Enhancing Adoption of Site-Specific Variable Rate Sprinkler Systems

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Abstract: Existing irrigation technologies are well advanced and would conserve large amounts of water if fully implemented. Adoption of site-specific technologies could potentially extend these water savings even more. However, more than twenty years of private and public research on site-specific variable-rate sprinkler irrigation (SS-VRI), also called zone control, has resulted in limited commercial adoption of the technology. Competing patents, liability and proprietary software have affected industry's willingness to move into a new technology area, but sales of these machines are increasing. Documented and proven water conservation strategies using site-specific irrigation are quite limited, and its cost-effectiveness has not been demonstrated. Marginal costs associated with site-specific technologies are high. Thus, SS-VRI is primarily being used for eliminating irrigation and chemigation on non-cropped areas of a field or for land application of liquid agricultural and municipal wastes. Various SS-VRI technologies for general crop production are to beginning to slowly gain widespread acceptance; however, they are operated considerably below their potential capabilities, which is expected to continue. Currently, these systems are largely focused on addressing symptoms of poor water and nutrient management. This relatively low level of management is where the technology is expected to stay in the future unless much higher costs for water and the implementation of substantial economic incentives for compliance with environmental and other regulations become significant factors. Research on SS-VRI technologies could also enhance management of uniform irrigation technologies. In the short term, attention must be given to addressing equipment deficiencies and developing basic criteria for defining management zones and locations of various sensor systems for both arid and humid regions. Training adequate personnel to help write prescriptions in humid and arid areas and to assist growers with the decision making process is also a high priority. This paper discusses some of the research and training needed to focus on developing and documenting cost-effective site-specific water conservation strategies in order to develop markets for these advanced irrigation technologies for general crop production.

Key Words: water resources, water management, irrigation, precision agriculture, decision support, adaptive control systems, automation, irrigation controls, sprinkler irrigation, wireless networks, sensors

Introduction*

Demands on the world's finite water supplies for uses other than agriculture are increasing at a rapid rate. Population growth is also reducing the land available for food production. Consequently, there is a pressing need for agriculture to significantly improve production on less land and less water. Thus, it is to the advantage of all to be able to utilize all available tools including various aspects of precision agriculture (PA) to their maximum potential to address these issues.

Recent innovations in low-voltage sensor and wireless RF technologies combined with advances in Internet technologies offer tremendous opportunities for development and application of real-time management systems for agriculture. These have enabled implementation of advanced state-of-the-art water conservation measures such as site-specific variable-rate sprinkler irrigation (SS-VRI) for economically viable, broad scale crop production with full or limited water supplies. SS-VRI technologies uses many of the same management tools as other precision agriculture technologies, and make it possible to vary water and agrochemical (chemigation) applications to meet the specific needs of a crop in each unique zone within a field.

Existing irrigation technologies are well advanced and would conserve large amounts of water if fully implemented to their capacity, but this is not happening. Adoption of site-specific irrigation technologies could potentially extend these water savings even more. However, in more than 20 years of public and private research pertaining to SS-VRI, demonstrated proof of any definitive economic benefits has failed to materialize. Consequently, there has been limited commercial availability of SS-VRI systems and relatively little use of site-specific sprinkler irrigation technologies as a management tool for general crop production. To put this in perspective, it is estimated that there are about 175,000 center pivot and linear move sprinkler systems in the USA (USDA, NASS, 2009); but the authors estimate that less than 200 of these machines currently have SS-VRI capabilities other than speed control, end gun and corner system controls, and it is not known how many are actually using SS-VRI capabilities for irrigated crop management.

Severely limited water supplies for irrigation and environmental issues in various areas in the western United States and around the world are driving renewed interest in SS-VRI by growers and policy makers. Several new SS-VRI systems have been purchased and installed around the world in the past couple of years, and the technology will likely continue to show moderate gains in the marketplace. Most of this growth will likely occur with speed control systems.

However, current uses of SS-VRI technologies for agricultural fields are generally on a fairly coarse scale and are often limited to site-specific treatment of non-cropped areas based on physical features such as water ways, ponds, or rocky outcrops where some interior sprinkler heads are turned off in these areas (either 0% or 100% applications). Their use for general crop production is still limited and is mostly directed toward treating symptoms of localized overirrigation, underirrigation, runoff, ponding, nutrient management and related issues under maximum ET scenarios, which often do not produce measureable savings in water or energy use although total field yields may increase. The current management levels are considerably below the potential achievable benefits of SS-VRI and even well below the potential for

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* Mention of trade names, companies or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture

conventional non-site specific systems. Unfortunately, this relatively low management level is where SS-VRI technology is likely to stay in the future until cost effectiveness can be increased by higher costs for water, the implementation of economic incentives for compliance with environmental and other regulations, and the development of research results on how to manage these systems and demonstrating the extent that economic returns can be increased using SS-VRI.

This paper discusses the historical development of SS-VRI technology (zone control) and some barriers to adoption. Various short-term and some long-term research needs are also suggested to focus on developing and documenting cost-effective site-specific water conservation strategies for self-propelled sprinkler systems in order to develop markets for these advanced irrigation technologies for general crop production.

Site-Specific Variable Rate Sprinkler Irrigation

SS-VRI can be defined as the ability to spatially vary water application depths across a field to address specific soil, crop and/or other conditions and treatments in ways that optimize plant responses for each unit of water. SS-VRI has its' roots in the location control of end guns and sequencing sprinkler heads on center pivot corner-arm systems. Advances in technologies including computers, electronics, communications, geographic information systems (GIS) and global positioning systems (GPS) have provided the tools for SS-VRI management to move to the next level.

Center pivots and linear move sprinkler systems are designed and generally operated so as to replace the average water used by the crop over the past few days as uniformly as possible across the field. Irrigations are frequent and apply relatively low amounts of water so that soil water is ideally maintained at relatively constant levels. The high frequency of the irrigations under these machines potentially reduces the magnitude of variability in soil water contents in the field. However, stochastic spatial and temporal variability of a number of factors across a field can still affect crop growth during the growing season and from one season to the next. These factors can influence management decisions over time, which may also introduce additional in-field variability to crop production. Consequently, the center pivot industry is beginning to market irrigation systems that can adjust for at least some of this spatial variability by zone control or speed control, both of which are often referred to as site-specific irrigation or variable rate irrigation. Kranz (2009) has summarized characteristics of some of the various commercial site-specific control systems.

Maximum application depths on self-propelled center pivots and linear move sprinkler systems are generally controlled by the speed of the machine. Some center pivots can change speed in as little as 2 degree increments as the machine moves around the field to effectively change application depths in each radial sector of the field. This is sometimes referred to as sector control. However, field variability seldom occurs in triangle-shaped parcels and adjusting machine speed may not be a sufficient level of control resolution as soil and crop conditions often vary substantially in the radial direction.

Zone control involves spatially defining management areas or zones following specific guidelines. Water is then applied to each management area (zone) by controlling water output from small groups of sprinkler heads along the length of the machine depending on location in the field. Zone control has the largest potential for achieving more efficient and economically viable management of water and energy, and is the general topic of this paper.

Simulation studies comparing conventional and site-specific irrigation have reported water savings of 0 to 26%. Ironically for well-watered crop production, water savings from site-specific irrigation maybe greatest in humid climates by spatially maximizing utilization of growing season precipitation (Evans and King, 2010). However, these water saving benefits have not been verified by field-based research.

Historical Development of SS-VRI

Many individuals, groups of researchers and companies have been developing SS-VRI technologies for at least the last 20 years. Almost all of the SS-VRI research done to date has been directed toward development and improvement of hardware and basic control software. As a result, several innovative technologies have been developed to variably apply irrigation water to meet anticipated whole field management needs in precision irrigation, primarily with self-propelled center pivot and linear move irrigation systems. Little research has been done on the economics or the management of these systems for greatest agronomic or resource conservation benefits. These efforts have been reviewed by Evans and King (2010), Evans et al. (2010) and others.

Commercial Adoption of SS-VRI

A program to extend SS-VRI technology was developed in 2005 by the University of Georgia to promote SS-VRI in the Flint River basin of Georgia using the FarmScan VRI system (only commercially available SS-VRI system at the time). The USDA-NRCS Environmental Quality Incentives Program (EQIP) provided 75%-25% cost-share funding for about 40 systems. Four additional SS-VRI systems were also purchased by growers without cost-share assistance. These systems were installed on peanut, cotton, and corn fields plus some turf farms. A companion USDA NRCS Conservation Innovation Grant also provided funds to demonstrate the benefits of SS-VRI for irrigation management, water conservation, and optimal application efficiency through a series of workshops and field days as well as some research efforts (Perry and Milton, 2007).

In 2006, an Australian company (Computronics) began selling SS-VRI controls for center pivots in the USA through a company in southeastern USA (Holder and Hobbs). In 2008, the marketing of Computronics was shifted to FarmScan. Starting in 2010, Valmont Industries (a major manufacturer of self-propelled sprinkler irrigation machines) began offering the FarmScan site-specific variable rate package through their dealer network based on a licensing agreement. Also, based on the licensing agreement, Valmont began developing a two different VRI packages based on their irrigation system control system. In 2010 Valmont began selling on a limited basis some zone control units, which was expanded in 2011 to offer both speed and zone control.

Some other center pivot manufacturers and related companies are also beginning to integrate various site-specific control options with their systems. For example, Lindsay Manufacturing started working with Precision Irrigation of New Zealand in 2011 and began to offer zone control in some countries. In 2009, AgSense began offering speed control as part of their add-on telemetry package. Integrating soil moisture monitoring with center pivot controls is also beginning to receive commercial attention by center pivot manufacturers.

In early 2011, it was estimated that over a 100 FarmScan VRI systems were installed (Rick Heard, 2011, personal communication). However, very few of these systems (estimated at 25% or less based on conversations) are using the full features of site-specific irrigation.

In the past several years, various commercial manufacturers of self-propelled sprinkler systems have been offering limited site-specific capabilities for center pivot and linear move sprinkler systems for tertiary treatment of agricultural processing and municipal wastewaters using soil biota and crop uptake for disposal. These systems are used to periodically apply water to specified areas within a field based on approved regulatory plans primarily for management of nitrogen, phosphorous and various potential biological contaminants in the effluent. These systems generally have static application maps that do not change from year to year and feedback mechanisms often consist of periodic soil water measurements and annual soil sampling to measure levels of various chemical and biological parameters. More recently, a few irrigation system manufacturers have begun offering VRI as an option on new center pivot installations.

Potential Barriers to Adoption

Generally, adoption of the various PA technologies including SS-VRI has been limited and its' use by early adopters has not always been sustained. Equipment has not generally been a restraining factor with regard to the adoption of SS-VRI and other PA technologies. For SS-VRI at least, this has been partially because the only choices for SS-VRI equipment and controls were third party sources until recently.

Barriers for SS-VRI

One potential barrier is that full implementation of SS-VRI generally has the most difficult requirements and the most complicated and costly control systems of all PA technologies because of complex spatial and temporal interrelationships of the soil-plant-atmosphere-irrigation systems. SS-VRI is also the most expensive in terms of management because of the much higher frequency of treatments compared to other PA technologies.

An additional reason for non-adoption is that government regulatory and action agencies generally do not support SS-VRI technologies for cost-share and other farm programs, especially at the local level, which may be partially due to a lack of understanding the technology and a shortage of regional research demonstrating benefits. In addition, manufacturer's distribution networks and dealers are sometimes cautious to embrace new technologies until they see opportunities for profit and have the resources and training to support the product.

Some of the slow rate of adoption problems have also been partially due to patent issues and high capital cost per hectare for the equipment. However, equipment costs are coming down due to technological advances.

Adoption Needs for SS-VRI

Some of the most common reasons for growers to invest in advanced irrigation technologies are to: 1) reduce labor costs, 2) minimize water costs due to pumping (higher irrigation efficiencies), 3) improve field scale yields with better application uniformities, and 4) use the "saved water on other fields (often referred to as water spreading). However, acquisition of an advanced irrigation technology does not always result in improved levels of management, which is often due to a lack of time by the operator to devote to better management or a shortage of appropriate scientific agronomic and irrigation knowledge by the operator. At the same time, the increasing complexity of implementing advanced irrigation strategies and other cultural activities place even greater demands on management, which is primarily addressed with the help of consultants.

Experience of the authors indicates that new agricultural technologies must overcome several stumbling blocks or expectations, all of which must be individually addressed in order to be accepted by producers. To be successfully adopted growers expect that the new technology will met the following criteria, which are: 1) to do what they are designed (and promised to do); 2) to be flexible to meet grower expectations; 3) to be easy to use, adjust and adapt to fit their perceived needs; 4) to be scalable to meet a wide variety of applications; 5) to be robust and durable with low hardware and software maintenance requirements; 6) to be easy to retrofit the system and to upgrade all components; 7) to be intuitive to operate for the end user; 8) to have good data management and interpretation capabilities and for future evaluations and analyses of the results; and, 9) to be affordable, reduce production costs and increase net returns (evident positive benefit cost ratio for producer); and 10) high quality technical support and educational efforts by the industry and extension are readily available. These ten factors as well as wide spread availability of the technology may also be affected by the manufacturer's assessment of the industrial effort (e.g., retooling), materials and fabrication costs. However, it's probably safe to say that most of these conditions for the adoption and sustainable use of SS-VRI have not been met and remain to be addressed by researchers and industry, and coordinated research programs addressing these issues must be conducted before the full potential of these technologies can be commercially realized (Evans and King, 2010).

RESEARCH NEEDS

Existing irrigation technologies are capable of conserving large amounts of water if implemented to their full capability. Adoption of site-specific irrigation technologies could potentially extend these water savings even more. SS-VRI could play a major role in maximizing net returns when implementing limited or deficit irrigation strategies in water short areas and in the optimal use of precipitation in humid regions. However, the high potentials of these technologies are not close to being realized because the necessary incentives and the supporting research base are both severely limited.

Sound decision making consists of defining the scale of the problem and how much is to be gained from solving the problem. However, SS-VRI has not followed this process. Almost all of the SS-VRI research done to date has been directed toward development and improvement of hardware and basic control software to implement SS-VRI. The net result of this earlier work is that SS-VRI has essentially become a solution looking for a problem. Unless the problems to be addressed can be precisely defined and quantified for research and education, SS-VRI will basically remain a novelty and research aimed at developing more complex SS-VRI technology will remain fragmented and a general waste of resources.

By definition "site-specific" means that such prescriptions will be climate, crop and region specific. Thus, it should be noted that transferability or SS-VRI research results to other regions will often not be appropriate, and this type of research will have to occur regionally where ever SS-VRI is practiced.

One of the major reasons attributed to the low adoption rates of SS-VRI has been the shortage of research by public and private groups demonstrating that this technology will better manage water and/or increase net returns. Past SS-VRI agronomic research was generally directed toward meeting full crop ET and maximizing yields per unit area with no concern for limited water availability scenarios.

Limited grower experiences over the past few years with new SS-VRI systems are providing some direction to the manufacturers, but verifying research is way behind. Documented and proven water conservation strategies using site-specific sprinkler irrigation for crop production are quite limited and its cost-effectiveness has not been adequately demonstrated regionally. This type of research is high priority for the adoption of SS-VRI. These critical research requirements have short term and long term considerations as well as critical technology transfer aspects, which are further discussed below.

Short Term Research Needs

Some general topics that need to be addressed to further encourage adoption in the short term are briefly discussed below. These include both commercial development and scientific research by public and private groups that addresses equipment, management and economic issues.

Equipment Needs

General operational criteria for grower acceptance of advanced SS-VRI systems include: 1) easy to retrofit to existing commercial center pivots, 2) maintain good water application uniformity within and between treatment areas, 3) robust electronics, 4) compatible with existing center pivot equipment, 5) bi-directional digital communications, and 6) expandability for future development and operational requirements. Any hardware and control limitations in this regard will need to be addressed by the manufacturers to facilitate successful marketing of the technology.

One constraint has been the limited availability of low- cost, reliable variable frequency drives (VFD) for large irrigation pumps to match variable irrigation system demands associated with SS-VRI, especially with multiple irrigation systems using a single pump. In addition, the highly variable flow requirements of SS-VRI systems used for chemigation may also require smaller VFD drives for injection pumps to maintain appropriate chemical concentrations.

Commercially available SS-VRI systems generally rely on some form of pulse modulation to control application depths. Thus, one area for improvement is the development of reliable valves at an economically viable cost that can cycle millions of times before failure. Some variable rate application methods may require more reliable, cost-effective flow-modulating sprinkler heads. However, equipment needs are relatively minor and are evolving much more rapidly in comparison to the development of management tools for growers and consultants for the optimal operation of these systems and maximization of benefits.

There is a concurrent need to develop improved control systems for site-specifically applying crop amendments (e.g., nutrients, pesticides) to improve profit margins and reduce environmental impacts with little additional cost (Watkins et al., 1998; King et al., 2009). These features add value to SS-VRI systems that help offset high initial capital costs and management expenses.

Defining Water Requirements

More than fifty years of research has been conducted to enable prediction of water requirements for well water crops that are actively growing free of pest or nutrient stress. Little is known about how pest or nutrient stress affects water requirements. Likewise, how evapotranspiration varies with yield potential is unknown. Crop water use is a combination of soil evaporation and plant transpiration. Stresses that inhibit plant development would be expected to decrease transpiration due to a reduction in leaf area. However, soil evaporation will likely increase due to more solar radiation reaching the soil surface. Water requirements for a well water crop under pest or nutrient stress may not change in proportion to yield potential.

Determining Economic Returns

Probably the most critical research needed to encourage adoption of SS-VRI is the development of guidelines and criteria for defining prescriptions for how a SS-VRI system can be used to increase economic return and achieve environmental benefits. Appropriate guidelines for economical management of SS-VRI systems that quantify the monetary value of various management alternatives have not been developed. Likewise, little research has been done on the economics of the number of zones or sectors or management of these systems for greatest agronomic benefit.

Use of SS-VRI to avoid irrigating non-cropped areas may be economical in terms of water and nutrient savings as well as avoidance of environmental and regulatory penalties. However, economics of SS-VRI for general crop production is a major concern because the water savings are typically only on the order of 5%-10% over more conventional management in arid areas, but may be as high as 26% in humid regions (Evans et al., 1996; Hedley and Yule, 2009; Evans and King, 2010). Thus, the marginal costs for the relatively small water savings are relatively high, which often makes purchasing and managing site-specific irrigation equipment difficult to justify economically.

Higher net returns to the grower may be needed to economically justify the capital costs of implementing site-specific irrigation management with center pivots (about \$200- \$550 ha^{-1}) additional depending on size and options over SS-VRI systems) plus extra mapping (commonly about \$15-\$20 ha^{-1}) and management costs. Reliable estimates of ongoing maintenance costs for SS-VRI are not known because of the low adoption rates. Operating costs will be higher as well because of added maintenance of sensors stations, communications, software maintenance, and consultant fees.

Anecdotal information from growers on fields with rolling topography using speed control (\$10-\$125 ha^{-1} depending on system) during the 2011 crop season indicates they believe payback for the SS-VRI aspects can be achieved in as little as one year due to the ability to reduce runoff in fields with rolling topography. Those using zone control SS-VRI attribute the observed benefits to a significant reduction of yield variability and higher overall productivity, which are largely due to minimizing areas of overirrigation and the associated reductions in runoff. In non-limiting water situations, savings in water or energy use have not been generally observed or cited as a benefit by growers. These practices also reduced leaching and soil erosion, and the reduced yield variability was probably more of a response to uniform access to applied fertilizers than to water However, these benefits have not been independently verified across different regions.

Development of Tools for Growers and Consultants

The short term research must also transfer the technology by producing tools for the industry to utilize in building prescriptions and managing SS-VRI systems. Some specific, identified tools for continued commercial development that will be required for sustained adoption of SS-VRI technologies include:

1) A need to develop guidelines and tools to assist consultants and growers in predefining rule bases or guidelines for management scenarios that are used for defining broad management areas that can be used to write general prescriptions. This information can also be used to define the requirements for the type and level of SS-VRI hardware for a field.
2) A need to develop tools that determine how to best locate various combinations of wireless sensors for maximum benefit across a management area or field and their use. Defined management zones will guide the placement of some sensor systems, but not all. In the short term, this goal would also apply to the improved management of conventional irrigation systems.
3) A need for the development and testing of easy-to-use integrated decision support systems for adaptive control starting with simple static scenarios for both humid and arid areas and build to include more complex dynamic conditions over the long term.

4) A critical, immediate need exists to define and implement specialized training on the hardware, software and advanced agronomic principles for growers, consultants, dealers, technicians, and other personnel on how to define management areas, write prescriptions and develop management guidelines.

These critical tools and management guidelines are further discussed below.

Tools for Defining Management Zones

Application of water with site-specific irrigation systems generally involves some type of variable rate application method in combination with geo-referenced maps or tables defining the various management zones. Management zones (sometimes also called management areas or productivity zones) are areas within a field that are relatively homogeneous with regard to at least one characteristic or factor (e.g., similar soils, topography, microclimate, harvested yields, pest pressures or plant response). These zones can also vary depending on the issue being addressed (e.g., irrigation, fertilizer, pests). Management zones for SS-VRI 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.

Because of large sizes of modern farm equipment, growers cannot usually manage PA on areas less than 0.4 ha (1 ac), which generally deal with relatively broad areas that account for topography, major soil texture changes or physical constraints. One manufacturer of SS-VRI self-propelled sprinkler systems (Valmont) offers the capacity to define up to 5400 management zones in a single field (about 0.01 ha/zone) based on various criteria, data sources and grower input. Even though most center pivot irrigators will typically have less than 10 management zones in a field, the capacity to have a large number of small zones allows for the composite definition of large zones with convoluted shapes. Basic and applied research is needed to provide guidance on how to best define the most appropriate agronomic management zones for SS-VRI.

Commercially, assistance in defining management zones or management areas and building suitable prescriptions is in its' infancy. Companies such as CropMetrics™ (http://cropmetrics.com/) have developed and are marketing a basic sets of tools and provide limited agronomic guidance to assist growers in defining static management areas, which are generally based on changes in soil texture or electrical conductivity (as a surrogate to water holding capacity) and topographic features. General guidelines may also be provided on irrigation management in the various zones. While a step in the right direction, management zones based on only one or two parameters are generally inadequate for optimal management because many of the other parameters affecting the crop can also vary independently throughout the season.

There is a critical need to develop basic rules or guidelines and tools for defining management zones, determining the best locations for sensor stations, and writing prescriptions for irrigation applications in different zones for both humid and arid regions. These agronomic and engineering tools would be used by consultants and growers and must allow for grower preferences, pest management issues and some economic considerations.

Tools for Optimal Placement of Various Sensor Systems

Recent innovations in low-voltage sensor and wireless radio frequency technologies combined with advances in Internet technologies offer tremendous opportunities for optimal management of SS-VRI systems. Sensors can be at fixed locations or mounted on the irrigation system, farm equipment or other mobile platforms depending on data needs and requirements.

Properly defined management zones will guide the placement of some sensor systems, but not all. There remains a critical need to develop tools that help define which sensors are needed and to determine how to best locate various combinations of wireless sensors for maximum benefit across a field. The integration of various sensor types that provides measurements at different temporal and spatial scales make it potentially possible to extend the range of point measurements and more accurately estimate the variability of other sensors and field data sets.

It is not possible to know the exact conditions in all areas of a field in real time. Therefore various estimating procedures or predefined management zones can potentially be used to account for this variability. Distributed in-field plant and soil sensors in combination with agro-weather stations can be used to measure climatic, soil water and other types of variability and assist in the development and implementation of optimal site-specific irrigation management strategies.

All sensor systems have their own particular limitations and scales and there is no perfect sensor or sensor system for managing SS-VRI systems. Thus, there is a need to continue the development and testing of a range of low-cost, wireless and non-intrusive sensors for spatially-distributed measurement of soil moisture and various crop response indicators for management of site-specific systems.

Decision Support

Most current irrigation decision support software (often called scientific irrigation scheduling programs) deigned to basically address temporal variability. They calculate timing and duration of water applications using algorithms that forecast irrigations based on historical weather patterns and predicted crop water use over a relatively short period (e.g., 3-14 days). Feedback to the process is usually made by spot measurements (e.g., soil water) and other data after the operation is completed and adjustments are made to the program for the following irrigation event. The next step is to include spatial variability in the process.

General, broad-based and easily modified software (decision support) for implementation of prescriptions for SS-VRI systems is not available for a multitude of crops, climatic conditions, topography, and soil textures. In the short term (e.g., next 5 years), development of basic decision support systems should focus on generalized regional-type prescriptions for humid and arid areas if SS-VRI is to become economically viable. There is a need to develop and market basic decision support programs with simple closed-loop feedback systems so that easy on-the-go corrections can be made to VRI irrigation systems and provide real time status information to the operator for other necessary adjustments.

Training for Technical Assistance for SS-VRI

Adjusting water application depths to account for spatial and temporal variability to fine-tune the water management can be a significant challenge and most producers will require agronomic and other types of assistance from multiple sources to successfully implement these technologies.

However, this is complicated by the acute shortage of available agronomic expertise to set up and maintain decision support software for each field (English, 2010). Growers generally do not have the interest, knowledge or the time to adjust and play for software; thus, dealers or consultants would likely have to provide this service. Thus, there is a critical need for trained personnel, who will often be independent from the equipment dealers, to assist growers in using these tools to write prescriptions, best locations for sensor stations.

The need for advanced training is immediate. However, training programs may be ineffective until results from the above list of short term research areas can properly define the scope and criteria for the training curricula and sufficient numbers of people are trained. Plans are being developed to produce this information, but much of these results may not be available for another 5 years or so, which may delay the progress of SS-VRI adoption. .

Conclusions

The potential to save water at the farm scale depends on the capabilities of the irrigation system and the operator to implement water-saving practices and technologies. Conventional irrigation technologies are well advanced and would conserve large amounts of water if implemented to the full extent of their capabilities. The resulting less-than-optimal levels of current irrigation management are primarily due to the lack of appropriate economic and social incentives to adopt the improved practices. Adoption of site-specific technologies could potentially extend these water savings even more; however, these same issues also apply to SS-VRI as the potential economic and water conservation benefits of these advanced systems have not been independently defined and quantified.

There have been over 20 years of government and private research on SS-VRI and the technology has been commercially available since the mid-1990s. However, adoption rates of SS-VRI have been quite low for a number of reasons. Almost all of the SS-VRI research done to date has been directed toward development and improvement of hardware and basic control software. Little research has been done on the economics, determination of the number of zones or sectors or the management of these systems for greatest agronomic or resource conservation benefits. Past research was generally directed toward meeting full crop ET and maximizing yields per unit area with no concern for limited water availability scenarios. Thus, the current state of the technology is essentially a solution looking for a problem.

Current uses of SS-VRI technologies for agricultural fields are generally on a fairly coarse scale and are often limited to site-specific treatment of non-cropped areas. Their use for general crop production is still limited and is mostly directed toward treating symptoms of poor water management under full ET conditions. Site-specific irrigation is basically used to provide water conservation benefits in cases of overirrigation, underirrigation, runoff, erroneous irrigation scheduling, in-season precipitation harvesting, or inefficiencies associated with particular crop production practices. In actuality, use of this site-specific technology today is basically for uniform nutrient management rather than water management.

The full potential of SS-VRI as well as conventional uniform irrigation systems are considerably higher that current practices. Unfortunately, this relatively low level of management is where SS-VRI technology is likely to stay in the future until cost effectiveness can be increased, which will be the result of several external factors.

In the short term, several equipment and research deficiencies need to be addressed to encourage further adoption. Equipment issues include the use of variable frequency pump motor controls for both irrigation and chemigation, and more reliable valves to control individual sprinkler heads. From a research standpoint, the foremost need is the development of guidelines and tools to assist consultants and growers in predefining rule bases for management scenarios that are used for writing dynamic prescriptions for defining management areas. Secondly, there is a need to develop tools that determine how to best locate various combinations of wireless sensors for maximum benefit across a field and their use. Thirdly, there is a critical need for the development and testing of easy-to-use basic, generalized decision support systems for SS-VRI starting with simple static scenarios for both humid and arid areas.

In addition, specialized, continual training on the hardware, software and advanced agronomic principles will be needed for growers, consultants, dealers, technicians and other personnel on how to define management zones (areas), write prescriptions and develop management guidelines. However, criteria for training individuals to develop management zones, write prescriptions and assist with the decision making processes has not been defined.

Ultimately, it is expected that higher costs for irrigation water, water scarcity and the implementation of economic incentives for compliance with environmental and other regulations will potentially provide the necessary incentives for much greater adoption of various advanced irrigation technologies. However, this must be supported by basic short-term and long-term research demonstrating how and the extent that net economic returns can be increased using both conventional and SS-VRI systems. These research priorities must be addressed for both humid and arid climates because the strategies and procedures may be quite different. It should be noted that this research on advanced SS-VRI irrigation management strategies, sensor systems and decision support would also improve our capacity to better manage conventional irrigation systems.

Various forms or aspects of SS-VRI are becoming commonly available and are probably here to stay at a low level. These marketing efforts are helping customers consider the future and how to position their farming operations including center pivot irrigation to take advantage of rapid changes in technology. However, the research effort needed to successfully and economically apply SS-VRI is substantial and will take several decades to address. With adequate funding, such field research will likely take 5 to 10 years to obtain measureable results. Maintaining the current levels of inadequate funding for field research on SS-VRI technology means that the time table to accomplish these goals will be substantially increased.

A suitable research and education program to adequately address the barriers to adoption and to practically achieve the potential benefits of SS-VRI will require considerable investment in these areas at a time the nation is attempting to reduce spending on domestic programs, such as public agricultural research. This means that bulk of research and education funding will have to come from SS-VRI equipment manufacturers and commodity groups. However, without a clear definition of the problem to be addressed and value to be derived, funding cannot be expected to available.

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