Center Pivot Irrigation System Modification to Provide Variable Water Application Depths

M. Omary, C. R. Camp, E. J. Sadler

Abstract. *A multiple-segment water application system was developed and attached to a commercial center pivot irrigation system to provide variable application depths within each segment at a given speed. Each segment was 9.15 m (30 ft) long and consisted of three parallel manifolds sized to provide 1x, 2x, and 4x, where x is a minimum application depth. The three manifolds could be operated individually or in various combinations to provide eight application rates (0-7x) at any given tower velocity. Water application depth varied from 0 to 12.4 mm (0 to 0.5 in.) when the center pivot was moving at 50% of full speed.*

Water was delivered via industrial, full-cone, and wide angle spray nozzles that were selected to provide the desired range of application depths for the entire length of the pivot. The irrigated areas for each angular increment were small at the pivot end of the system and required nozzles with small discharge rates while at the distal end the areas were larger required nozzles with larger discharge rates. Agricultural chemicals, especially nutrients, that can be injected into the irrigation water may also be applied at the same range of rates provided the chemical concentration is constant.
Keywords. *Irrigation, Center pivot, Site-specific.*

Different types of soils have different water holding capacities and hydraulic conductivities; therefore they require different water application depths and rates to reach field capacity and to minimize runoff. In addition, nutrient contents may vary and accordingly soils may require different application rates of nutrients. In recent years, much emphasis has been placed on site-specific management for agriculture or what has become known as precision farming. It includes soil mapping (Muhr et al., 1994), soil nutrient assessment (Hans and Breadmaker, 1994; Zhang et al., 1994), and yield monitoring (Karlen et al., 1990; Sadler et al., 1995).

By 1995, center pivot/linear move irrigation systems accounted for 6.29 million ha (15.53 million ac) out of a total U.S. irrigated area of 24.44 million ha (60.34 million ac) (25.7%) (Irrigation Survey, 1996), and most of these systems were center pivots. Currently, center pivot systems are designed to apply a uniform depth of water along the entire length of the pipeline and in the traveling direction. Different application depths may be achieved by changing system speed, but the application depth remains uniform along the pipeline.

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Few attempts have been made to modify moving irrigation systems (center pivot and/or linear) to obtain different application depths for various segments along the pipe line and different application depths at different locations in the direction of travel of the irrigation system. Roth and Gardner (1989) modified a lateral move irrigation system to test different application depths of water and nitrogen. The system consisted of three lines where one line applied five different application depths to five different treatment in one experimental block along the irrigation system. The second line applied different arrangement for the same application depths to irrigate different block. The third line applied uniform depth along the irrigation system. The system did not have the possibility of combination of application depths to apply different depths in the moving direction. Therefore it cannot be used for site-specific management where the different application depths depend on the natural field soils layout and not specific designed layout. Duke et al. (1992) and Fraisse et al. (1992) modified a linear irrigation system to provide variable water and nutrient application rates using pulsed sprinklers. The water and nutrient application rate was determined by the rate at which the water supply to each manifold was pulsed via alternately switching supply solenoids on and off. Stark et al. (1993) reported the development of a control system for site-specific application of water and chemicals that could be used on linear and center pivot irrigation systems. This system used a microprocessor to control individual nozzles, lateral speed, and flow rate of the chemical injection pump according to a spatially referenced mapping system. A U.S. patent was awarded to this system for variable rate application of irrigation water and chemicals (McCann and Stark, 1993). The above were systems developed to control the flow rate of one or more individual sprinklers. Usually, commercial irrigation sprinklers require medium to high [200-400 kPa (30-60 psi)] water pressure and have a

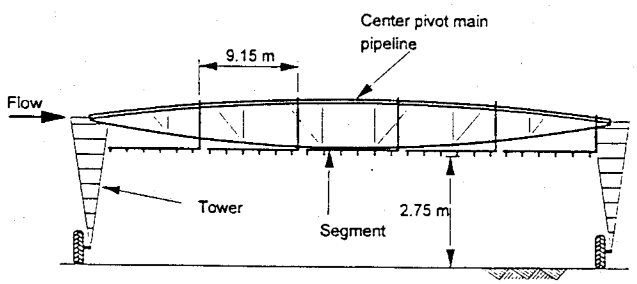

Figure 1–Diagram of one center pivot span with the modification.

wetted radius of several meters [>5 m (>16 ft)]. A large wetted radius makes it difficult to confine water application to small areas without undesired application to adjacent areas. Also, unnecessary overlapping can adversely affect application uniformity. In the case of systems with low energy precision application (LEPA), water is delivered near the ground surface and may not be effective for canopy wetting of tall crops.

This article describes the development of a variable rate water application system to independently apply variable water application depths to small discrete areas under the center pivot system (Camp and Sadler, 1994). This system was installed on a small center pivot system to be used for research purposes, but it should have ultimate application in the irrigation industry.

Material and Methods

System Design

The irrigation system was a commercial center pivot with some modification regarding the hydraulic systems. Additional threaded ports were added on the main pipeline [17 cm (6.625 in.) nominal diameter] of the center pivot system to supply water for the new delivery system. The center pivot system had three spans; one span was 39 m (128 ft) long and two were 48.8 m (160 ft) long each, which provided a total length of 136.6 m (448 ft) and an irrigated area of 5.9 ha (14.57 ac). The maximum travel speed of the end tower was 3.85 m/min (12.6 ft/min). Water was pumped from a reservoir into the center pivot system via five pumps, the number in operation depended upon the water flow rate required. The pump system control pressure was 275 kPa (40 psi) and the flow rate was 0 to 300 L/min (0-800 gal/min).

Several requirements were established for the new water application system. First, the modified system must apply water and chemicals to discrete areas [about 100 m^2 (1,076 ft^2)] based either on data stored in a data base or measured directly by sensors. The rational for 100 m^2 areas was based on the spatial features of the soil that were approximately 16 m (52 ft) wide. Therefore the research control element was 10 m (33 ft) wide. Second, it must provide overhead water and chemical application for tall crops such as corn. Third, the system must be capable of applying a range of application depths to the small discrete areas.

To meet the previous requirements, the system was designed to consist of segments or sections 9.15 m (30 ft) long, with each segment having three separate manifolds. Figure 1 shows a diagram of one center pivot span [48.8 m (160 ft)] divided into five segments. Each segment was connected separately to the center pivot main pipeline. Figure 2 shows one segment consisting of three separate manifolds spaced 30 cm (12 in.) apart. Each manifold was connected to the supply pipe via a flexible hose and quick connector. Water flow to each manifold was controlled by a solenoid valve and the pressure was regulated. The solenoid valves were connected to a control system that opened and closed each solenoid valve based on data base values and the segment location in the field. A low pressure drain valve was installed at the supply end of each manifold near the solenoid to permit quick drainage of the manifold when the solenoid was switched off. A pressure relief valve was installed at the distal end of each manifold to facilitate quick escape of the trapped air when the solenoid was switched on. The water application devices were attached to the manifold via 30 cm (12 in.) length and 12.5 mm (0.5 in.) diameter of PVC pipe. This pipe length could be changed to adjust height of these devices if desired.

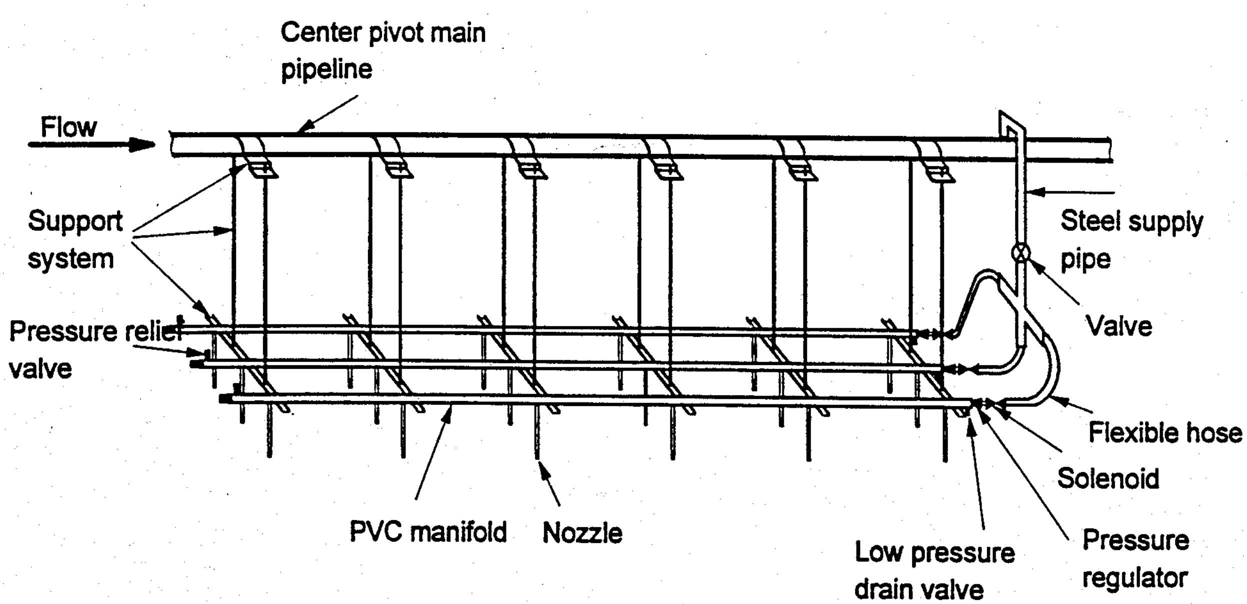

Figure 2–Diagram of a segment showing the main components of the water application system.

Water Application Devices

Because of the small segment length and the desire to prevent or minimize water from one segment overlapping adjacent segments, water application devices with small wetted diameters, 3 to 5 m (10-15 ft) were required. However center pivot system do not move continuously, but rather in a step-wise fashion; therefore, water application devices with a large enough wetted radius to insure overlapping and better application uniformity in the direction of system travel were required. In addition, a large range of water application rates were required along the length of the center pivot system to apply comparable application depth near the pivot point as at the distal end.

Conventional overhead water application devices (sprinklers) usually have large wetted diameters, which will cause excessive overlapping between adjacent segments. In addition, conventional sprinklers require medium to high pressure [>250 kPa (36 psi)] for operation. Taking all the above into consideration, wide-angle industrial spray nozzles (Fulljet Spraying Systems Co.) were selected and evaluated. These nozzles were full cone with a wide spray angle (112° to 120°), and had a wide range of flow rates and sizes, ranging from 1.06 L/min (0.28 gal/min) (1/8 in. nozzle) to 18.92 L/min (5 gal/min) (1/2 in. nozzle), both at 70 kPa (10 psi). Nozzle spray patterns were evaluated for placement at various heights and pressures. Additional tests were conducted to determine the effect of the close spacing [30 cm (12 in.) or less] on the nozzle spray pattern.

Laboratory and Field Testing

Several laboratory and field tests were conducted to evaluate the spray nozzles and the water application system. The first two tests were conducted in the laboratory under no wind conditions.

Nozzle Evaluation

Four nozzles (one size from each nozzle size category; 3.2, 6.3, 9.5, and 12.7 mm (1/8, 1/4, 3/8, and 1/2 in.) were selected for evaluation of distribution pattern at different heights and inlet pressures. Measurement of the patterns was necessary to determine the spacing requirement between manifold nozzles and to calculate distribution uniformities. Water distribution was measured by placing a line of cups, 15 cm (6 in.) apart, under a nozzle, which was installed at the specified height and directly above the first cup. The cups were 94 mm diameter and 120 mm height. The cup dimensions and spacing were according to ANSI/ASAE S436, *ASAE Standards* (1994). Water was applied for 20 min at constant pressure. Each measurement was replicated three times. The water pressure was controlled by pressure regulator and measured by pressure gage with 210 kPa (30 psi) scale and 3 kPa (0.2 psi) accuracy.

Nozzle Orientation

In order to achieve a full cone water distribution, the nozzle design caused the water to spin inside the nozzle prior to exiting the orifice. During nozzle testing, water application depth measurement indicated that average application depth might not be symmetrical for the full circle. Therefore tests were conducted to measure the effect of nozzle orientation on the average application depth. The first test was conducted for fixed nozzles using eight lines of collection cups extending outward from the nozzle and spaced 45° apart. Cups were spaced 15 cm (6 in.) apart along each line and water was collected for a 20 min period during each test.

The second test was conducted for a moving nozzle. Two lines of cups stretched on the two sides of the nozzle were moved perpendicular to the line of the cups. The lines were spaced 30 cm, and the cups on each line were spaced 15 cm (6 in.). The lines of cups were attached to wheels and placed on rails parallel to the moving direction. The line of cups was pulled using a motor and the moving speed was measured.

Field Tests

A prototype segment of three manifolds (19, 25, and 38 mm diameters [0.75, 1, and 1.5 in.)] was constructed and mounted at the center of the second span of the three-span center pivot system. Flow meters were installed at the supply end of each manifold and pressure gages were installed at both ends of each manifold. Three parallel rows of collection cups were placed on the ground and parallel to the manifolds; both rows and cups were spaced 30 cm (12 in.) apart.

Two tests were conducted to evaluate the performance of the prototype segment. In the first test the center pivot system was stationary, and each manifold was directly above a row of cups. In the second test the center pivot system was moving at 25% of maximum speed across the lines of collection cups, and only one manifold spraying water. In the stationary tests, water was collected for 15, 10, and 6 min when the small, medium, and large nozzles were used respectively. Each test was conducted separately. Water collected in the cups was measured and the application depth in centimeters per hour was calculated. The tests were conducted at the last two weeks of October and according to ANSI/ASAE S436, *ASAE Standards* (1994). The wind speed at the test time was less than 3.2 km/h (2 mile/h). Each test was replicated three times.

Results and Discussion

Nozzle Evaluation

Typical distribution patterns for nozzles at 105 kPa (15 psi) water pressure and at 2.75 m (9 ft) height are presented in figure 3. In general for the range pressure tested, the distribution pattern is trapezoidal with a slight peak at low pressure [70 kPa (10 psi)], and triangular with smaller or no peak for higher pressure [140 kPa (20 psi)]. Distribution pattern data were used to calculate the uniformity coefficient between two fixed adjacent nozzles for different spacings. This was done by determining the desired distance between nozzles and sum the total water depth from the overlapping nozzles. The distance between nozzles was a multiplication of 15 cm which was the spacing between the collection cups. The overall water depth pattern between two adjacent nozzles was used to determine the Christiansen coefficient of uniformity.

The distribution pattern of a single stationary nozzle was used to simulate the distribution pattern for nozzle moving at constant velocity corresponding to 50% of the maximum tower speed at the midpoint of the center pivot system. The simulation was done by assuming that the nozzle is moving in a straight line. This assumption is valid

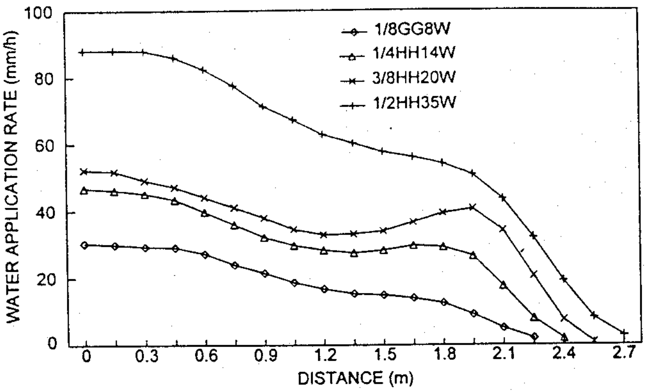

Figure 3– Typical water distribution pattern for 105 kPa pressure and 2.75 m height for stationary nozzles.

since the spraying radius [2.0 to 2.5 m (6.5 to 8 ft)] of nozzles is very small comparing to the center pivot radius (73 m). The Christiansen coefficient of uniformity was calculated using the simulated moving pattern. It can be seen from the results in table 1, when nozzles were fixed, uniformity was higher for the nozzles at a higher elevation [2.75 m (9 ft)] and higher pressure [105 and 140 kPa (15 and 20 psi)]. When nozzles were simulated for moving conditions, low uniformities for fixed nozzles were improved significantly, while high uniformities for fixed nozzles were essentially unchanged. The reason for improving uniformity for moving nozzle is that a fixed point on the ground (or collection cup) will receive water from different segments in the water distribution pattern of the nozzle. In addition to the uniformity, wetted diameters increased only 6 to 17% when pressure was doubled [70 to 140 kPa (10 to 20 psi)].

Table 1. Measured wetted diameter and calculated uniformity coefficient for different heights and pressures, assuming 150 cm spacing between nozzles

Pressure	(kPa) (psi)	70 (10)		105 (15)		140 (20)	
Height	(cm) (ft)	213 (7)	275 (9)	213 (7)	275 (9)	213 (7)	275 (9)
1/8GG8W*							
Flow rate	(l/h)2 (gal/h)	181.8 (48)		217.8 (57.5)		249.8 (66)	
Wetted diameter	(m) (ft)	1.80 (5.9)	2.00 (6.6)	2.10 (6.9)	2.30 (7.5)	2.10 (6.9)	
Uniformity coeffi. (%)‡		87.0	93.2	89.3	95.9	95.8	
Uniformity coeffi. (%)§		99.4	97.5	94.1	95.1	95.1	
1/4HH14W*							
Flow rate	(l/h) (gal/h)	318.0 (84)		385.8 (102)		431.4 (114)	
Wetted diameter	(m) (ft)	1.95 (6.4)	2.25 (7.4)	2.10 (6.9)	2.40 (7.9)	2.25 (7.4)	2.55 (8.4)
Uniformity coeffi. (%)‡		80.7	81.2	86.8	95.1	91.0	98.0
Uniformity coeffi. (%)§		91.2	89.4	91.0	93.5	91.8	97.8
3/8HH20W*							
Flow rate	(l/h) (gal/h)	454.2 (120)		544.8 (144)		613.2 (162)	
Wetted diameter	(m) (ft)	2.25 (7.4)	2.40 (7.9)	2.35 (7.7)	2.55 (8.4)	2.40 (7.4)	2.70 (8.9)
Uniformity Coeffi. (%)‡		81.8	87.2	91.1	99.1	95.2	95.3
Uniformity Coeffi. (%)§		87.9	89.6	91.7	95.7	94.3	98.3
1/2HH35W*							
Flow rate	(l/min) (gal/h)	681 (180)		795 (210)		954 (252)	
Wetted diameter	(m) (ft)	2.35 (7.7)	2.50 (8.2)	2.45 (8.0)	2.75 (9.0)	2.60 (8.3)	
Uniformity coeffi. (%)‡		87.2	95.9	94.3	97.6	98.4	
Uniformity coeffi. (%)§		91.9	94.3	94.2	98.6	96.6	

* Manufacturer item code.
† Manufacturer specifications.
‡ Christiansen coefficient of uniformity for static nozzles.
§ Christiansen coefficient of uniformity for simulated moving nozzles.

Nozzle Orientation

An average water pattern depth was calculated from the eight patterns of water depths. The average water depth for each pattern was compared to the average depth from the average pattern. There was no significant difference between the average depth of the single lines and the average depth of the average line at $\alpha = 0.05$ level.

In the second test, the nozzle was moving relative to the collection cups. The water from the two lines was averaged to create an average pattern. When average water depth on one side of the nozzle was compared to that on the other side, there was no significant difference at $\alpha = 0.05$ level.

Field Test

Figure 4 shows the water application rate for each manifold. Christiansen uniformity coefficients were 78.6, 81.0, and 81.9% for the three manifolds (entire length) with small, medium, and large nozzles, respectively. When only the portion of the manifold between the two end nozzles was used, the coefficients were 86.4, 83.5, and 87.2%. Measured flow rates in the manifolds were 1.1, 2.0, and 3.79 m^3/h (290, 528, and 1,001 gal/h) compared to total nozzles designed rates of 1.1, 1.91, and 3.95 m^3/h (290, 505, and 1043 gal/h) for small, medium, and large nozzles, respectively. The flow meters were standard as used in municipal water distribution systems.

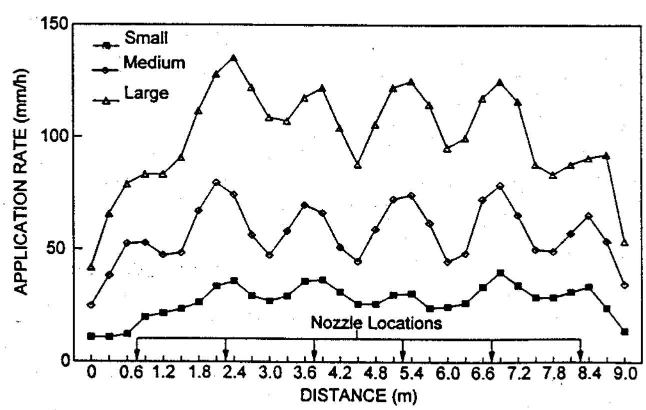

Figure 4–Water distribution patterns of three stationary manifolds with three different nozzles; small, 3.2 mm (1/8 in.); medium, 6.3 mm (1/4 in.); and large, 12.7 mm (1/2 in.) diameter. The nozzles were at 270 cm from the ground.

Application depth evaluation for the moving system was conducted only for large nozzles because of adverse wind conditions. Measured and design depths are shown in figure 5. The Christiansen uniformity coefficient was 84.5% when using data for the total length of the manifold and 86.8% when using data only between the two end nozzles. Average measured application depths were 11.9 and 12.4 mm (0.47 and 0.49 in.) for the total length of the manifold and between the two end nozzles respectively compared to 14 mm (0.55 in.) for the design depth.

SUMMARY

In designing the multiple segment water application system for a center pivot irrigation system, several design requirements were taken into consideration: overhead application, low water pressure, and segment length. A 140 kPa (20 psi) maximum water pressure was available and 9.15 m (30 ft) of section length was required. To achieve several application depths, three manifolds with different nozzle sizes were used. The short length of the segment required nozzles with small wetted diameters. The laboratory and simulation results show high application uniformity (Christiansen coefficient of uniformity was greater than 90%). The field test showed slightly lower uniformity. In addition to the wind factor which always affects the uniformity, several factors can be considered to improve the uniformity: (1) higher water pressure [140 to 210 kPa (15 to 25 psi)] will improve the distribution pattern of the nozzles; (2) longer segment [>15 m (>50 ft)] will reduce the end effect of each segment; (3) use of half-circle nozzles at the ends of each segment will increase the application depth at the segment ends and improve overall uniformity.

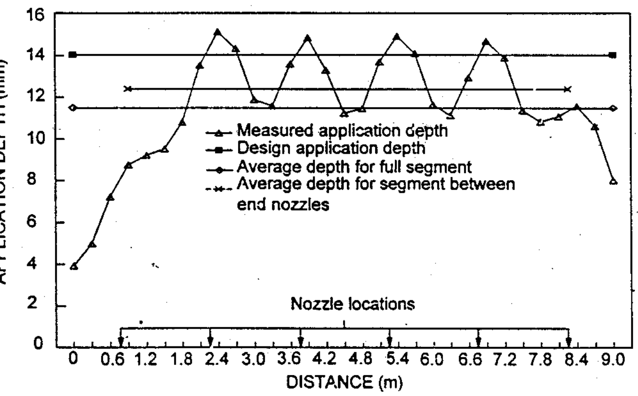

Figure 5–Water application depth patterns of manifold with large nozzle [12.5 mm (1/2 in. diameter)] and the pivot system moving at 25% of maximum speed.

REFERENCES

ASAE Standards, 41st Ed. 1994. S436SEP92. St. Joseph, Mich.: ASAE.

Camp, C. R., and E. J. Sadler. 1994. Center pivot irrigation system for site-specific water and nutrient management. ASAE Paper No. 94-1586. St. Joseph, Mich.: ASAE.

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

Fraisse, C. W., D. F. Heermann and H. R. Duke. 1992. Modified linear move system for experimental water application. In *Advances in Planning, Design, and Management of Irrigation Systems as Related to Sustainable Land Use*, 367-376. Leuven, Belgium: Center for Irrigation Engineering.

Hans, D., and J. D. Breadmaker. 1994. Soil nutrient mapping implication using GPS. *Computer and Electronics in Agric.* 11(1):37-51.

Irrigation Survey. 1996. *Irrigation J.* 46(1):24-39.

Karlen, D. L., E. J. Sadler, and W. J. Busscher. 1990. Crop yield variation associated with coastal plain soil map units. *Soil Sci. Soc. Am. J.* 54(3):859-865.

Muhr, T., H. Auernhammer, M. Demmer and K. Wild. 1994. Inventory of fields and soils with DGPS and GIS for precision farming. ASAE Paper No. 94-1583. St. Joseph, Mich.: ASAE.

McCann, I. R. and J. C. Stark. 1993. U.S. Patent No. 5,246,164. Method and apparatus for variable application of irrigating water and chemicals.

Roth R. L. and B. R. Gardner. 1989. Modified self-moving irrigation system for water-nitrogen crop production system. *Applied Engineering in Agriculture* 5(2):175-179.

Sadler, E. J., W. J. Busscher and D. L. Karlen. 1994. Site-specific yield histories on a SE coastal plain field. In *Site-specific Management for Agricultural System Proc.*, 154-166. Madison, Wis.: ASA, CSSA, SSSA.

Stark, J. C., I. R. McCann, B. A. King and D. T. Westermann. 1993. A two-dimensional irrigation control system for site-specific application of water and chemicals. *Agronomy Abstracts* 85:329.

Zhang, B., N. Zhang, M. D. Schrock, J. L. Havlin and G. J. Kluitenberg. 1994. Development of a field-scale GIS database for spatially variable nitrogen management. ASAE Paper No. 94-3550. St. Joseph, Mich.: ASAE.

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