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MODIFIED CENTER PIVOT SYSTEM FOR PRECISION MANAGEMENT OF WATER AND NUTRIENTS

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Summary:

A commercial center pivot was modified to provide variable water and chemical applications to 100-m^2 areas by adding three manifolds in each of 13 segments 9.1 m long along the truss and a computer to control the system. Water and nitrogen were applied to a fixed-boundary field experiment in 1995. Based on these experiences, a second pivot will be modified to allow variable applications to highly variable soils with irregular-shaped areas.

Keywords:

Precision agriculture, Variable rate, Nitrogen, Center pivot, Computer controlled

INTRODUCTION

The coarse-textured soils of the southeastern Coastal Plain often exhibit greater variability within comparable field sizes than do soils of other regions, especially the finer-textured soils of the midwestern plains and western valleys. The region is comprised of nearly level, sandy surface soils with a sandy clay subsoil (Pitts, 1974; USDA-SCS, 1986). In addition to a coarse texture and low water-holding capacity, many of the soils have compacted layers, which restrict root growth to very shallow depths (0.30 to 0.45 m; 12 to 18 inches). Soil spatial variability is characterized by differences in soil texture, water characteristics, organic matter content, depth to clay, inherent fertility, and extent of layering in the profile. The combination of highly variable rainfall and the effect that many of these variables have on water and nutrient availability creates a complex management scenario, which is generally ignored in current cropping management systems.

Because total annual rainfall may be adequate for crop production, it is often necessary to justify development of site-specific irrigation systems for the region. The climate is humid, subtropical, has a mean frost-free growing season of about 250 days, and rainfall is often poorly distributed during the year and growing season. Average annual rainfall in Florence, SC, is 1100 mm/yr, and normally exceeds evapotranspiration. Most growing-season rainfall results from afternoon convective thunderstorms, which causes both high spatial variability in rainfall and significant runoff. Mean monthly rainfall during the growing season is about 125 mm/mo, but can vary from lows of about 20 mm to highs of about 250 mm. This rainfall variability, coupled with the low water holding capacity of soils, often causes crop yield reduction. Sheridan et al. (1979) reported that on average 22 consecutive days with 6 mm or less rainfall would occur during the growing season every other year. Drought of this length reduces growth and yield of most crops on these soils.

Based on observations of spatial patterns in crop growth, especially during periods of plant water stress, the major factor contributing to yield variability for soils in the Coastal Plain appears to be water relations (Karlen et al., 1990; Sadler et al., 1995a; 1995b). Results from our ongoing research study that investigated crop yield for 14 crops during an 11-year period in the southeastern Coastal Plain found no useful correlation between yield and several patterns of variation, including soil classification and fertility. Because of the combined effect of climate and soil variability, and the uniform application rates of most irrigation systems, optimum management of irrigation and nutrients applied via the irrigation system is often not possible, even for relatively small center pivot or linear irrigation systems (Camp et al., 1988).

Consequently, a Florence ARS design team developed specifications for a computer-controlled, variable-rate center pivot system in 1991 (Camp and Sadler, 1994).
Other research groups have been working independently toward similar goals. Lyle and Bordovsky (1981, 1983) used three individually-controlled manifolds, each delivering discrete but different flow rates, in various combinations to achieve a series of discrete incremental application rates. This system was installed on a Low Energy Precision Application (LEPA)

irrigation system to provide a range of application rates that were uniform for all segments along the truss. Duke et al. (1992) and Fraisse et al. (1992) modified a linear irrigation system to provide variable water and nutrient application using pulsed sprinklers mounted on discrete manifolds [21 m (70 ft) in length] along the truss. The application rate was determined by the rate at which the water supply to each manifold was pulsed via switching the solenoids on and off for varying portions of a base time period, usually 1 min. The advantage of the pulsed-manifold/sprinkler system is that only one sprinkler is needed, where other designs require multiple sprinklers, nozzles, and manifolds. The disadvantages of this system are the interactions between pulse rate, sprinkler diameter, and the start/stop movement of towers. Stark et al. (1993) developed a patented control system (McCann and Stark, 1993) to provide site-specific application of water and chemicals for both linear and center pivot irrigation systems. This system consisted of conventional sprinklers controlled by a microprocessor and used three sprinkler sizes (1/4, 1/4, and 1/2 of full flow) to provide 1/4, 1/2, 3/4, and full irrigation rates. The computer also controlled irrigation system travel speed and chemical injection pump flow rate, both based on a spatially-referenced mapping system. King et al. (1995) reported further developments on a 100-m linear system and a 7-tower, 210-m center pivot system using two sprinklers delivering 1/3 and 2/3 of a target application depth.

The objectives of this paper are to describe the variable-rate center pivot irrigation system developed at Florence, to report results of its use in a replicated experiment during 1995, and to illustrate its capabilities for application in site-specific management of water and chemicals.

MATERIALS AND METHODS

Design Considerations

The basic requirement of the irrigation system was to apply water and chemicals to discrete 100-m^2 areas within the system based on soil, crop, and weather data stored in a data base or measured directly by sensors. Both maximum water application uniformity and minimum affect on adjacent areas were desired. Water application was needed at sufficient depth to replace maximum daily potential ET while the system moved at normal operating speeds (usually 50% of maximum speed). Seven discrete fractions of maximum potential ET were selected as a first approximation of true variable-rate irrigation. The control element area was defined as 100 m^2, which relates to a length along the truss of about 10 m (32.8 ft) and an appropriate angular sector provided by a mean travel distance of about 11 m. Spatial location of each element would be determined either by system operating parameters (angle of rotation, position along the truss) or remote telemetry (e.g., global positioning system). Application rates would be determined from digitized maps in computer memory; and algorithms would select appropriate application depths based on one or a combination of several parameters, including soil and crop properties, historical yields, and real-time sensors. The variable-rate application system would be achieved by modification of commercial center pivot irrigation systems equipped with a computer-aided management system.

Because irrigated area in a center pivot system is not a linear function of distance from the center, sprinkler application rates must increase with distance from the center. This range of application rates must be incorporated into the design of any variable-rate water and chemical application system. The desired range of irrigation application depths per revolution was 0 to 12.5 mm at a normal tower speed. In commercial center pivot systems, the range of tower velocities is obtained via changes in the duty cycle of the end tower drive motor (range of 0 to 100%). For this system, the normal speed selected was half of maximum speed (cycle timer=50%). In some systems, the cycle base period is selectable (e.g., 30 s or 60 s), which, in connection with the cycle timer, determines the actual on/off times for the end tower. The step-wise movement of the truss has an undesirable effect on water and chemical application uniformity because the sprinkler moves at a constant velocity for part of the cycle but otherwise remains stationary. Generally, the larger the sprinkler wetted diameter, the better the application uniformity for the step-wise movement and tower misalignment of commercial center pivot systems. Unfortunately, both the relatively short manifold length (9.1 m) of this modified system and the requirement to confine water and/or chemicals to the intended application area require a smaller sprinkler wetted diameter, which severely limits the potential selection of acceptable sprinklers, especially for locations nearer the outer end. Although it should improve application uniformity, the tower drive system was not modified at this time to provide continuous but variable-speed movement because of added system complexity and cost.

Another concern was the magnitude of error in position determination when the angular position of the truss (measured at the pivot) and sprinkler location along the truss are used to determine locations within the system. Truss misalignment at each tower (unknown deviation from straight line) can contribute significant error to this position determination. For small systems, such as the one used here, this error is smaller that it is for a large systems with 10-12 towers, where a bow-shaped truss alignment would cause accumulated rather than offset errors. The truss alignment system was not modified, but it was adjusted to provide minimum misalignment error.

System Implementation

Two small, three-span, commercial center pivots were purchased in 1993 (Valmont Irrigation Inc., Valley, NE[1]). With a total length of 137 m, each provided an irrigated area of 5.8 ha. The systems were standard commercial systems except for two specifications: oversize truss rods to increase the truss load capacity, and threaded ports in the system pipe to supply water to individual manifold segments. Both systems included programmable computer management control systems that could also be programmed and controlled from a remote base station, which was also purchased. Two sprinkler systems were provided with each system; overhead

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[1] Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Dept. of Agr. and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

sprinklers and LEPA quad sprinkler heads on drop tubes to allow immediate irrigation capability, but these systems are separate from the variable rate system.

The variable-rate water application system, installed on one center pivot, was designed, constructed, and installed in cooperation with Coastal Plain Experiment Station, University of Georgia, Tifton, GA. The center pivot length was divided into 13 segments, each 9.1 m (30 ft) long, starting with the outer tower (see Fig. 1). (A small section of the truss (18.3 m, 60 ft) near the center was not modified.) Each segment had three parallel, 9.1-m (30-ft) manifolds, each with six industrial spray nozzles spaced 1.5 m (5 ft) apart. Water was supplied to each set of three manifolds (one segment) from the system pipe via 5-cm (2-inch) diameter ports, distribution manifolds, and drop hoses. Each manifold had a solenoid valve to control flow, a pressure regulator, a vacuum breaker, and a low pressure drain. The last two items facilitated rapid evacuation of the manifold to prevent water transfer to adjacent segments caused by slow drainage. The three manifolds and their unique set of nozzles were sized to provide 1x, 2x, and 4x of a base application depth at the location of that specific segment, which meant that actual flow rates of the nozzles increased with distance from the center to account for the increased area irrigated per unit angle traveled. All combinations of the three manifolds provided 0x, 1x, 2x, 3x, ...7x the base depth. The 7x depth was designed for 12.5 mm (0.5 inch) when the outer tower was operated at 50% duty cycle. Additional details regarding construction and operation of this variable-rate application system were reported by Omary et al. (1996). The small size of these center pivot systems, 137 m (450 ft), allows the system to travel the full circle in about 4 hours at 100% duty cycle. When drift is excessive or of special concern, the application system can be converted to a LEPA-type bubbler by fastening flexible tubes around each nozzle, which delivers water to near the ground surface, depending upon tubing length.

The variable-rate application system is under the overall control of a 80386 PC (Horner Electric model HE693PCC344, Indianapolis, IN) with hard disk drive, floppy drive, serial ports, and peripheral connectors, which was mounted on the programmable logic controller (PLC) backplane (GE Fanuc model 90-30, Charlottesville, VA) and connected via the system buss. The PLC was mounted on the mobile portion of the system about 5 m (16 ft) from the center, from which it controlled all manifold solenoids. Angular location of the truss is determined from the C:A:M:S™ (Valmont Irrigation, Inc.) management system, which required a communication link between the mobile PC and the stationary C:A:M:S™ system. This was achieved with a short-range, radio-frequency modem (900 MHZ, spread-spectrum modems; Comrad Corp., Indianapolis, IN). A schematic diagram of various communication links is shown in Fig. 2. Power for the computer and PLC system was provided by a transformer, which converted the irrigation system power supply (480 VAC, 3 phase) to 120 VAC. Power for the solenoid control circuit (24 VAC) was also provided by transformers, but with a primary source of 120 VAC. Software was written in Visual Basic for DOS (Microsoft Corp., Redmond, WA) to convert a set of control values to on-off settings in the directly-addressable solenoid control registers of the PLC. The on-board PC repeatedly interrogates the C:A:M:S™ unit to determine the angular position of the truss and other parameters to provide assurance of proper operation. From the angular position and the fixed position of each segment along the truss, the segment location, expressed in polar coordinates, is established for that time. Once the location is determined, the control program in the PC checks each segment to see whether a boundary has been crossed. If not, the interrogation cycles continue until a boundary is crossed by one or more segments, and a change is needed. When a boundary is crossed, the appropriate table lookup is performed, and the solenoid registers are set accordingly. The software also includes a routine, based on position measurements, to correct systematic errors in the reported angular position of the truss. A diagram showing the control logic of the software in included in Fig. 3.

Nitrogen Application

The chemical injection system designed and installed on the modified center pivot system is based on the principle of maintaining a constant chemical concentration in the water supply line. Consequently, variable chemical application amounts can be applied to each segment by varying the water application amount. To achieve constant chemical concentration in a system where the water flow rate varies with the number of solenoids switched on at any time, the chemical injection rate must also vary with water flow rate. The variable-rate injection pump (Ozawa R & D, Inc. model 40320, Ontario, OR) had four heads, operated on 24 VDC, was located at the pivot center, and was connected to a chemical storage tank and the water supply pipe (via check valve). Pump injection rate was varied by the number of heads used and the pump speed, which was controlled by adjusting the 0-5 VDC signal sent to the pump controller. To keep the chemical application rate proportional to the water flow rate, the on-board PC calculated the water flow rate, calculated the required chemical injection rate, computed the 0-5 DC voltage setting required to provide the required injection rate, and reported it to the operator. This system was used to apply all sidedress nitrogen (UAN 24S) for corn during the 1995 growing season. The operation was monitored and controlled manually, which required the operator to manually input values to a CR7 data logger/controller (Campbell Scientific Inc., Logan, UT). In the future, the 0-5 VDC value will be communicated directly to the pump controller. The spatially-variable nutrient applications in 1995 were accomplished using a low-volume, spatially-variable water application. Independent spatial application of water and chemicals using this multiple-manifold application system would require control of multiple injection points, at least one for each segment. Control of such a system would be complex, but not particularly difficult; however, the requirement for multiple pumps and distributed chemical storage made this option too costly and generally not feasible at this time.

A preliminary evaluation of spatial uniformity of nitrate concentration in irrigation application was conducted during 1995. Samples were collected by placing a 500-ml (0.5 qt) container directly under randomly selected (both in space and time after pressurizing the manifold) nozzles with the center pivot irrigation system in normal operation, while applying UAN 24S to corn. The total discharge from each nozzle was collected for the time required to fill the container. Nitrate concentration of the collected solution was analyzed using a specific-ion electrode (Orion electrode model 93-07, Boston, MA), While the UAN solution included other forms of nitrogen, analysis for nitrate should provide satisfactory data for comparing concentrations among spatially-variable samples.

Water Supply

While the primary focus of this paper is on the irrigation system, the system to supply the variable water flow rates may be of interest. The system was designed and constructed about two years before the center pivot irrigation systems were purchased in anticipation of needs for variable application rates. The pressurized water supply also supplies water to other irrigation systems at the research center, ranging from trickle to high-volume guns. Water was supplied at variable flow rates, but at constant pressure to all irrigation systems, including both center pivot systems, via an underground pipe. A lined reservoir (about 7,600 m^3 capacity; 2 million gallons), constructed to exclude runoff water, was filled by a float-controlled vertical-shaft turbine pump delivering 1,515 L/min (400 gal/min) open discharge from a well 128 m (420 ft) deep. Water was pumped from the reservoir into the pressurized supply pipe via five pumps, the number in operation depended upon the water flow rate required. The system control pressure was 275 kPa (40 psi) and the pumping system flow rate was 0 to 3,000 L/min (0-800 gal/min). A PLC-based control system measured water pressure in the supply line and, based on a table of values, switched on the appropriate combination of pumps to maintain the desired pressure. For more precise control of flow rates, especially those between the discrete values provided by the various pump combinations, a pressure-relief valve discharged excess water into the reservoir when pressure exceeded the control pressure.

Operation in a Replicated Field Experiment

The modified center pivot system was sited on a relatively uniform soil area. Because of the relatively good soil uniformity, a traditional field experiment with fixed plot boundaries was selected for fine-tuning the technology under more controlled conditions than the highly variable soil conditions where the second center pivot system was sited. The objectives of the experiment were to test rotation, irrigation, and subsoiling effects on a corn-soybean rotation vs. continuous corn, both with conservation tillage. Subsoiling vs. not subsoiling was tested to see whether managing water via irrigation would offset the need to increase rooting depth via subsoiling because both practices are energy intensive and add significant operating costs.

There were three rotations (corn-corn, corn-soybean, and soybean-corn), two tillage practices (subsoiled, and non subsoiled), three water managements (rainfed and tensiometer-controlled and crop-stress-controlled irrigation), two nitrogen regimes (single sidedress, and multiple sidedress), and four replications, which provided a total of 144 plots. All rows were planted and all subsequent operations were performed in a circular pattern that coincided with the travel pattern of the center pivot system. Individual plots were established in a regular 7.5° by 9.1-m (30-ft) pattern, which made the minimum plot length 10 m (33 ft.) in segment 8, and 15 m (49 ft) in segment 13. As depicted in Fig. 4, the experimental plots were sited on the outer six of 13 segments of the center pivot system, on the most uniform soil areas. The outer segments were used so that planting and other field operations could be performed easily. Each of the four replicates were located in angular sectors of the circle (Fig. 4).

RESULTS AND DISCUSSION

The system was changed from a commercial center pivot irrigation system to a site-specific center pivot irrigation system by installation of the three-manifold, multiple-segment water application system, the PLC control system, and control software. Initially, the control software was somewhat primitive and fragile, but evolved during the growing season through experience and modification. At the beginning of the season, system operation required periodic manual intervention and re-initialization but, by the end of the season, the system operated unattended except for monitoring via the remote C:A:M:S™ base unit. Acceptable distribution uniformity within control elements and expected border effects between elements with different application depths had been measured previously (Omary et al., 1996). Observations and measurements during the 1995 season presented no evidence that the border width or distribution uniformity was different from that measured previously. Water ponding and surface redistribution had been a concern during design, because of the relatively high instantaneous application rates caused primarily by the small wetted diameter of the industrial spray nozzle. Even collection of nozzle discharge during nutrient application into a 37-mm-diameter (1.5-inch) flexible hose did not cause excessive local ponding and runoff. Irrigation amounts for various treatments by date for corn and soybean are shown in Tables 1 and 2, respectively.

Sidedress nitrogen applications, including amount of N, for all treatments are shown in Table 3. Flexible hose, 37-mm-diameter (1.5-inch), was attached to the 2x nozzle and extended to near the ground surface to prevent drift and reduce potential plant damage. The 2x nozzles delivered 3.6 mm (0.14 inch) of water at 50% duty cycle and 1.8 mm (0.07 inch) at 100%. Nitrate concentration in samples collected from randomly-selected nozzles on two dates in 1995 during sidedress nitrogen application to corn is reported in Table 4. Nitrate concentration of the ten samples collected during each of two dates ranged from 202 to 274 mg/L on June 14 and from 246 to 291 mg/L on June 21, both with a target application rate of 22.4 kg/ha N. The mean N concentrations for the two dates were 244 and 270 mg/L, respectively, with standard deviation values of 17.8 and 13.6 mg/L. These preliminary values indicate relatively uniform N concentrations among the nozzles sampled, both in space and time after manifold pressurization. Further evaluation will be necessary, especially to include distribution uniformity of the water application system, before definitive conclusions can be reached regarding this nutrient application system.

Future work will include addition of a pesticide application system and improvement in control software and communication reliability between various system components. The second center pivot system, sited on highly-variable soils typical of many southeastern Coastal Plain fields, will be modified based on experiences gained with the first system and improved technology. Completion of modification on and full operation of the second system will represent full implementation of variable-rate management of water, nutrients, and pesticides for small areas of variation with irregular boundaries, which reflect the conditions found in a typical, highly-variable Coastal Plain field.

The management software will also be modified to accommodate irregular soil unit boundaries and to optimize water and chemical applications for each segment in relation to the location of each soil unit. Sensors to provide real-time or near real-time feedback of crop conditions will be added to both systems to improve crop management and to detect dynamic crop variation during the season.

SUMMARY AND CONCLUSIONS

Modifications to a commercial center pivot irrigation system produced a system that provides site-specific, variable-rate application of water and nutrients. The system has 13 segments, each 9.1 m (30 ft) in length, along the truss, which allow variable application rates of water and nutrients to control areas of about 100-m^2 area, the exact size depending upon the segment position on the truss and its travel distance per unit angle of rotation. Seven discrete rates can be applied independently within each segment. A programmable, computer-controlled management system obtains positional and other information from the center pivot control system via a radio frequency modem and opens the appropriate valves to obtain application rates for specific areas. Water and nitrogen applications to a fixed-boundary field experiment were successfully accomplished during 1995. Preliminary observations and evaluation of water and N application uniformities indicate that system performance is acceptable. More extensive evaluation will be required before definitive conclusions can be reached with regard to system performance. Experience gained with this system will be used to modify a second commercial center pivot irrigation system for site-specific water, nutrient, and pesticide management on a site with variation (irregular boundaries) typical of Coastal Plain fields.

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Table 1. Irrigation events during the 1995 growing season for corn.

Date	DAP*	Depth mm (inches)	Treatments†
April 17	13	5 (0.2)	Irrigated and Rainfed‡
April 19	15	12.5 (0.5)	Irrigated and Rainfed‡
April 27	23	12.5 (0.5)	Irrigated and Rainfed‡
April 28	24	12.5 (0.5)	Irrigated and Rainfed‡
May 8	34	12.5 (0.5)	Irrigated and Rainfed‡
May 9	35	12.5 (0.5)	Irrigated and Rainfed‡
May 19	45	12.5 (0.5)	TENS and PSTRESS
May 23	49	12.5 (0.5)	TENS and PSTRESS
May 26	52	12.5 (0.5)	TENS and PSTRESS
June 26	83	12.5 (0.5)	TENS and PSTRESS
June 28	85	12.5 (0.5)	TENS and PSTRESS
June 30	87	12.5 (0.5)	TENS and PSTRESS
July 3	90	12.5 (0.5)	TENS and PSTRESS
July 7	94	12.5 (0.5)	TENS and PSTRESS
July 10	97	12.5 (0.5)	TENS and PSTRESS
July 14	101	12.5 (0.5)	TENS and PSTRESS
July 20	107	12.5 (0.5)	TENS and PSTRESS

* DAP = days after planting.
† Irrigated=All irrigated treatments; Rainfed=Non-irrigated treatments, rainfall only; TENS=Tensiometer treatment; and PSTRESS= Plant stress treatment.
‡ Pre- and post-plant irrigation to achieve seed germination and seedling established during severe drought.

Table 2. Irrigation events for soybean during the 1995 growing season.

Date	DAP*	Depth mm (inches)	Treatments†
July 14	53	12.5 (0.5)	TENS and PSTRESS
July 17	56	12.5 (0.5)	TENS and PSTRESS
July 25	64	12.5 (0.5)	TENS and PSTRESS
July 28	67	12.5 (0.5)	TENS and PSTRESS
July 31	70	12.5 (0.5)	TENS and PSTRESS
August 2	72	12.5 (0.5)	TENS and PSTRESS
August 9	79	12.5 (0.5)	TENS and PSTRESS
August 14	84	12.5 (0.5)	TENS and PSTRESS
August 17	87	12.5 (0.5)	TENS and PSTRESS
August 18	88	12.5 (0.5)	TENS and PSTRESS
August 21	91	12.5 (0.5)	TENS and PSTRESS
August 23	93	12.5 (0.5)	TENS and PSTRESS
August 25	95	12.5 (0.5)	TENS and PSTRESS

* DAP = days after planting.
† Treatment definitions are the same as those defined in Table 1.

Table 3. Nitrogen applied to corn via injection into irrigation water during the 1995 growing season.

DAP*	N Application (kg/ha)	Duty Cycle, No. of Passes	Treatments Fertilized†
58	22.5	50%, 1	All
64	112.3	100%, 2	Single
65	22.5	50%, 1	Multiple
69	22.5	50%, 1	Multiple
71	22.5	50%, 1	Multiple
76	22.5	50%, 1	Multiple
78	22.5	50%, 1	Multiple

* DAP = Days after planting, which occurred on April 4, 1995.
† Nitrogen sidedress treatments were either a single application or multiple incremental applications.

Table 4. Measured nitrogen concentration in randomly-collected nozzle discharge for site-specific center pivot irrigation system during 1995 growing season.

Location*	Date	Target Application (kg/ha)	N Concentration (mg/L)
A20S8	June 14	22.4	274
A12S9	June 14	22.4	202
A17S9	June 14	22.4	240
A7S9-1	June 14	22.4	242
A7S9-2	June 14	22.4	244
A7S9-3	June 14	22.4	248
A7S9-4	June 14	22.4	254
A12S13	June 14	22.4	244
A12S8	June 14	22.4	248
Mean (Std. Dev.)			244 (17.8)
A18S10-1	June 21	22.4	287
A18S10-2	June 21	22.4	268
A18S10-3	June 21	22.4	280
A18S10-4	June 21	22.4	291
A13S8-1	June 21	22.4	273
A13S8-2	June 21	22.4	250
A13S8-3	June 21	22.4	267
A13S8-4	June 21	22.4	264
A24S8	June 21	22.4	246
A24S10	June 21	22.4	270
Mean (Std. Dev.)			270 (13.6)

* Location codes refer to 7.5°-sector number (A) and segment (along truss) number (S).

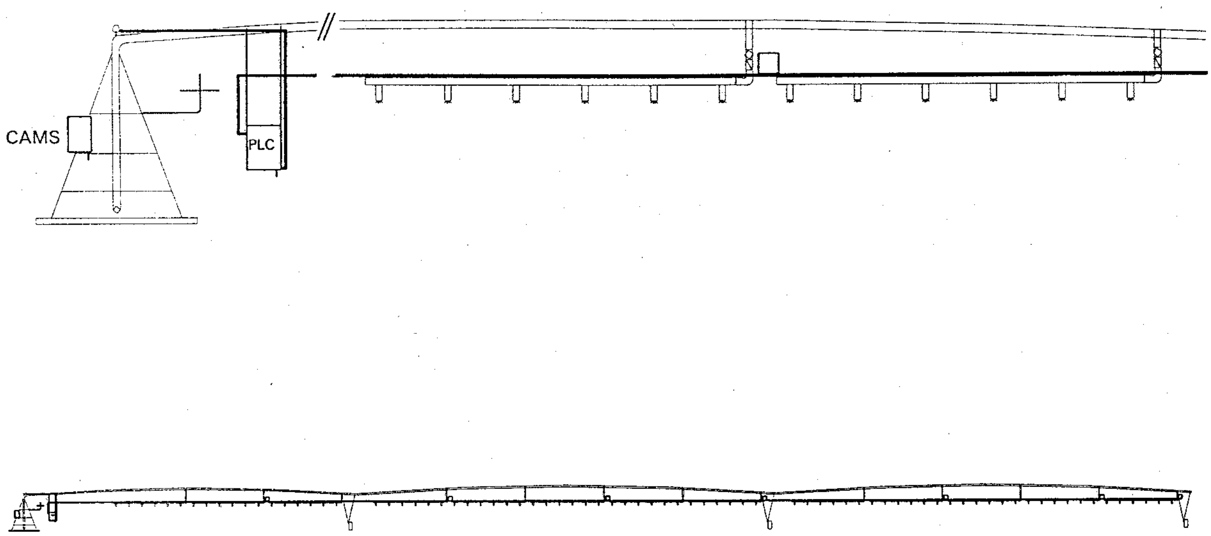

Figure 1. Schematic diagram of modified center pivot irrigation system showing side view and detail of communication hardware and two segments along the truss.

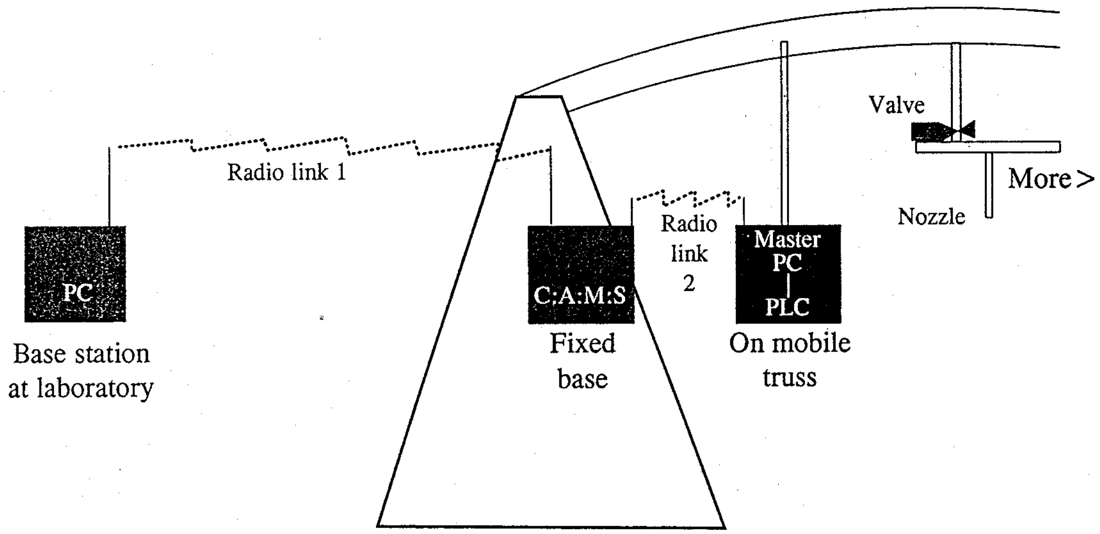

Figure 2. Schematic diagram of system communication links for a site-specific, variable-rate center pivot irrigation system.

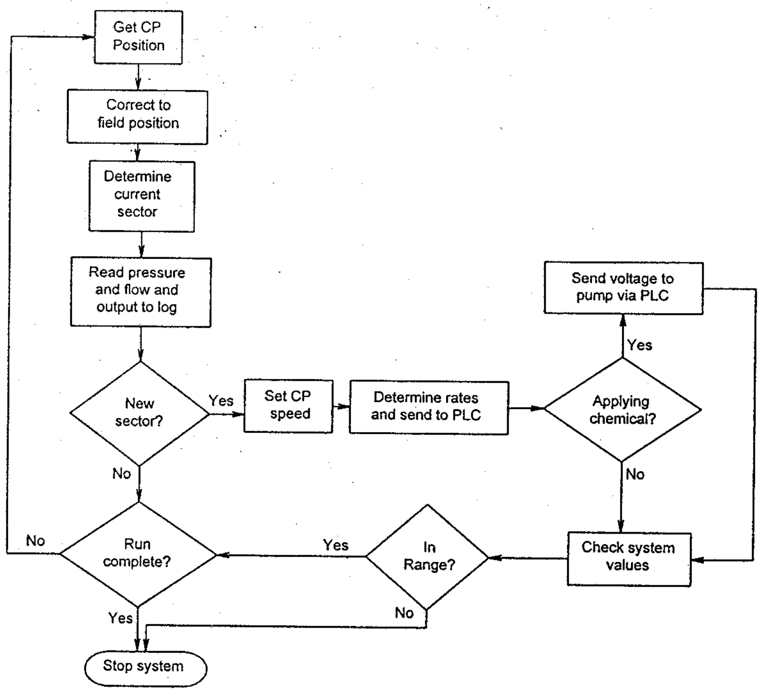

Figure 3. Diagram of control program logic for management of a variable-rate, site-specific irrigation system for application of water and nutrients.

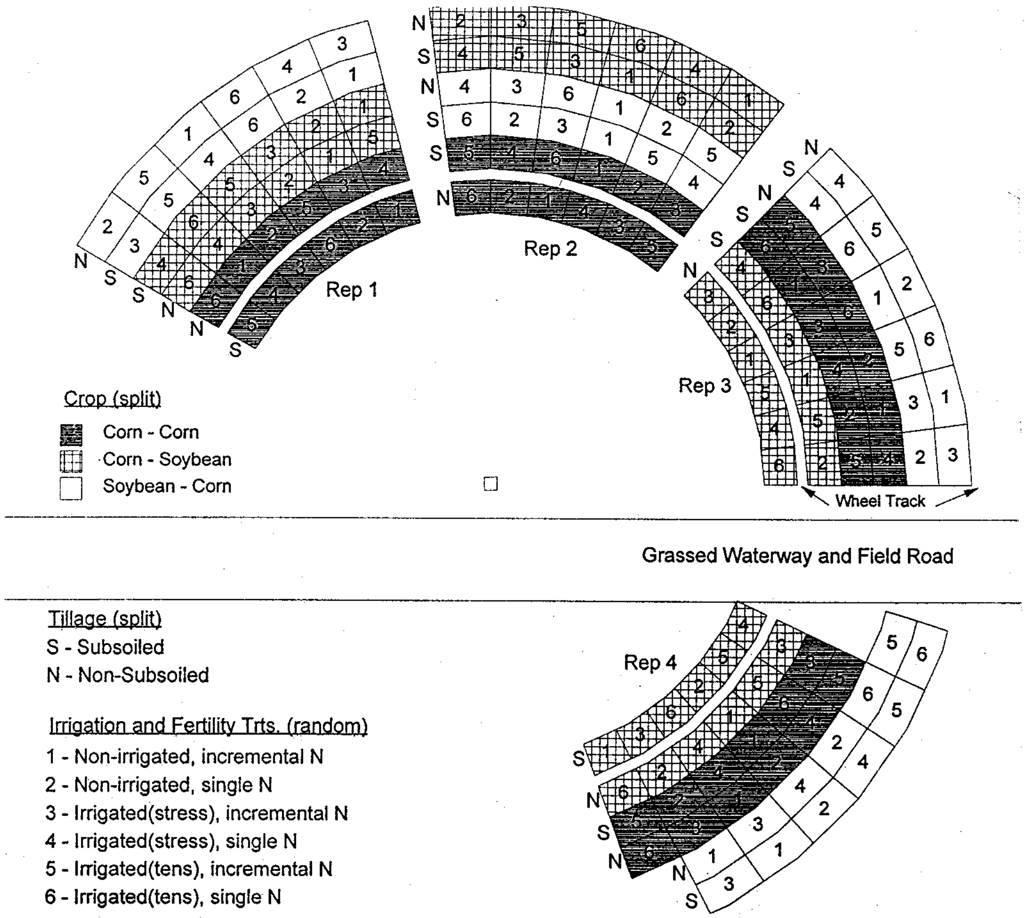

Figure 4. Diagram of field experiment where water and nitrogen were applied via a site-specific center pivot irrigation system, showing segments 8-13.