TECHNOLOGIES FOR VARIABLE WATER APPLICATION WITH SPRINKLERS

G.W. Buchleiter, C.R. Camp, R.G. Evans, B.A. King 1

ABSTRACT

Several technologies have been developed by researchers to variably apply water with self-propelled sprinkler systems. Incremental step changes in application rates are achieved by operating various combinations of multiple sprinklers with different size nozzles. A second approach pulses various groups of sprinklers intermittently to achieve the desired variation. A third approach uses a variable size orifice to change the flow rate through a sprinkler. All of these approaches have performed satisfactorily in field scale installations.
Keywords: center pivot, sprinkler irrigation, variable rate, uniformity

INTRODUCTION

Over the past 30 years, various technologies have been developed to aid producers in improving irrigation management and reducing irrigation costs. The general evolution of sprinkler products has been to improve the system application uniformity as well as reduce operating costs by reducing the pressure requirements. Improving the application uniformity has enabled the irrigator to meet the irrigation requirements over more of the field while minimizing the amount of overirrigation.

In recent years, there has been interest in the irrigation research community to develop technologies that make it possible to intentionally vary water application amounts across a field because of various management objectives. However, technology for varying applications along the mainlines of self-propelled sprinklers is not commercially available. Understandably, most researchers doing replicated randomized treatments in irrigation and nutrient studies, like the ease and time savings of an automated system for variable application. However, there are also many situations on commercial farms where variable application may be desirable. In humid environments where irrigation is done to supplement rainfall, the general management strategy is to irrigate enough to supply the crop needs until the next rainfall event comes. Thus it may be desirable to apply more water to areas with low water-holding capacities than to areas with high water-holding capacities. In some situations it may be desirable to apply smaller irrigation amounts when resuming irrigation following a rain in order to have adequate storage capacity for future rainfall. In the Pacific Northwest, it may be desirable to not irrigate certain areas within a field such as rock outcroppings or very steep slopes. Producers interested in precision farming may want to apply different amounts of water within a field because of site-specific soil conditions and/or the translocation of water due to topography. However, the general approach in all of these situations, is to apply water uniformly on subareas within a field knowing the depth will be different for adjacent subareas.

TECHNOLOGICAL APPROACHES

Currently all major self-propelled sprinkler manufacturers have microprocessor based control equipment capable of varying application depths in the direction of travel. Although some of the manufacturers are interested in variable application along the sprinkler mainline, systems with this capability are not commercially available. Researchers interested in varying applications

1 G.W. Buchleiter, Agric. Engineer, USDA-ARS Water Management Unit, Fort Collins, CO 80523
C.R. Camp, Agric. Engineer, USDA-ARS Coastal Plains Soil Water Plant Unit, Florence, SC
R.G. Evans, Agric. Engineer, Biological Systems Engineering Dept., Washington State University, Prosser, WA
B.A. King, Assoc. Professor, University of Idaho, Aberdeen, ID

both in the direction of travel and perpendicular to the direction of travel, have used several different approaches for variable water application on self-propelled irrigation systems.

Incremental changes with multiple sprinklers

Lyle and Bordovsky (1983) used three individually-controlled manifolds along the mainline, each delivering discrete but different flow rates, in various combinations to achieve discrete incremental application rates. This approach was used by the USDA-ARS Coastal Plains Soil, Water, and Plant Research Unit in Florence, SC on 2 small center pivot sprinkler systems (Camp et al., 1999). Water was applied to discrete areas based on the desired treatments of the research project. The mainline was divided into 13 segments. Each 9.1 m segment had 3 independently controlled, parallel manifolds with spray nozzles spaced 1.5 m apart. Because of the necessity to minimize water from one segment overlapping with adjacent segments, wide-angle industrial spray nozzles (Fulljet Spraying Systems Co.) with wetted diameters of 3-5 m were used. The manifolds and nozzles were sized to provide 1/7, 2/7, and 4/7 of a base application depth. Thus all combinations of the 3 manifolds can deliver from 0 to 100% of the base amount in 1/7 increments.

The control system consisted of a small 80386 microcomputer (Horner Electric, Indianapolis, IN) with a hard disk drive, floppy drive, and serial ports, connected via the system buss to a programmable logic controller (PLC): (GE Fanuc 90-30, Charlottesville, VA*). This control unit mounted on the movable part of the system about 5 m from the pivot, was linked to the stationary base station first by spread-spectrum radio telemetry and later by direct cable. The on-board computer compared position data from the computerized pivot control panel with user specified angles, to determine when solenoid valves needed to be opened or closed to achieve the desired application depth. Based on user-specified amounts for the various research plots, the on-board computer determined and initiated the necessary commands to actuate the appropriate solenoid valves.

Researchers at the University of Idaho employed a similar incremental approach of using pairs of sprinklers with different nozzle sizes on a 3 span linear move machine. However, the implementation used different technologies. A microprocessor transmitted the necessary control signals through a single cable to control modules operating electric solenoid valves that directed flow to the appropriate sprinkler nozzles (McCann et al., 1997)

Pulsing groups of sprinklers

A second method for variable rate application is a pulse approach where sprinklers are operated for a user specified portion of a base time period. An advantage of this approach is that the application depth can be varied continuously rather than in incremental steps of the method described previously. Researchers with the USDA-ARS Water Management Unit in Fort Collins, CO modified a linear move irrigation system to provide variable water application with this pulse approach by installing a separate manifold (22 m in length) on each half-span of a 4 span system (Duke et al.,1992; Fraisse et al., 1995). Solenoid actuated control valves mounted at each tower, controlled flow into each manifold. Drops spaced at 1.5 m along each manifold, conveyed water to check valve, 41 kPa pressure regulator, and nozzle assembly approximated 0.5 m above the ground surface. The check valve was necessary to prevent draining the drop tubing during the off time of each cycle. Since part of the area irrigated by this linear move machine was a randomized block research plot with varying irrigation treatments, LEPA Quad-spray nozzles (Senninger Irrigation, Orlando, FL) in the flat spray mode with a wetted radius of about 2 m, were used to minimize the width of transition zones between treatments.

---

* Mention of specific names of products is only for the benefit of the reader and does not imply endorsement by USDA-ARS, Washington State University or University of Idaho.

The control system consisted a PLC (GE Fanuc 90-30, Charlottesville, VA) linked with a set of control switches that could be activated either manually or controlled by the standard computerized control panel (CAMS®, Valmont Industries, Valley, NE). The PLC and control switches were mounted on the movable tower cart adjacent to the computerized control panel. A radio telemetry system linked the CAMS control panel with a stationary base station located in the farm office. The PLC was programmed to apply varying depths in each of the 8 half-spans depending on the settings of the control switches.

A similar approach for pulsing groups of individual heads was developed and tested on a prototype system by researchers with Washington State University, USDA-ARS (Prosser, WA) and industry partners (Evans et al., 1996a; 1996b; Evans and Harting, 1999). The 45 ha center pivot was divided into 30 zones with two to four heads in each zone. Each rotator spray head (Nelson Irrigation, Inc, Walla Walla, WA) included a pressure regulator and a water-operated normally open solenoid valve to regulate when water was applied. The individually addressable controllers were linked together through a 2-wire RS485 bus (current based) along the pivot lateral. Each of the thirty zones were turned on or off by individual custom-built zone controllers that were linked to a central computer through a spread-spectrum radio modem (900 MHz FreeWave Technologies Inc., Boulder, CO).

A computer in the farm office linked a center pivot irrigation simulation model (CPIM) with a Geographical Information System (GIS) (Evans et al., 1993) and an irrigation scheduling program (Han et al., 1996) to develop optimum irrigation water application maps. The desired irrigation amount in a management zone was done by cycling the sprinklers on and off at selected intervals over a 250 sec time period. Thus, a total off time of 50 seconds out of every 250 seconds resulted in an 80% of maximum application. This control system theoretically allows application depths ranging anywhere from 0 to 100% but practically is limited to 5% increments.

Concepts from this system have been incorporated into a precision irrigation system designed for three adjacent circles on a large commercial farm (Harting, 1999). The control system is composed of off the shelf programmable logic controllers, electric solenoid valves and hydraulic valves. Sprinklers are controlled in groups of four and pulsed on and off in a 1 minute duty cycle.

Variable orifice sprinkler

A third approach for variable application that is similar to pulsing but does not completely turn flow off, is to alternately insert and remove a concentric pin in the sprinkler orifice using a linear actuator (King and Kincaid, 1996; King et al., 1997). Maximum flow occurs when the pin is removed. When the pin is inserted, the flow is reduced by the ratio of the cross sectional area of the pin to the cross sectional area of the sprinkler orifice to a known lower limit. Time-averaged variable flow between the lower limit and maximum flow is achieved by moving the pin in and out at an appropriate duty cycle. Time average application rate ranging from about 40 to 100% of the maximum flow can be achieved with minimal effect on the sprinkler application pattern. Prototype sprinklers have been field tested on a 3 span, 100 m linear move irrigation system located at the University of Idaho Aberdeen Research and Extension Center. Sprinklers with 138 kPa pressure regulators, were installed at a 3 m spacing at approximately 2 m above the ground.

A commercial power line communication network (Echelon Corp, Palo Alto, CA) linked with two microprocessors, controlled 5 independently operated, sprinkler control nodes. Each control node controlled either 6 or 7 sprinklers so that every sprinkler was individually addressable by the master controller.

RESULTS

The Christensen Coefficient of Uniformity (CU) was used to assess water application uniformity. Field tests were usually conducted according to standardized procedures such as ANSI/ASAE S436 (ASAE Standards, 1996). Computer simulations are also used to determine CU. Generally, CU values greater than 80% are considered acceptable, and CU values greater than 90% are readily achievable.

Field tests of the USDA-ARS (Florence, SC) system, gave CU values of 78.6, 81.0 and 81.9% for the static manifolds (9.1 m long) with 3.2, 6.4, and 12.7 mm nozzles, respectively. Measured CU improved to 86.4, 83.5 and 87.2%, respectively, when only the 6 m length between end nozzles where the research plots were located, was considered. When the pivot was moving at 25% of maximum speed, the CU for the 12.7 mm nozzle was 84.5% for the entire length and 86.8% for the middle 6 m of the manifold (Omary et al., 1997). CU values for several tests in the directions parallel and perpendicular to the direction of travel were comparable with values ranging from 89 to 92%. These measured values compared very favorably with a simulated CU of 92% when there was no change in application depths between plots (Camp et al., 1998). However, uniformity was reduced slightly in the transition areas when there were different application depths in adjacent plots.

For the USDA-ARS (Fort Collins, CO) system, application uniformities were evaluated using both simulation program results and field measurements. Since all of the LEPA nozzles were the same size, the simulated CU for continuous movement was quite high at 97%. The primary concern was the potential impact on CU in the direction of travel from the on-off pulsing of the heads as well as the on-off tower movement. Water depths were measured with .10 m x 1.52 m x .10 m sheet metal troughs oriented with the long axis parallel to the mainline and spaced .76 m apart in the direction of travel. Table 1 summarizes the measured and simulated values for pulse duty cycles of 25, 50 and 75% and percent timer settings of 17, 45, and 75%. Generally there was good agreement between measured and simulated values. The results show that CU decreases with increasing speed (i.e. higher percent timer setting), but were generally less affected by the duty cycle (i.e. pulse on-off times).

Table 1. Measured and simulated application uniformities for pulsing method (Fraisse et al., 1995).

Timer setting (%)	Duty Cycle (%)	Meas. Mean depth (mm)	Measured CU (%)	Simulated CU (%)
17	25	4.6	93.0	95.2
	50	9.3	95.5	95.2
	75	15.0	90.6	95.1
45	25	2.5	91.2	91.9
	50	5.0	91.9	94.9
	75	7.1	92.8	91.4
75	25	1.5	83.5	79.9
	50	2.8	90.8	87.6
	75	4.4	95.4	95.5

Integrated systems using the pulsing concept to vary water application on commercial fields have been successful in demonstrating available technology and the benefits of improved management. The Washington State University has shown substantial reductions in water and nitrate leaching while improving the quality of the potatoes harvested.

Table 2 shows the measured water application uniformities in both directions for the University of Idaho linear move system for various levels of relative application. Along the mainline, catch cans were placed at 1 m interval in 2 lines that were spaced 4 m apart. In the direction of travel, catch cans were placed at 1 m interval in 3 lines spaced approximately 5 m apart in the center of the span.

Table 2. Measured application uniformities for variable orifice approach

Relative Application (%)	Parallel to mainline (%)	Direction of travel (%)
100	96.2	97.5
84	94.8	97.2
68	94.1	96.3
52	90.9	97.4
35	89.7	93.0

All three approaches achieved very acceptable application uniformities in the 90% range and are technical feasible. However, further testing and evaluations are needed to ascertain the economic feasibility and reliability of these technologies prior to possible commercialization.

FUTURE DIRECTION

The goals of precision farming to manage production inputs more effectively will continue to fuel interest in variable application of water and chemicals through self-propelled irrigation systems. The economic viability of this practice will depend in large part on the value of the crops grown, the degree of variability within a field, and potentially the values people place on the environment. In environmentally sensitive areas that are susceptible to leaching of nitrates, variable application may eventually be required to minimize environmental degradation and satisfy regulatory agencies that producers are acting responsibly. Regardless of which technology approach is used to vary application, it will be an integral part of a larger, computerized control system designed to improve and fine-tune management decisions.

REFERENCES

1. Camp, C. R., E. J. Sadler, D. E. Evans, and J. A. Millen. 1999. Precision management with a site-specific center pivot irrigation system. In R. Walton and R. E. Nece (eds.) Proc. 1999 International Water Resources Engineering Conf., Environmental and Water Resource Institute. Aug. 8-12, Seattle, Washington. ASCE, Reston, VA. (CD-ROM)

2. Camp, C. R., E. J. Sadler, D. E. Evans, L. J. Usrey, and M. Omary. 1998. Modified center pivot system for precision management of water and nutrients. Applied Engr. in Agric. 14(1):23-31.

3. Duke, H. R., D. F. Heermann, and C. W. Fraisse. 1992. Linear move irrigation system for fertilizer management research. In *Proc. International Exposition and Technical Conference*, pp. 72-81. Fairfax, Va.: The Irrigation Association.

4. Evans, R.G., S. Han, L.G. James and M.W. Kroeger. 1993. CPIM - A Computer Simulation Program for Center Pivot Irrigation Systems. ASAE Technical Paper No. 93-3065, ASAE, St. Joseph, MI.

5. Evans, R.G.,S. Han, S.M. Schneider, and M.W. Kroeger, 1996a. Precision Center Pivot Irrigation For Efficient Use Of Water And Nitrogen. . Proc. of 3rd International Conference on Precision Agriculture. Minneapolis, MN. June 23-26. ASA, CSSA, SSSA, Madison, WI. pp 75-84.

6. Evans, R.G., S.M. Schneider, R.A. Boydston, and S. Han, 1996b. Precision Agriculture for Center Pivot Irrigated Wheat and Potatoes in Washington. ASAE Tech. Paper PNR-967502. Presented at 51st Annual Meeting of Pacific Northwest Section of ASAE. Yakima, WA. September 22-24. 15 pp.

7. Evans, R.G. and G.B. Harting, 1999. Precision Irrigation with Center Pivot Systems on Potatoes. Proc. ASCE 1999 International Water Resources Engineering Conference. August 8-11. Seattle, WA.

8. Fraisse, C.W., D.F. Heermann, H.R. Duke. 1995. Simulation of Variable Water Application with Linear-Move Irrigation Systems. *Trans. of ASAE.* 38(5): 1371-1376.

9. Han, S., R.G. Evans, and S.M. Schneider, 1996. Development Of A Site-Specific Irrigation Scheduling Program. ASAE Technical Paper No. 96-2076. ASAE. St Joseph, MI.

10. Harting, G.B., 1999. As the Pivot Turns. *Resource.* American Society of Agricultural Engineers, St. Joseph, MI. April 6(4):13-14.

11. King, B. A. and D. C. Kincaid. 1996. Variable flow sprinkler for site-specific water and nutrient management. ASAE Paper no. 962074.

12. King B. A., R. W. Wall, D. C. Kincaid, D. T. Westermann. 1997. Field scale performance of a variable rate sprinkler for variable water and nutrient application. ASAE Paper no. 972216.

13. Lyle, W. M., and J. P. Bordovsky. 1983. LEPA irrigation system evaluation. *Trans. of the ASAE* 26(3):776-781.

14. McCann, I.R., B.A. King and J.C. Stark, 1997. Variable Rate Water and Chemical Application for Continuous-Move Sprinkler Irrigation Systems. *Applied Engineering in Agriculture*. 13(5):609-615.

15. Omary, M., C. R. Camp, and E. J. Sadler. 1997. Center pivot irrigation system modification to provide variable water application depth. *Appl. Eng. Agr.* 13(2):235-239.