DESIGN CONSIDERATIONS FOR SITE SPECIFIC IRRIGATION

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ABSTRACT

Interest in optimal management of irrigation and nutrient applications for spatial variation has increased during the past decade because of the availability of global positioning and yield monitoring equipment at affordable cost. The degree and source of spatial variation depends upon many factors, but overall management and control principles should apply to most locations. Overall management strategies (environmental protection, resource conservation, economics, etc.) must be known for each application. However, the number and size of management zones within an irrigation system will vary with location. Crop responses to variable inputs of water, nutrients, and pesticides must be determined. Once this information is available, irrigation and nutrient combinations can be determined for specific management zones within the irrigation system. Research at several U. S. locations is developing much of this information. Also, control software is being developed for managing irrigation and fertilizer applications in these management zones via center pivot and linear irrigation systems.

KEYWORDS: Precision agriculture, site-specific, irrigation, water management, controls, agricultural systems, self-propelled irrigation

INTRODUCTION

In the decade of the nineties, economic pressures encouraged improvements in management to reduce year-to-year variability and increase overall production efficiency. The convergence of several technologies led to the increase of precision agriculture, which is management custom tailored for the conditions at specific sites within a field. Precision agriculture adapts to resource variability with goals to both increase production efficiency and reduce risk of adverse environmental impact. The convergent technologies that have made this possible include: the global positioning system (GPS); sensors, including the yield monitor; geographic information systems (GIS), including those specifically made for handling yield maps; variable rate technology (VRT) controllers; and high speed computers, which of course are embedded in almost all the other technologies listed. In sum, farmers now have capabilities they have never had before.

The first commercial precision agriculture technology was for site-specific application of dry granular fertilizer (Wollenhaupt and Buchholz, 1993), based on a patent issued in 1986 (Ortlip, 1986). Since that time, there have been other application technologies developed, e.g., technologies for pesticides and liquid nutrients. However, there are several pieces of evidence to indicate that water may be a key crop production factor that should be managed on a site-specific or precision basis. The first is the lack of correlation between yield and fertility with many crops, whether done on a grid sampling basis or on site-specific application of nutrients (Pierce and Nowak, 1999). Secondly, remote sensing images of spatially variable crop temperature indicate spatially variable crop water stress (Moran and Jackson, 1991; Kustas and Norman,

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1996). Third, there is a historical knowledge base linking water holding capacity to texture, which is known to vary spatially. Fourth, climatic studies have successfully explained year-to-year yield variability by growing-season rainfall. Where water is the limiting factor, there is a known nearly linear dependence of yield on applied water (e. g., Howell et al., 1990) that gave rise to the water use efficiency concept and crop production functions. From limited data, surface water content (Lascano et al., 1999) and evapotranspiration (e. g., Sadler et al, 2000) appear to be distinctly variable in different regions of some fields. From these observations, one can easily conclude that water bears significant consideration as a candidate for precision management.

Variations in water availability across a field because of different soil characteristics may cause farmers to: 1) ensure that areas with the smallest water holding capacity receive adequate water; 2) manage the whole field based on average soil water conditions; or 3) limit water application to avoid overirrigating the wettest areas. All of these cases will cause overirrigation or underirrigation of other areas due to the current inability to differentially irrigate based on soil and plant factors within a single irrigated field. Chemical leaching below the root zone, surface runoff, and potential yield decreases in particular areas can occur under each management scenario.

Elevation differences cause pressure changes in a moving irrigation machine and can cause both surface and subsurface lateral movement of water in the soil profile toward low areas. These effects can be regulated to some degree with pressure regulating valves or flow control nozzles. Elevation changes encourage surface runoff and encourage ponding at the lower elevations (Han et al., 1996a; Sudduth et al., 1996). The combination of these factors can accelerate leaching of soil nutrients and other agrochemicals past the root zone in some areas of a field, reduce crop quality and yields as well as cause excessive energy use for pumping.

It is evident that the ability to more precisely manage small areas of the field will be necessary to further reduce potential groundwater degradation. However, wide variations in soil textures, soil chemical properties, subsurface conditions, micro- and macro-topography, drainage, crop growth and water use, insect/weed/disease problems, soil compaction, weather patterns, irrigation system operation and maintenance, wind distortion of sprinkler patterns, as well as external factors such as herbicide drift, make the determination of management practices ("prescriptions") within discrete areas of a field very difficult.

Research on variable rate self-propelled irrigation systems (but not variable precision) began in the early 1980s. Lyle and Bordovsky (1981, 1983) used three individually-controlled manifolds, each delivering discrete but different flow rates, in various combinations of different sized sprinkler heads 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. Roth and Gardner (1989) used three lines on a linear irrigation system to apply five different water depths to a series of plots, but the depth distribution among plots was fixed, and independent control of application depth either along the system length or travel direction was not possible.

Based on the indicated potential for fully site-specific irrigation, research was initiated at four sites, independently at first, then with shared information as awareness developed of other work. The group at Fort Collins, Colorado, developed a 4-span linear-move site-specific irrigation machine for research purposes (Fraisse et al. 1992; Duke et al., 1992). At approximately the same time, the University of Idaho group received a patent on a method and apparatus to variably apply irrigation water and chemicals (McCann and Stark, 1993). That group later described two site-specific irrigation machines (King et al., 1995). Concurrently, in Florence, South Carolina, design criteria for a site-specific center pivot irrigation machine were developed (Camp and Sadler, 1994); it was constructed in 1995 (Sadler et al., 1996; Omary et al., 1997). Starting in 1994, Washington State University began development of a custom control system on a commercially operated center pivot system (Evans et al. 1996a; Evans 1997; Evans and Harting, 1999). Harting (1999), also in central Washington State, designed and installed PLC-based control systems on three full and three partial (first span only) commercially operated center pivot systems. At all four locations, various techniques were used to design and control their individual irrigation machines. This paper discusses design considerations gleaned from these experiences.

VARIABLE RATE PRECISION IRRIGATION

A wide variety of communications protocols, control systems and computer interfaces have been developed to interact with self-propelled irrigation systems, their chemical injection systems, valves and sprinklers to implement site-specific management maps for water and agrochemical applications. The control systems are linked to nozzle hardware, which is discussed in another paper in these proceedings.

Precision application technologies can be used to treat a whole field or to treat small areas of a field with simple on/off sprinkler controls in single span-wide treatment areas. Small area control systems would be used to manage irrigation in well-defined areas where the cost of a full precision irrigation control system is not justified such as rock outcrops, waterways, or under the first span from the pivot. Analysis of field data (Evans et al., 1996a, 1996b) has shown that application depths are normally reduced by either no more than 15-20% or by 100% (no application, as would be the case of rock outcrops or waterways). They also concluded that lesser values would not usually be needed except for chemigation. It should be noted that those conclusions pertain to arid or semi-arid western US conditions, and it is not yet clear that lower flow rates are not needed in the humid eastern US.

Design water application rates are generally very low for the first span from the pivot point to the first tower because it moves much more slowly than the outer towers. This area is typically either over-watered by as much as 20% because nozzles currently available will not allow for the correct application of water or too dry because the nozzles are very small and prone to plugging. The often-wetted foliage in this area also has higher incidences of fungal diseases. One option is to turn off every other sprinkler along the first span for one or two rotations, and then turn on the sprinklers that are off and turn off the sprinklers that are on for one or two rotations. Another approach to eliminate both the over-watering and plugging problems within the first span area is to use large nozzle sizes and cycle the sprinklers on and off applying the desired amount over time. Controls to specifically treat predesignated fixed wet spots, dry spots or nonproductive areas (e.g., rocky outcrops that receive no irrigation or fertilizers) could be implemented based on position or specific triggering mechanisms placed in the field.

DESIGN CONSIDERATIONS

The design of a suitable site-specific irrigation machine is doubly complex. Layered atop the usual design issues required to create a traditional machine are the various considerations associated with variable-rate equipment. The additional site-specific design considerations include the variation to be addressed, the causes of the variation to be addressed, the system capabilities needed to achieve the management desired, the constraints inherent in the existing equipment, existing knowledge, and the philosophy of the owner/operator. These considerations are not mutually exclusive, nor do they lend themselves well to categorization.

The first consideration is the objective of the management desired or, in other words, what is the effect of the variation to be addressed. It may be to avoid crop stress or to optimize economic return, to adapt to treatment variability such as in research plots or nurseries, to allow deficit or partial irrigation to solve limited-resource allocation problems, to comply with exclusion zones or other regulatory constraints, to avoid adverse environmental impact, or to avoid rock outcrops, roads, well heads, or water bodies (either ephemeral, such as collections in potholes, or permanent, such as streams or irrigation canals).

A second consideration is to determine the objective of the management technique. This could include adapting to rainfall or irrigation runoff caused by slope in the field, adapting to antecedent events or practices, adapting to soil or other resource variability, or adapting to spatial pest pressure or nutrient shortages.

A third consideration is the objective of the application system itself. A person may want to manage irrigation only, to manage irrigation and fertility, or to manage both irrigation and fertility but add pesticide management as well. Obviously, for each of these three situations, the equipment is an accumulation of the irrigation machine, fertilizer injection, and pesticide application hardware.

Yet another consideration regards objectives related to existing equipment, knowledge, and social constraints. If an existing machine is to be retro-fitted, if historical knowledge of equipment and management exist, or if the operator has particular policies, then the design must be altered to account for these special cases. For instance, a management approach can determine whether irrigation applications are scheduled or are in response to sensors.

All the above considerations bear on the design objectives of the irrigation machine. They combine to determine the spatial resolution needed, the resolution of the controlled variable, and the controls needed to accomplish the desired management. Ultimately, they constrain the selection of all components of the irrigation machine and the water supply equipment. And of course, cost and economic benefit impact all the above considerations.

Resolution

Specific considerations must be made regarding the spatial resolution needed to address the variable effect. The main factor is the severity of the variation being managed. For instance, how rapidly does the soil texture change or the soil fertility change that one is trying to address? What level of control is required in the transition zone from one region to the next, and what are the penalties for improper control at the transition point? In certain cases, such as regulatory compliance, the cost of being wrong is extreme, and the economics of being right are probably, but not necessarily, of lesser importance.

Another consideration is what interactions occur between components and their capabilities. The primary interaction is between cost and the desired resolution; the finer the resolution, the higher the cost of the equipment. Another interaction is nozzle choice; wetted radius of the nozzle affects the resolution that can be obtained. For instance, a high pressure nozzle that has a wetted radius of 20 m will obviously have a wider transition zone between an applied and non-applied area than a nozzle with a wetted radius of 5 m.

If the VRT applicator uses an on/off or pulse mode approach, the phase of the sprinkler's actions can interact with the start-stop travel motion of the system and, therefore, adversely impact the uniformity. This is potentially worse when the cycles are near the same length and out of phase. If the sprinkler is on when the machine is stopped and off when the machine is moving, a series of wet spots will be separated by dry areas. This is exacerbated if the sprinklers used have a small wetted radius.

Another specific consideration has to do with the positioning choice. On a center pivot with a known central point, position determination is different from a linear move system with no fixed point. The center pivot can often use the angle returned by the resolver at the center instead of requiring a separate positioning system. This approach works better on shorter pivots with fewer spans. Linear move systems and large center pivots that have more accumulated deflection from perfect alignment probably will require GPS or some correction to the resolver for typical accumulated flex of the multiple spans.

Equipment

In general, the devices that have to be added to an otherwise commercial irrigation machine include variable rate technology (VRT) sprinklers, VRT water supply, VRT nutrient injection, and VRT pesticide applicator. In addition, knowledge of the position of the machine, some automatic data collection capability, and lastly, agronomic knowledge, such as which recommendations will be made or which production functions can be optimized. The control system of the device usually will need expansion, replacement, or supplementation. Control systems will be discussed by Evans et al., (2000).

VRT Applicators. The most critical hardware need in site-specific irrigation has been reported to be a variable-rate sprinkler (Anderson and Humburg, 1997). So far, there have been three approaches implemented for making a VRT irrigation sprinkler. These include pulsing sprinklers for time-proportional control (Fraisse et al. 1992; Evans et al., 1996a), using multiple manifolds with different-sized nozzles in combinations to create a stepwise range of rates (Camp and Sadler, 1994; King et al., 1995; Wall et al., 1996; Omary et al., 1997), and altering the aperture of a nozzle with an inserted pin to achieve two rates and then cycling the pin for time-proportional control between the two rates (King and Kincaid, 1996; King et al., 1997). Each of these techniques has advantages and disadvantages, and each affects the design of the remainder of the system. These will be discussed further by Buchleiter et al. (2000), and are mentioned briefly here because of their interactions with other components of the design.

VRT Water Supplies. Often lost in the discussions about site-specific irrigation machines is the question of how to supply water at constant pressure to a device that can rapidly vary its demand. This is an important consideration, which has been addressed in two ways in the applications above. The solution with the smaller number of components is a variable-rate pump, as done by Harting (1999). Such a solution is expensive [ranging from \$315/kW (King and Wall, 2000) to ~\$335/kW (Evans, 1999, personal communication)] compared to constant-rate pumps. However, this is approximately the same cost as a multiple-pump plant as used by Camp et al. (1998). There, a series of four increasingly larger pumps, each drawing from a reservoir, were linked in parallel and used in combinations with pressure bypass to the reservoir to provide constant pressure at all flow rates. A third alternative might be a constant-rate pump with a recirculating bypass. Although initial costs would be expected to be lower, operating costs would be expected to be higher for this solution than for the others. This issue was addressed by King and Wall (2000), who determined that variable-frequency pumping plants would save approximately 12% of the energy cost of a constant-speed pump under VRT irrigation. Variable-frequency pumps would not be cost-effective unless electrical utilities imposed performance constraints or altered the price structure. They concluded that the wasted energy when a centrifugal pump was operated to be self-limiting would not offset the additional cost of a VRT pump.

VRT Nutrient Injection. In all known applications, variable-rate injection of nutrients has been accomplished by maintaining a constant concentration of the nutrient in the supply, and using the capabilities of the irrigation machine to vary the amount of water applied. This requires a knowledge of the flow rate, either by direct measurement or by the controller adding the design (or individually measured) flow rates of the sectors that are on at a given time. With that information, the controller must inject nutrients at a flow rate that is proportional to the flow rate of the water through the system.

The primary difficulty encountered with this system is the delay in transporting the nutrients to the far end of the machine. This requires a startup zone that either can tolerate a shortage of nutrients on the far end, or stationary operation with the end span spraying to move the water/nutrient mixture through the machine. It appears that the startup zone could be traversed again after shutdown, in the same travel direction, to allow the nutrient to be flushed from the system, thus compensating for the shortage in the first pass during startup. Doing this would cause twice the amount of water, but could theoretically meet the design specifications for the nutrient application. This would be easily accomplished with a full-circle center pivot, but partial circles and linear move machines would have to deadhead back to the beginning of this startup zone.

VRT Pesticide Applications. Application of pesticides with irrigation machines can be done using direct injection or by adding a separate supply and manifold system. Direct injection, which is essentially the same as described above for nutrients, is subject to all considerations mentioned above, compounded by the limits of the pesticide label. Fewer new pesticides are being labeled for injection through irrigation systems. Therefore, most implementations use a separate supply tank, pump, manifold, and nozzle system to apply pesticides. This approach uses the irrigation machine as a ground transport device. Anderson and Humburg (1997) provide a discussion of issues associated with chemical application using irrigation machines.

Position Determination. Although most precision agriculture applications depend on the GPS system for position information, builders of site-specific irrigation machines have used several alternatives because of cost or the ability to exploit inherent knowledge of the position. Monitoring the location of a center pivot is much simpler than is the case for linear move systems because one end (pivot point) always stays at the same point. On the other hand, linear move machines require determination of location of both ends of the machine.

The question of desired accuracy depends upon the smallest area to be managed as well as upon sprinkler wetted diameters. Three general methods have been used to determine the machine position, which are: 1) determination of angular location of the first span from analog or digital resolvers, either on the pivot slip rings or attached externally; 2) one or more electronic compasses (usually with RS-232 output); and 3) differential global positioning systems (DGPS). Buried wires, lasers, and other distance measuring and alignment technologies could also be used. Halderson et al. (1991) described a linear move machine with furrow-following guidance that detected mechanical flags to mark plot positions. Heermann et al. (1997) described a combination of non-differential GPS and dead reckoning to determine location. Falling costs of both GPS equipment and differential correction may make DGPS the method of choice in future applications. This may continue to be the case, despite the elimination of selective availability in May 2000, to retain the reduction in atmospheric and other errors provided by differential correction.

The position of a center pivot is determined by either the first tower, the end tower, or both. The most common method uses devices placed at the pivot point that report the position of the first tower. The assumption is that the first tower is pointing to the end tower position and that the machine operates in a straight line. The actual alignment of a center pivot is bow-shaped which causes accumulated rather than offset error in positioning (Camp et al., 1996). However, the general bow-shape remains relatively constant for a given direction of travel so that actual position can be adjusted mathematically (King and Wall, 1998). This method is relatively easy to implement, cost effective, and easy to install and maintain. Alternatively, a pivot may be straightened using a laser (Phene et al., 1985).

The theoretical accuracy of first-tower positioning on center pivots is limited by the accuracy of the resolver that provides the estimated position of the first tower. Analog resolvers can report positions that can be ±1.5° of where the first tower is (1.5-m error). An error of 1.5° results in 10-m difference (390-m machine) between the first and end tower position if there is no bowing (i.e. the machine is perfectly straight). Digital resolver systems provide resolution within 0.5°, or roughly 3 m for the end tower on the 390-m machine. These errors are irrespective of the error associated with the bowing of the machine. A resolver is approximately the same cost as an electric compass and less expensive than DGPS, but can provide only first tower positioning.

End tower positioning reports the actual position of the end tower(s) and is therefore more accurate than systems reporting only the first tower position (Evans and Harting, 1999). Either an electronic compass or DGPS system can be placed on the end tower and report its position independent of the alignment of the center pivot. End tower positioning is more expensive but more accurate than first tower positioning since the actual position of the end tower is reported, not estimated. End tower positioning with DGPS receivers makes it possible to determine the end tower position to within ~1 m (0.13° on a 360-m machine). Of course, any bow must be accounted for to estimate the intermediate tower positions. Speed of the irrigation machine is well within GPS design limits and does not impact accuracy. The DGPS positioning is easier to use, since local calibration is not required and does not require a correction to north. DGPS approaches tend to be most appropriate for linear move systems and may be used in combination with dead reckoning techniques to reduce costs (Heermann et al., 1997).

Accuracy can be improved if electronic compasses are placed on both the first and end towers, which can allow a correction for the bow. However, electronic compasses must be calibrated for local conditions. If they must be set up to give a position that is corrected to true north, additional time is required. Mathematical error adjustments may be required depending on its location in the field with some models. In addition, electronic compasses should be placed a minimum of one meter away from any electrical current source, magnetic field, or steel structure to reduce errors.

End tower positioning also provides additional safety checks for machine operation, which are: 1) determination if the rate of change for the end tower position is too slow; 2) determination if the rate of change for the end tower position is too fast; and 3) distance from the pivot to the end tower decreases. These conditions indicate major alignment system or other safety system failures. The additional safeties provide early warning of failures and therefore increase operational flexibility, decrease repair time, and reduce costs. The first two checks are available with the electronic compass and all three are available with the DGPS option.

VRT Recommendations. The hardware capabilities for site-specific irrigation described above have been demonstrated to function adequately to manage irrigation on a site-specific basis. However, the limiting factor for site-specific irrigation is the same as it is for other precision agriculture: the machines work, but what do we tell them to do? Despite the long-term work in water use efficiency and production functions, there are no complete descriptions of these characteristics that have been determined specifically for site-specific irrigation. Early in the development of site-specific fertilizer recommendations, it was discussed whether recommendations developed using historical fertility trials can be applied on the within-field scale (Hergert, et al., 1997). The same holds for traditional production functions. Even those determined on an individual field are the result of field averages. Research is currently underway to evaluate production functions for specific points within fields, each with specific soils and terrain attributes (Camp et al., 2000).

CURRENT IMPLEMENTATIONS

So, with these admittedly numerous considerations in mind, please refer to Table 1, which summarizes the characteristics of the several known site-specific irrigation machines. These descriptions are provided to show how the various design considerations were addressed in these implementations, and to provide a reference to citations with further documentation.

POTENTIAL IMPROVEMENTS

Needs exist at several levels, from hardware to knowledge on the part of the operator. A primary hardware need is still an economical variable-rate sprinkler with a wide range of flow rates for a given design (ideally 0-100% of full) and essentially constant relative spray distribution at all flow rates. This would remove the requirement for multiple manifolds in the stepwise solutions (lessening cost and weight of manifolds), and eliminate cycling issues with pulsed systems. If these sprinklers could be controlled using some addressable bus control system, it would reduce wiring costs and difficulties. In addition, a low-cost solution to the variable-rate water supply would benefit future applications. Reliability of the hardware will be critical for commercialization. More work on soil-based or machine-based sensing of crop condition needs to be integrated into irrigation machine control. On the software side, user interfaces need to be developed to facilitate management entry and presentation of applications. Still lagging is the knowledge base to make economic decisions for variable control of these machines. As more research is conducted using the existing machines and more site-specific machines are developed, site-specific production functions and other recommendations will be developed. The training of operators to manage these machines on a day-to-day basis then becomes critical.

CONCLUDING STATEMENTS

Irrigation and chemical management are central to improved crop production and improved environmental stewardship on irrigated lands. Despite the inherent high frequency and fairly uniform applications of center pivot irrigation systems, considerable yield variations still exist, which are often attributed to spatial variability in soil water holding capacities and related nutrient availability. However, with appropriate controls, sensors, and decision making tools, center pivot and linear move irrigation systems can be managed to account for spatial variations in water and chemical requirements. Integrated global positioning systems (GPS), yield monitoring, geographic information systems (GIS), "smart" sensors, remote sensing, various computer models, extensive field sampling programs, and real-time monitoring of climate and field parameters make it possible to optimize irrigation water management for spatial and seasonal variability. Microprocessor-controlled systems linked to a central integrating computer provide a unique sensor platform as well as control capabilities for precision crop management. These systems provide an effective, practical and economical means to deliver site-specific crop management for water and many agrochemicals in irrigated fields. Position in the field can be determined by differential GPS, electronic compasses, or electronic resolvers (analog and digital).

The ability to vary water application along the main lateral of a self-propelled irrigation system based on position in the field allows the field manager to address specific soil and/or slope conditions. By aligning irrigation water application with variable water requirements in the field, total water use may be reduced (but certainly distributed differently), decreasing deep percolation and surface run off. Reducing excess water applications will decrease the potential to move nutrients past the plant root zone and the fungal disease pressure should also decrease. Precision application technologies can be used to treat small areas of a field with simple on/off sprinkler controls in single span-wide treatment areas or to treat the whole field by controlling all spans.

Four different approaches to precision irrigation with self-propelled irrigation systems are summarized in this paper. All of these approaches worked well for their designed purposes.

Table 1. Summary of characteristics of precision irrigation systems developed by different groups across the USA.

Location	Type (#)	Length (# spans) x trvl (linear)	Control element size along boom, then along travel	Nozzle type (# for multiple)	Wetted radius	Water supply method	Control type	Nutrient injection	Pesticides
Ft Collins, CO Fraisse et al. 1992, Duke et al. 1992	Linear (1)	176 m (4) x 640 m	22 m x 53 m	Pulsed	3.8 m	Single turbine pump, pressure regulator	PLC		
Aberdeen, ID King et al. 1995	Linear (1)	100 m x 180 m	9.1 x 9.1 m, then 18.2 x 18.2 m	Multiple (2) stepwise	9 m	Single turbine pump	Bus	Yes	
Aberdeen, ID King et al. 1995	Pivot (1)	210 m (7)	28.7 m x 5.6 degree	On/off	9.1 m	Single turbine pump	Bus		
Aberdeen, ID King et al. 1996	Pivot (1)	354 m (9)	38.1 m x 6 degree (more for inner rings)	Multiple (2) stepwise	9 m	Single turbine pump	Bus	Yes	
Aberdeen, ID Wall et al. 1996	Pivot (1)	392 m (10)	38 m x 1 degree ctrl	Multiple (2) stepwise	10 m	VR Pump	Bus	Yes	
Florence, SC Camp & Sadler 1994	Pivot (2)	140 m (3)	9.1 m x 7.5 degree (#1), 4 - 16 deg (#2)	Multiple (3) stepwise	2.5 m	Multiple pumps	PLC	Yes	
Prosser, WA Evans et al. 1996a	Pivot (1)	390 (8)	6-12 m x 0.5 degree ctrl	Pulsed	9 m	Press. System Mainline	RS-485 custom	Yes	
Paterson, WA Harting 1999	Pivots (3 full, 3 part)	360 (7)	12m x 0.13 degree ctrl (GPS)	Pulsed	9 m	Press. System Mainline	PLC	Yes	Yes

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