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Visual soil water status indicator for improved irrigation management☆

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Abstract

A device to aid in irrigation scheduling by visually indicating current soil water status relative to an upper and lower set point was developed and field tested. The device can be used by farm managers to easily evaluate current soil water status from a distance. This information can be used to guide irrigation scheduling decisions throughout the season. Seven farm managers evaluated the device on seven commercial potato fields. Two study fields, one with and one without soil water status indicators, were established with each farm manager. Water application was measured in each field. Collectively, farm managers applied 7% (2.9 cm) less water to fields with the soil water status indicators than comparison fields. Average water application was significantly less ($P = 0.04$) for fields with soil water status indicators. The basic elements of the soil water status indicator and its operation are presented. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Irrigation scheduling; Irrigation management; Soil water content; Monitoring system

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1. Introduction

Irrigated agriculture in the US has a significant impact on local and regional water resources, particularly water quality. Competition for finite water resources and increasing public concern about water quality are becoming major challenges facing producers. This, combined with an increasingly competitive global market, is making good irrigation management a necessity in order to maintain economic viability.

Research on irrigation scheduling began more than 50 years ago, yet irrigation scheduling based on quantitative measurements has not been adopted by US producers anywhere near its potential level. Irrigation scheduling demands routine and consistent evaluations that are very difficult to achieve for farm managers who must oversee all the farming activities. Machinery breakdowns, labor management, sick livestock, and family and community obligations often have greater priority than routine irrigation scheduling activities. Once an irrigation scheduling program is interrupted, it is easier to revert to a routine which is less time consuming and provides assurance against crop water stress, but is not necessarily efficient in terms of water, energy, and fertilizer use. There is a definite need for new tools and/or approaches to irrigation scheduling that foster wide scale adoption through ease of use.

Irrigation scheduling has been an important topic in agricultural research for several decades and continues to be so today. Consequently, there is a vast amount of literature on irrigation scheduling and water management. Recent studies have involved comparison of irrigation scheduling methods for a particular crop (e.g. Stockle and Hiller, 1994) and comparison of soil water measurement methods (e.g. Ley, 1994; Yoder et al., 1998). The rapid increase in capabilities and decreasing cost of electronics has fostered development in irrigation automation (e.g. Clark et al., 1994; Phene, 1996; Smajstrla and Lacascio, 1996; vanBavel et al., 1996). Irrigation scheduling computer models continue to be developed and are now called decision support models which incorporate crop growth models, leaching models, and use new computational techniques such as fuzzy logic and neural networks (e.g. Broner et al., 1996; Clyma and Martin, 1996; Ribeiro et al., 1998). Very few studies have dealt with on-farm implementation or economics (e.g. Kranz et al., 1992; Buchleiter et al., 1996; DeTar et al., 1996; Shannon et al., 1996). There is a large and widening gap between state of the art and current on-farm irrigation scheduling practices. Clyma (1996) suggests that producers need simpler, more comprehensive support to achieve improved irrigation management at the farm level. Soil–water–plant relationships, although superficially understood by most producers, are not understood by many in sufficient depth to be applied in making irrigation management decision. Most producers are overwhelmed by state of the art irrigation scheduling tools and lack the skills necessary to install, operate, and troubleshoot them.

In discussions with local producers regarding irrigation management, several stated that they would like an irrigation scheduling tool that warns them when soil water content has decreased to a critical level and irrigation is needed. One producer stated that he wants a device that he can observe as he passes by the field and know current soil water status. He can then use this information in instructing employees performing the irrigation operations. These comments and requests instigated the development and testing of a visual soil water status indicator. A literature search for such a device revealed the previous development of an irrigation alert system (ASAE, 1997). This irrigation alert system used a switching tensiometer, simple electronics, and a common mousetrap to raise a flag when a set point soil water tension was reached. The objective of the work reported here was to further develop and evaluate a visual soil water status indicating system for improved irrigation management. The basic elements and operation of the improved visual soil water status indicator are described. Observations of field performance and producer response are presented.

2. System description

The form of the visual soil water status indicator (VSWSI) has evolved over time based on field testing and user feedback. In its current form, the VSWSI can utilize either a tri-state or proportional display to visually indicate current soil water status relative to two user-specified set point values. The tri-state display is depicted in Fig. 1 with gray scale shading. In practice, three highly visible colors are used to display current soil water content relative to the two set points. White is used to show soil water content above the upper set point. Fluorescent blue is used to show soil water content between the lower and upper set point. Fluorescent orange is used to show soil water content below the lower set point. The colored display area measures approx. 12 cm by 28 cm and is surrounded by a 5 cm white border to maximize visibility for distant viewing.

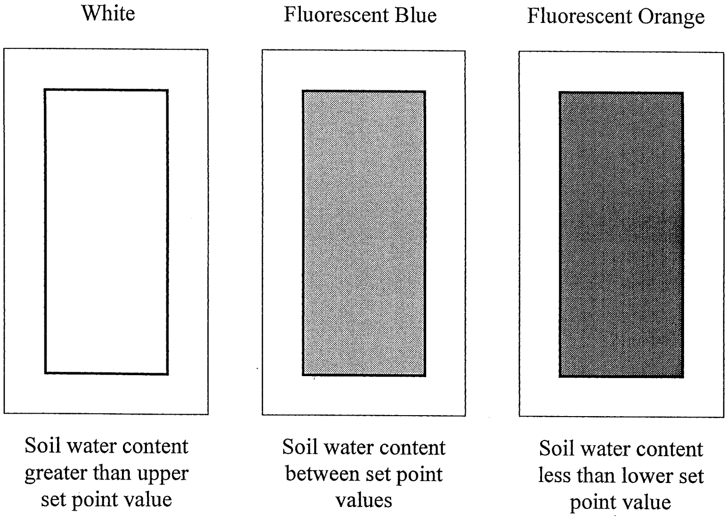

Fig. 1. Visual soil water status indicator tri-state display.

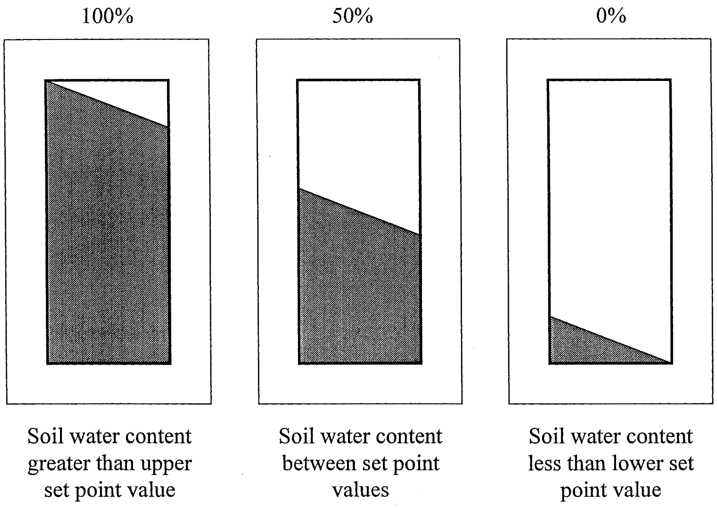

Fig. 2. Visual soil water status indicator proportional display.

The proportional display is more quantitative and functions similar to the fuel gauge in an automobile (Fig. 2). Two user-specific set point values are required for the VSWSI to function. The upper set point represents the display full value (100%) and the lower set point represents the display empty value (0%). The size of the colored display area is the same as that for the tri-state display. Fluorescent orange and white are used for maximum visibility. The proportional display was developed to provide a more refined water status scale to allow a user to readily assess the urgency of irrigation while maintaining a reasonable physical size for the device and being readily discernable from a distance.

2.1. System implementation

The two user-specified set point values required by the VSWSI are the volumetric soil water contents representing the optimum soil moisture range for the crop. For example, with potatoes, the optimum soil water content range corresponds to 65–95% available soil water (ASW). Thus, the lower set point is the volumetric soil water content corresponding to 65% ASW and the upper set point is the volumetric soil water content corresponding to 95% ASW.

The VSWSI is intended to serve as a guide for making in-field refinements to irrigation duration and interval as opposed to determining the actual irrigation schedule. Few irrigation systems for agricultural crops have on demand capability for all field locations. Most irrigation systems spread the water over the area using a series of irrigation sets (field subareas) with an appropriate duration and interval. For example, microirrigation systems can have a 24 h irrigation interval with durations in terms of minutes or hours. Conversely, surface irrigation systems can have irrigation intervals of days or even weeks with durations of hours or days. The

VSWSI can be used to make in-field refinements to the irrigation duration or interval based on observation of current soil water status at the time irrigation begins. For example, with the tri-state VSWSI, if fluorescent orange is displayed then the current soil water content is below the optimum level. Depending upon how long this status has existed, the irrigation interval may need to be shortened to maintain optimum soil moisture over the irrigation interval. Alternately, the irrigation duration may need to be increased to store more water in the soil for plant use between irrigations, if possible. The proper solution depends upon the irrigation system constraints and site-specific soil and crop characteristics. Similarly, if white is displayed when irrigation is scheduled to begin, then irrigation needs to be delayed and the irrigation interval and/or duration needs to be adjusted. The VSWSI provides current soil water content information in an easily understandable format for rapid in-field use.

2.2. System construction

The VSWSI is designed to be as maintenance free as possible for 'hands-off' operation. A photovoltaic (PV) panel is used to maintain stored energy in a 12 V lead acid rechargeable battery. The electronic components are housed in a water tight enclosure. A 12 VDC permanent magnet gear motor is used to actuate the visual display. For the tri-state VSWSI, magnetic reed switches are used to determine and set the color of the display. For the proportional VSWSI, a single-turn potentiometer provides feedback to determine and set the position of the display.

Visual display of current soil water status relative to the set points is achieved using a 15 cm diameter painted drum that rotates inside a 20 cm diameter drum having a 12 by 28 cm rectangular cutout through which a section of the inner drum can be viewed. Both drums are made of PVC pipe that is resistant to ultraviolet light. The inner drum is offset from the center of the outer drum toward the rectangular cutout to maximize view of the inner drum. The assembly is oriented vertically when installed in the field. The watertight enclosure and PV module are mounted to a loose fitting cap on the top end of the outer drum. The cap can be rotated independent of the outer drum to allow the PV panel to be oriented for maximum solar radiation independent of viewing direction for the visual display. The bottom end of the outer drum is left open for drainage of irrigation and rainfall that enters through the rectangular cutout. Electrical energy from the PV panel is used to maintain the charge on a 1.3 Ah 12 V rechargeable sealed lead acid battery. This storage capacity provides sufficient energy to power the VSWSI for 5–7 days without input from the PV module. Cost to construct the VSWSI excluding the soil moisture sensor(s) was approx. $225.

2.3. System electronics and operation

A block diagram of the electronic elements and the control and power management scheme for the VSWSI is shown in Fig. 3. The nominal 12 VDC from the battery is used to power the gear motor and soil moisture sensor(s) directly. The CS615 Reflectometer (Campbell Scientific, Inc., Logan, UT)[1] is used to measure volumetric soil water content. This soil water sensor uses the time domain reflectometry principle to measure soil water content (Bilskie, 1997). This particular sensor was selected due to its low power requirement, relatively large sample volume, and repeatability. The electronic hardware is designed to multiplex up to four soil water sensors. A 12 VDC to 5 VDC step-down converter is used to power the electronic components. A resistor-capacitor timing circuit using a low-power voltage comparator activates the step-down converter to power the microprocessor, LCD, and EEPROM. Following completion of code to process a measurement and position the visual display, the microprocessor resets the timing circuit turning off the 5 VDC supply. The timing circuit resistor and capacitor were sized to activate the VSWSI at 15–20 min intervals. A low-power battery charging circuit is used to provide a controlled charge to the lead acid battery from a 1.4 W PV panel. All electronic components except the timing, battery charge, and 12 VDC to 5 VDC converter circuits are not energized between readings to minimize energy use. The maximum quiescent energy draw on the battery by these circuits is approx. 700 μA. A serial EEPROM is used to provide nonvolatile read-write memory for retaining set point values between soil moisture readings.

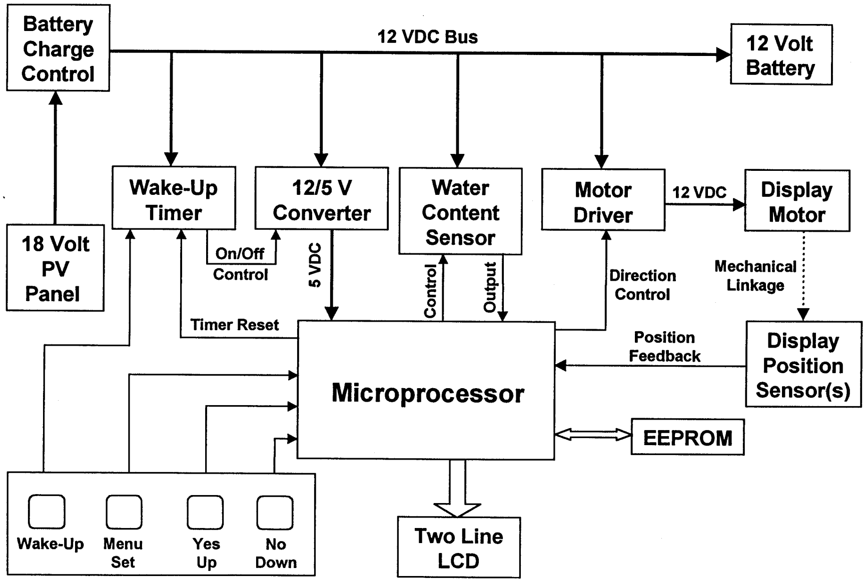

Fig. 3. Block diagram of electronic elements and the control and power management scheme for the VSWSI.

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[1] Mention of trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the authors or their institutions and does not imply approval of a product to the exclusion of others that may be suitable.

The operation of the VSWSI is as follows. When the microprocessor is energized by the timing circuit, the last soil moisture reading and set points are read from the EEPROM. Next, power is applied to the soil water content sensors. Each one is sequentially enabled and the output read by the microprocessor. The corresponding soil water contents are calculated, averaged, and compared to the set point values. The corresponding state or position of the visual display is calculated. The current state or position of the display is determined and adjusted if necessary, to display the current soil water status. Next, the current soil water content(s) and set points are stored in the EEPROM. Finally, the microprocessor resets the timing circuit that powers down the microprocessor by switching off the 12 VDC to 5 VDC converter.

User interface to the VSWSI is through a four-button panel and two-line, 16 character LCD. The timing circuit can be bypassed by pressing the '*Wake-Up*' button which causes the microprocessor to perform the default instruction set for updating the soil water status display. A menu mode of operation can be invoked by pressing and holding the '*Menu*' button followed by pressing the '*Wake-Up*' button. Operation of menu mode allows the user to view the last measured soil water content(s), adjust the set point values, and take a soil water content reading to update the display. The remaining two buttons of the four-button panel serve as the '*Yes*/*No*' or '*Up*/*Down*' inputs required to navigate through menu mode operation.

3. Field testing and evaluation

The tri-state display design of the VSWSI was tested in irrigated commercial potato fields in southeastern Idaho. Commercial potato production was selected for field testing because potatoes are very sensitive to water management, both to over- and under-irrigation. Farm managers involved in potato production are well aware of the importance of irrigation scheduling and willing to investigate new irrigation scheduling tools.

Twenty-one of the VSWSIs were constructed and installed in seven commercial potato fields in southeastern Idaho. The seven fields were under the control of seven different farm managers. Three VSWSIs were installed in each of the seven fields along with two catch cans at each VSWSI location to monitor water application. Five of the fields were irrigated with center pivot irrigation systems, one was irrigated using a linear-move irrigation system, and one was irrigated using a solid-set sprinkler system. For each center pivot system, a VSWSI was installed under the fourth, sixth and eighth spans and radially aligned so that they were irrigated at the same time. For the linear-move system, a VSWSI was installed under the first, second, and third spans and aligned so that they were irrigated at the same time. With the solid-set sprinkler system, each VSWSI was located more than 6 m from the nearest sprinkler head and distributed within the same irrigation block.

Each VSWSI was equipped with a single CS615 reflectometer to measure soil water content. The 30-cm CS615 reflectometer was installed vertically in the center of the potato hill and positioned to measure soil water content 8–38 cm below the top of the hill. This provided a measure of average soil water content over the bulk of the active crop root zone. The operating principal of the VSWSI was explained to each farm manager. In consultation with the farm manager and based on soil texture, the set points for each VSWSI installation were established. Each farm manager was encouraged to establish their own set points after they became comfortable with the operating principle of the VSWSI. Every VSWSI installation was visited 3 to 4 times a week. On each visit, the operation of the VSWSI was validated and the soil water content and water application in each catch can were recorded. Tensiometers were installed and maintained at some sites for comparison with soil water content readings of the VSWSI.

Farm managers who were selected for the study had multiple potato fields separated by a distance of three km or more. Water application to a similar potato field under the farm manager's control and located some distance away but without the VSWSI was monitored and compared to water application on the field with the VSWSIs. A similar field was defined as having the same potato variety, water applied by the same type of irrigation system, and planting and harvest dates within days of each other. Water application was monitored at three sites in each comparison field. Water application on the two fields for each farm manager was monitored on the same schedule. The fields were located some distance apart to limit extrapolation of soil water content information from the field with the VSWSIs to the one without.

4. Results and discussion

The observed states of two VSWSIs throughout the irrigation season for one study site under center pivot irrigation are shown in Fig. 4. The VSWSIs were located under spans six and eight of the center pivot system. The solid line in each graph shown in Fig. 4 represents the volumetric soil water content reading of the VSWSI at each observation. The letter (R, W, B) symbol along the bottom of each graph shown in Fig. 4 represents the display color of each VSWSI at each observation. The upper dashed line in each graph of Fig. 4 represents the value of the upper set point and the lower dashed line represents the value of the lower set point. The soil texture at this study site ranged from sand to loamy sand. Consequently, soil water content was very dynamic throughout the irrigation season. During the peak water use period the irrigation interval was approx. 18 h. Thus, observations at two-day intervals did not allow the characteristic draw down and replenishment of soil water to be adequately captured. The results shown in Fig. 4 document that the VSWSIs functioned as designed throughout the irrigation season.

The upper and lower set point values for each VSWSI installation were different to reflect differences in soil texture at each location. The optimal range in

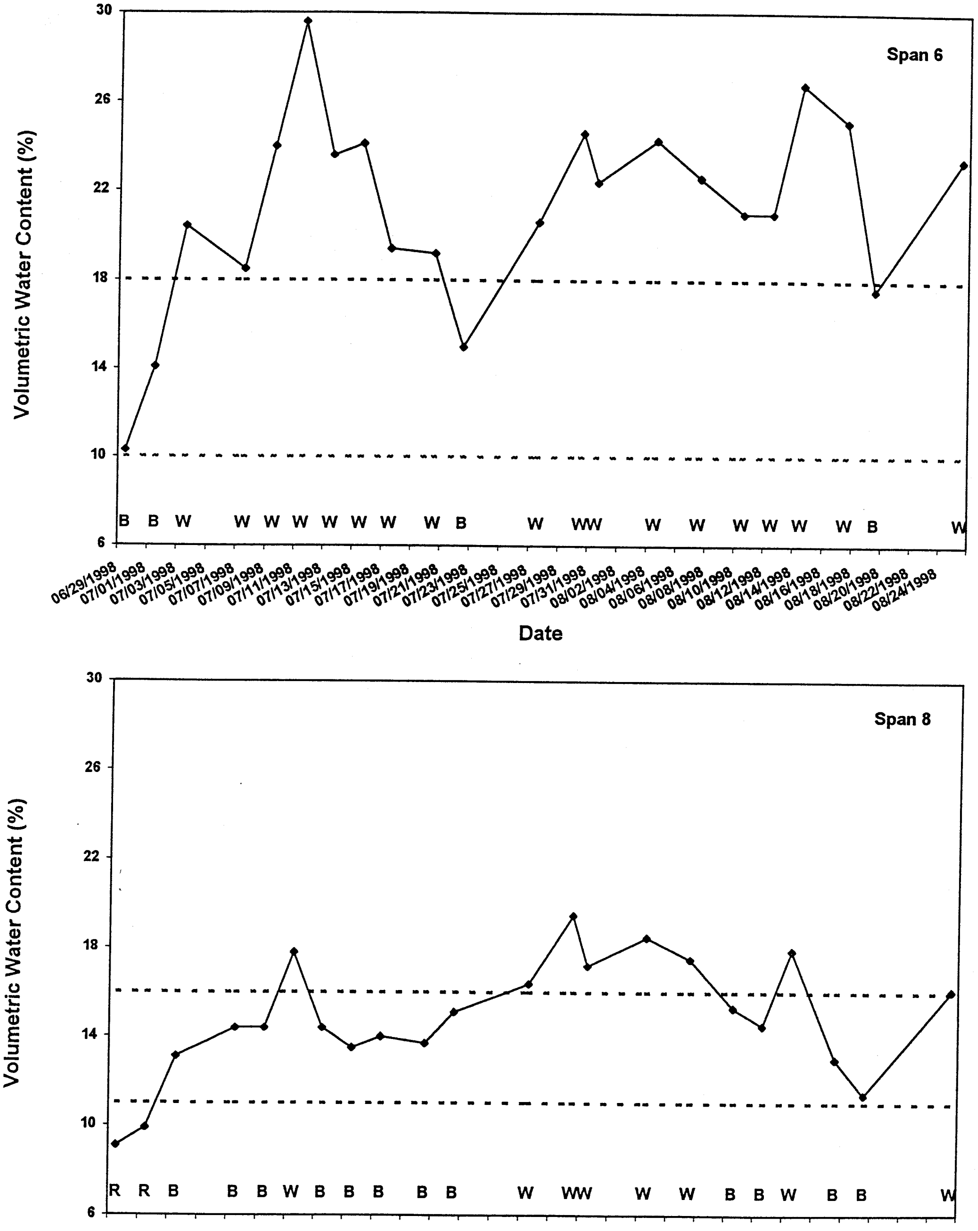

Fig. 4. Observed states of two VSWSIs throughout the irrigation season under a center pivot irrigation system.

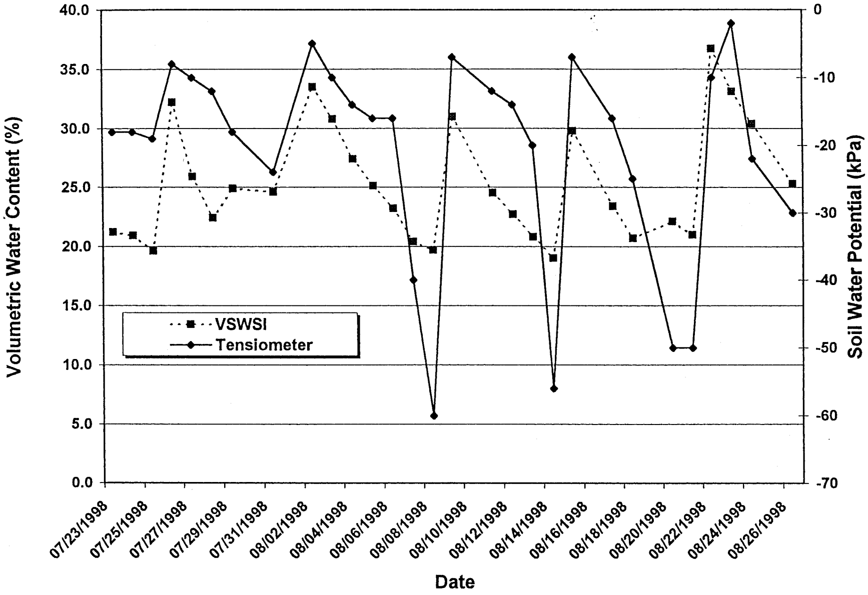

Fig. 5. Comparison of measured soil water potential and volumetric soil water content over a 30-day period.

volumetric water content for crop production is a function of soil texture as well as crop type. The optimal range for potatoes in sand is approx. 11–16% as was used for the VSWSI under span 8. The optimal range in a sandy loam soil is approx. 18–25%. The sandy loam values apparently should have been used for the VSWSI under span 6 because the measured soil water content was above the upper set point value throughout most of the irrigation season. This observation highlights the main potential problem with implementation of the VSWSI concept. A good understanding of soil-water-plant relationships is needed to determine the set points required for effective operation of the VSWSI. Most farm managers have heard of available soil moisture but few have heard of volumetric soil water content and virtually none can relate the two as needed to implement the VSWSI concept. However, this is an educational issue which applies to using any soil water monitoring device for irrigation management and not an inherent fault specific to the VSWSI concept.

Comparison of soil water potential measured using a tensiometer with volumetric soil water content measurements of a VSWSI is shown in Fig. 5. The data were collected over a 30-day period under a solid-set sprinkler system. The tensiometer was installed in the center of the potato hill with the tip located approximately 20 cm below the top of the hill. The soil texture at this location was sandy loam to silt loam so soil water content was not as dynamic as that for the center pivot site of Fig. 4. The irrigation interval was 6–7 days and observations were made daily which allowed the characteristic draw down and replenishment of soil water to be captured. Soil water potential and volumetric soil water content measurements tracked each other very well throughout the 30-day period. The results show that the VSWSI performed very well under field conditions and that the CS615 reflectometer provides an effective means of monitoring soil water content in the active root zone of the potato hill. A second CS615 reflectometer could potentially be used to monitor soil water content in the lower part of the crop root zone separately. The VSWSI could then be used to show an appropriately weighted average soil water content for the whole crop root zone.

Measured water application to fields equipped with VSWSIs and the farm manager's standard irrigation practice on a distant comparison field is shown in Fig. 6. Water application varied between farm managers due to differences in crop harvest dates associated with different varieties. Water application monitoring started on all fields on 10th June and lasted through the irrigation season. The water application depths shown in Fig. 6 represent the average for each field based on two measurements taken at each of the three VSWSI installations in each field. Collectively, water application for fields equipped with VSWSIs was 7% (2.9 cm) less than the comparison fields under the farm manager's standard irrigation practice. Statistical evaluation of water application between comparison fields using a paired t-test indicates that average water application was significantly less ($P = 0.04$) for fields equipped with VSWSIs. This result is consistent with the tendency of irrigation managers to apply additional water to minimize risk when in doubt about irrigation scheduling. The cost of additional water is considered small in comparison to the potential loss in economic return resulting in crop water

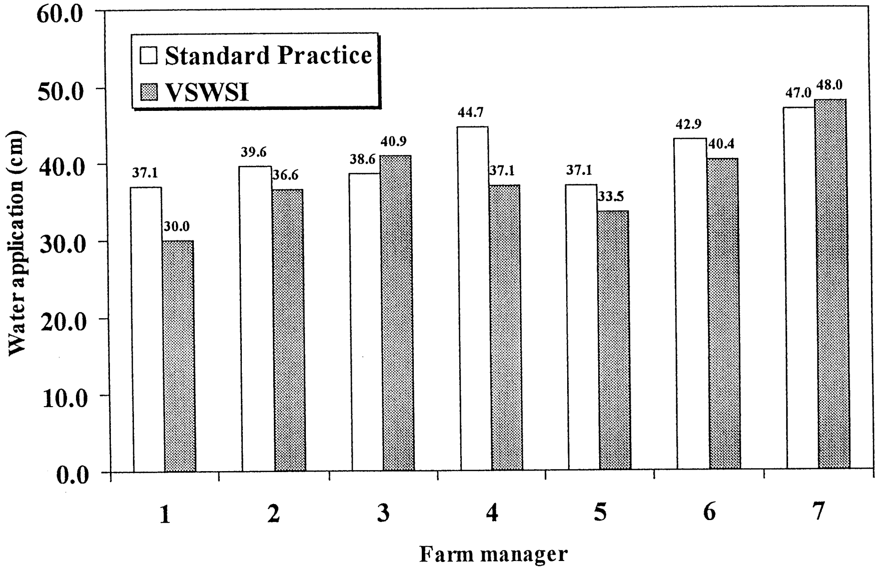

Fig. 6. Comparison of water application between fields with VSWSIs and farm manager's standard irrigation practices.

stress. Reduced water application to fields equipped with VSWSIs demonstrates that the device can be used as an effective irrigation scheduling tool. The visual display of current soil water status, which can be readily interpreted in the field by busy farm managers, greatly enhances the utility and acceptance of the device as an irrigation scheduling tool.

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