 0.95 (Scherer et al., 1999). The coefficients of uniformity at different pulsing levels and the CP speed of this study are shown in Table 1. The solenoid valve functioning (open and close) had no effects on the CU, and the uniformity of the nozzle output was not adversely affected by using the pulsing technique for water application as compared to the uniformity of a conventional CP system, although an insignificant deviation in water distribution patterns could be attributed to the small loss in pressure due to the solenoid valve installation which has a low impact on the distribution patterns (Fraisse et al., 1995). In this study, and based on Equation 1 (Heermann et al., 1992), the CU was between 86.4 and 97.8 % as shown in Table 1. Michael et al. (2006) came to a similar conclusion that tested uniformity of the variable-rate centre pivot and linear move irrigation control systems and measured CU equal to 93 and 84 % for centre pivot and linear move, respectively. Also Moore et al. (2005) found a high quantity of CU between 79 to 95 % for irrigation depths between 6 to 25 mm by a variable rate linear move. Although high values of CU were obtained under all pulsing levels, but slightly lower application uniformity was obtained for reduced application rates (in agreement with King and Wall, 2001).

Figure 2. Measured application depths (curves) relative to the target irrigation depths (horizontal lines which are showing the target depths) for three different sets of spatially variable application test and three different speed dial setting of 15, 20 and 30 % on CP control box.

## DISCUSSION AND CONCLUSIONS

Higher error application of irrigation depth under low pulsing level of 10 % found in this study is in agreement with our field observations and also in agreement with Fraisse et al. (1995) and Duke et al. (1997) as valves had a discrete response time for opening and closing (valves open quickly but required a longer time to close) and solenoid-actuated diaphragm valves close slower than they open. This valve closing delay was not accounted for in these feasibility tests but can be easily incorporated into the PLC. This was important to prevent any other factor affecting the water distribution except the open/close time of the solenoid valves. However it is concluded that determination of irrigation depth must be based on field measurement not based on theoretical calculation. Field observation showed that 20 seconds pulsing interval was too short due to valves being turned on and off at various pre-planned locations in the field (because of water hammer). Therefore the pulsing interval was increased to 100 seconds, but it is proposed to apply a pulsing interval longer than 100 seconds. However results exhibited that with some exceptions a pulsing technique operated successfully, meanwhile providing a flexible means of applying variable water treatments in agreement with other mentioned literatures

**Table 1. Average coefficient of uniformity from different pulsing level and CP speed**

| Pulsing Level (%) | CU at CP speed of 15 % (%) | CU at CP speed of 20 % (%) | CU at CP speed of 30 % (%) |
|---|---|---|---|
| 10 | 89.9 | 92.0 | 86.4 |
| 30 | 92.7 | 97.6 | 89.8 |
| 40 | 93.8 | 94.7 | 89.3 |
| 60 | 96.5 | 92.7 | 97.1 |
| 70 | --- | --- | --- |
| 90 | --- | --- | --- |
| 100 | 97.8 | 97.5 | 96.3 |

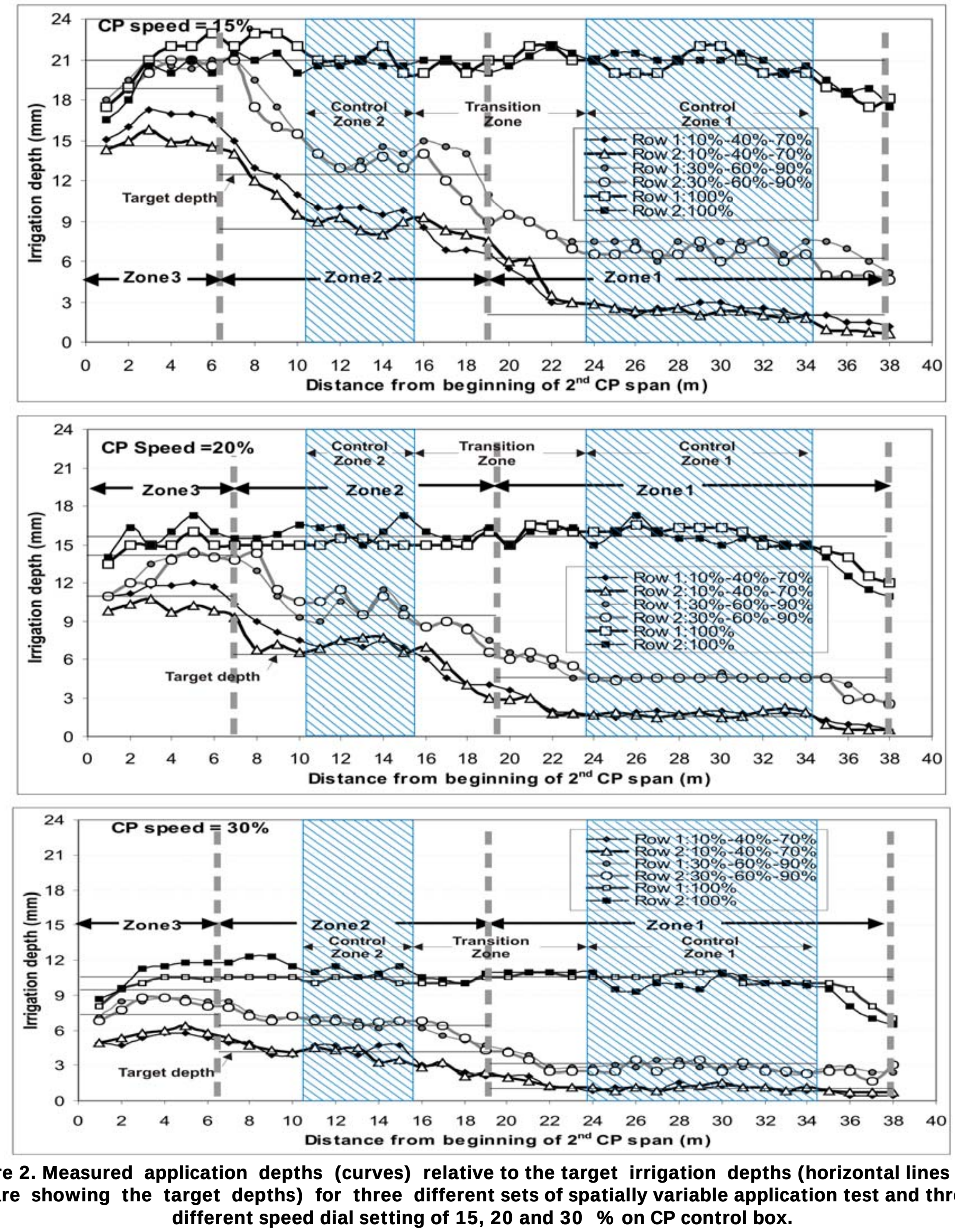


**Figure 2. Measured application depths (curves) relative to the target irrigation depths (horizontal lines which are showing the target depths) for three different sets of spatially variable application test and three different speed dial setting of 15, 20 and 30 % on CP control box.**

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