SITE-SPECIFIC WATER AND NITROGEN MANAGEMENT FOR POTATOES WITH CENTER PIVOT IRRIGATION

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ABSTRACT

Center pivots are the most commonly used irrigation system for potato production in the Pacific Northwest and Intermountain West. Conventional irrigation management treats the field as a homogeneous unit in regards to irrigation water requirements. However, differences in irrigation water requirements often develop throughout the season within center pivot irrigated potato fields that can reduce field scale tuber yield and quality. This study investigated the potential increase in gross return from increased tuber yield and quality under site-specific versus conventional uniform irrigation management with center pivot irrigation. In 2001 and 2002, one quadrant of an 11.5 ha center pivot irrigated field was divided into eighteen arbitrary irrigation management zones. One-half of the management zones received site-specific irrigation management and the remainder received equal irrigation based on the average irrigation requirement for the nine zones. The difference between mean seasonal irrigation amounts for the treatments was less than 13 mm for both years. Total tuber yield was not significantly different ($p<0.05$) for both years. However, based on a tuber quality adjusted price structure for processing potatoes, the trend in gross receipts was approximately \$159/ha (\$64/ac) greater under site-specific water management compared to conventional uniform irrigation management for the field site. In 2004, the potential increase in gross return from conjunctive site-specific water and in-season nitrogen management was investigated. Total tuber yield was not significantly different ($p<0.05$) between treatments. The trend in gross receipts was approximately \$324/ha (\$131/ac) greater under conjunctive site-specific water and nitrogen management compared to conventional uniform water and nitrogen management. Water use efficiency was not significantly different ($p<0.05$) between treatments in any study year. However, water use efficiency trended higher under site-specific water management averaging 5% greater in study years 2001 and 2002 and 14% greater in 2004.

INTRODUCTION

Interest in site-specific irrigation management has emerged over the past decade in response to successful commercialization of other site-specific application technologies in irrigated agriculture. This interest is due partially to the desire to improve water use efficiency and partially due to the need to implement site-specific water management to complement site-specific management of other crop inputs such as nitrogen for groundwater protection. A holistic approach to site-specific crop management in irrigated agriculture includes water as one of the primary inputs. Extension of the site-specific crop management concept to irrigation follows from the fact that excessive and deficient water availability greatly impacts crop yield and quality.

Continuous-move irrigation systems provide a natural platform upon which to develop site-specific irrigation management technologies due to their current and increasing usage and high degree of automation. Control systems and hardware to implement site-specific irrigation management have been reported in the literature (e.g. Fraisse et al., 1995; King et al., 1996; Sadler et al., 1996; Evans et al., 1996; Harting, 1999; and Perry et al., 2003). However, many issues relating to reliability, management and economic viability need to be addressed before commercialization and producer adoption can be expected.

Implementation of site-specific irrigation management will require additional irrigation system hardware, labor, and information on site-specific soil and/or crop water status. Costs associated with these additional requirements will need to be covered by increased receipts from improved crop yield and quality in order for the technology to be adopted by producers. Site-specific irrigation management will not likely be an economically viable practice for all crops and all growing conditions. However, it may be universally beneficial in regards to reducing the impact of irrigated agriculture on regional water resources through improved field-scale water use efficiency and reduced localized leaching of nitrogen from the crop root zone.

The economic requirement of increased receipts to offset increased irrigation costs limits site-specific management to commodities such as potatoes where yield and quality are highly sensitive to root zone water availability (Wright and Stark, 1990) and the commodity price structure is heavily dependent upon crop quality. In Idaho, which provides more than 25% of total U.S. fall potato production, sales contracts for processing potatoes normally include a base price plus tuber quality incentives and disincentives, thus total crop receipts are strongly influenced by soil water availability throughout the growing season.

Few studies have been conducted to evaluate the profitability of site-specific water management. Studies reported in the literature often have used simulation models based on theoretical crop production functions. In each case, soil water holding capacity was considered as the only factor influencing crop yield and the basis for needing site-specific water management. In reality, many factors influence crop yield and quality besides soil water availability, although it generally has a predominant adverse affect when well outside the optimum range.

Watkins et al. (2002) used a simulation approach to evaluate the economic and environmental benefits of site-specific irrigation management for seed potatoes in Idaho. They concluded that site-specific water management was more likely to be both economically and environmentally beneficial than variable rate nitrogen application for the study conditions. Watkins et al. (2002) acknowledged that the model was not calibrated to simulate nitrogen losses and neither yield nor nitrogen loss predictions were validated. Sensitivity analysis of the results showed that a small increase in estimated costs for site-specific irrigation management over conventional uniform irrigation management costs would result in the latter being more economical.

Oliveira et al. (2004) used a simulation model to evaluate the economic return of site-specific drip irrigation management for tomatoes in Tennessee. Based on 30 years of historical climate data they found that conventional uniform irrigation management using the soil type with the lowest water holding capacity to schedule irrigations had the same economic return as site-specific irrigation management. However, uniform irrigation management required 20% more water application compared to site-specific irrigation management.

Sadler et al. (2002) conducted a three-year field study to measure the mean response of corn to irrigation and compare variation in crop response within and among soil map units. Variation in crop response to irrigation was significant both between and among soil map units. Over the three-year study, the optimum irrigation amount varied from 61% to 120% of the irrigation base rate calculated as 100% of evapotranspiration minus precipitation. One conclusion of the study was that achieving optimum site-specific irrigation management based on *a priori* information will be a significant challenge. The variation in crop response to irrigation by year, soil map unit, and within soil map unit highlighted the need to use empirically derived site-specific crop response data to adequately simulate crop growth to site-specific water management in any economic analysis.

The study of Sadler et al. (2002) represents the only known data set of empirical site-specific crop response to water. It is not feasible to develop empirical crop response relationships for all crops, conditions, and locations in order to assess the economic return from site-specific irrigation management. Thus, field experimentation of site-specific irrigation management based on real-time measurements of soil and/or crop water status will play a substantial role in evaluating the economic and environmental benefits of site-specific irrigation management.

The underlying thesis of conventional uniform irrigation management is that soil water availability must remain within an established optimum range throughout the growing season for maximum crop yield and quality. However, this does not alone ensure maximum yield and quality as many other factors can affect crop yield and quality. As a first step to field experimentation, site-specific water management, based on site-specific soil water monitoring to maintain soil water within an established optimum range throughout the growing season is the basis for the current research. The objective of field studies conducted in 2001 and 2002 were to compare site-specific water management against conventional uniform water management based on continuous soil water monitoring to evaluate potential increase in potato yield, quality, and resulting increase in crop receipts, if any. The objectives of a field study conducted in 2004 were to implement independent site-specific in-season nitrogen application and compare site-specific water and nitrogen management against conventional uniform water and nitrogen management to evaluate the potential increase in potato yield, quality, and resulting increase in crop receipts.

METHODS AND MATERIALS

The field studies were conducted at the University of Idaho Aberdeen Research and Extension Center in 2001, 2002, and 2004 using a center pivot irrigation system equipped with the variable rate irrigation control system described by King et al. (2000). Briefly, variable rate water application along the center pivot lateral is achieved using two sprinkler packages sized with application rates of 1X and 2X. Solenoid valves on each sprinkler provide ON/OFF control of each sprinkler resulting in application rates of 0X, 1X, 2X, and 3X using ON/OFF sequencing. Valve control is provided by a supervisory control and data acquisition (SCADA) system that utilizes RS-232, power line carrier, and radio frequency communication media to link system-mounted controls and in-field stationary data loggers to a master computer. The SCADA system is designed to upload logged soil moisture, water application, and environmental data from in-field sensors when the center pivot lateral is within low-power radio frequency range. The data is stored in the master computer located at the pivot point and downloaded to a portable computer for analysis and site-specific irrigation scheduling decisions.

In 2003, the center pivot system was modified to include a separate low volume chemical application system to allow independent site-specific water and nitrogen application. The chemical application system consists of a 51 mm (2 in) diameter PE pipe placed along the top of the 191-m (628-ft) center pivot lateral with an outlet at each tower. The outlet at each tower is connected to two 25 mm (1 in) diameter PE pipe manifolds equipped with microsprinklers spaced 2.7 m (8.7 ft) apart. Each microsprinkler manifold is one-half the center pivot span length to provide one-half span length radial resolution in chemical application control, equal to that of water application control. The microsprinkler manifolds are suspended below the water application sprinklers at a height of about 1.5 m (5 ft) above ground level. The microsprinklers are Nelson S10 Spinners each equipped with gray plates and a 138 kPa (20 psi) Nelson Mini Regulator and Drain Check (Nelson Irrigation Corp., Walla Walla, WA). A solenoid activated diaphragm valve is used to control flow into each microsprinkler manifold and ON/OFF pulsing is used to control chemical application rate. The microsprinkler drain check valves keep the manifold from draining when microsprinkler flow is off. A separate 3.7 kW (5 hp) centrifugal pump is used to pressurize the chemical application system. An 1890 L (500 gal) plastic tank is used to provide on-site and on-demand mixed chemical solution for the chemical application system. A fixed pipe orifice with a pressure regulated solenoid activated diaphragm valve is used to provide a known water flow rate into the mixing tank from the pressurized irrigation water source. A positive displacement chemical injection diaphragm pump is used to provide a controlled and known flow rate of chemical into the water stream entering the mixing tank. Variable rate chemical application is achieved by controlling the ON/OFF times of each chemical application microsprinkler manifold and flow rate of chemical injected into the water stream entering the mixing tank. The design application rate of the chemical application system is 0.31 L/s/ha (2 gpm/ac). The minimum uniform water application depth of the chemical application system is 0.8 mm (0.03 inch) for this particular center pivot system.

Each year one 2.9 ha (7.1 ac) quadrant of the center pivot irrigation system was divided into eighteen arbitrary irrigation management zones. Different quadrants were used in 2001 and 2002 with 2001 and 2004 being the same quadrant. Soil texture in the upper 60 cm (2 ft) of the soil profile was determined in the laboratory using the hydrometer method (Gee and Bauder, 1986) based on soil sampling of the field on a 30.5 m (100 ft) hexagonal grid. Soil texture at unsampled locations was estimated using block kriging. Soil texture ranges from a loamy sand to silty clay loam and results in a two-fold variation in water holding capacity for the field site, which is representative of many commercial potato fields in the region. The eighteen arbitrary management zones were blocked into nine groups of two according to most similar soil texture in the top 30 cm (1 ft) of the soil profile. Irrigation treatments of site-specific irrigation management (SSIM) and conventional uniform irrigation management (CUIM) were randomly assigned to the experimental units in each block. The resulting experimental design is a randomized complete block with two treatments and nine replications.

An experimental plot measuring 6.5 m by 10 m (21.3 ft by 33 ft) was established in each experimental unit located approximately three-quarters of the radial span length outward from the pivot point under a particular span. A custom data logger (King et al. 2000) recorded soil water content at two depths, soil and air temperature, relative humidity, and water application at 30-min intervals. The instrumentation was installed immediately following crop emergence. The soil water sensors (CS615, Campbell Scientific, Logan, UT) were installed in the crop row at 45° inclines to measure soil water content at depths of 2-23 cm (1-9 in) and 20-41 cm (8-16 in). The soil water sensors were placed about 5 cm (2 in) offset of the crop row and adjacent to an actively growing potato plant. An installation jig was used to ensure that the sensors were installed identically in all experimental plots.

A site-specific irrigation decision support model was used to determine the irrigation requirement of each irrigation treatment in each experimental unit. The irrigation decision model used a conventional soil water balance in combination with estimated potato evapotranspiration (ET) to compute the minimum irrigation amount needed to maintain 65% available soil moisture (ASM) in the 41 cm (16 in) soil profile until the next scheduled irrigation. Potato ET was obtained from published regional values of daily crop evapotranspiration (USBR 2004). These daily ET values are computed based on climatic parameters from a network of weather stations using a modified Penman equation (Wright, 1982). For this study, potato ET was estimated using climatic data from a weather station located within 1.6 km (1 mile) of the field site. The soil water balance was used to account for actual potato ET being less that estimated potato ET due to site-specific factors. For example, assume estimated ET is 7 mm/day (0.28 in/day) or 14 mm (0.55 in) for two days until the next scheduled irrigation. Thus, without site-specific information on soil water content, the irrigation depth would need to be 14 mm. However, if soil water data shows that 9 mm (0.35 in) is available above the lower limit (65% ASM), then only 5 mm (0.2 in) needs to be applied to sustain 65% ASM until the next scheduled irrigation. Applying this soil water balance throughout the season allows irrigation to follow actual crop ET without actually knowing the value of crop ET while assuring that sufficient water is available until the next irrigation event. However, this approach requires soil water content measurements that are representative to true field conditions. If they are biased or incorrect, excess or deficit soil water conditions will prevail. Field capacity at each site was estimated based on soil sand and clay content and in-situ field capacity tests (Cassel and Nielsen, 1986) across the field site. Permanent wilting point was estimated based on soil sand and clay content (Rawls et al., 1982). Irrigation frequency was once or twice weekly at the beginning and end of the growing season and three times weekly from mid-June through mid-August.

In 2004, site-specific nitrogen management was coupled with site-specific water management using the independent chemical application system to apply in-season N based on the potato N management guideline of maintaining a minimum 15,000 mg/kg N concentration in potato petioles (Stark and Love, 2003). Petiole samples were collected in each experimental plot on Tuesday of each week. Based on the difference between N concentration in the petioles and 15,000 mg/kg, N application on Friday of the same week in the form of Urea Ammonium Nitrate was determined using the following algorithm: difference < -3,000 mg/kg, apply 40 lb N/ac; -3,000 < difference < 0 mg/kg, apply 30 lb N/ac; 0 < difference < 3000 mg/kg, apply 20 lb N/ac; 3000 mg/kg < difference, apply 0 lb N/ac. In-season site-specific N management was applied weekly over a six-week period from 28 June through 13 August. Conventional uniform N management was coupled with uniform water application with weekly N application computed as the average of the N applications determined for the experimental units under the uniform N management treatment using the same in-season N management algorithm.

Russet Burbank potato crops were planted on 9 May 2001,1 May 2002, and 6 May 2004 with a seed piece spacing of 30 cm (12 in) and row spacing of 91 cm (36 in). Fertilizer, herbicide and fungicide were applied following University of Idaho potato production guidelines (Stark and Love, 2003). Fertilizer (2001, 2002), herbicide, and fungicide applications through the irrigation system were done uniformly using the 3X application rate with a minimum amount of water application according to label recommendations. At harvest, tuber samples from three 9.1m (30 ft) sections of crop row from each experimental unit were collected on 5 Oct. 2001, 10 Oct. 2002, and 15 Oct. 2004. Tuber samples were weighed, sized and graded within 30 days of harvest. Specific gravity was determined with the standard weight-in-air/weight-in-water method using a sub sample of U.S. No. 1 grade tubers weighing 0.170 to 0.283 kg (6 to 10 oz).

RESULTS AND DISCUSSION

In 2001, the average seasonal irrigation depth for the SSIM treatment was 503 mm (19.8 in), which is essentially equivalent to the 500 mm (19.7 in) applied to the CUIM treatment. The minimum seasonal irrigation depth applied under the SSIM treatment was 437 mm (17.2 in) and the maximum depth was 597 mm (23.5 in). In 2002, the average seasonal irrigation depth for the SSIM treatment was 432 mm (17.0 in), which is slightly less (3%) than the 445 mm (17.5 in) applied to the CUIM treatment. The minimum seasonal irrigation depth applied under the SSIM treatment was 372 mm (14.6 in) and the maximum depth was 498 mm (19.6 in). In 2004 the average seasonal irrigation depth applied to the SSIM treatment was 384 mm (15.2 in), which was 8% less than the 416 mm (16.4 in) applied to the CUIM treatment. The minimum seasonal irrigation depth applied under the SSIM treatment was 331 mm (13.0 in) and the maximum was 452 mm (17.8 in). Over the three study years, the variation in seasonal irrigation depth under the SSIM treatment ranged from 82 to 119% of the average application depth, which is within the 61 to 120% range in optimal water application depth reported by Sadler et al. (2002) for corn over 12 soil map units in South Carolina

In 2004, average seasonal N application was 210 kg/ha (187 lb/ac) for the SSIM treatment and 216 kg/ha (193 lb/ac) for the CUIM treatment. The minimum seasonal N application under the SSIM treatment was 168 kg/ha (150 lb/ac) and the maximum was 247 kg/ha (220 lb/ac).

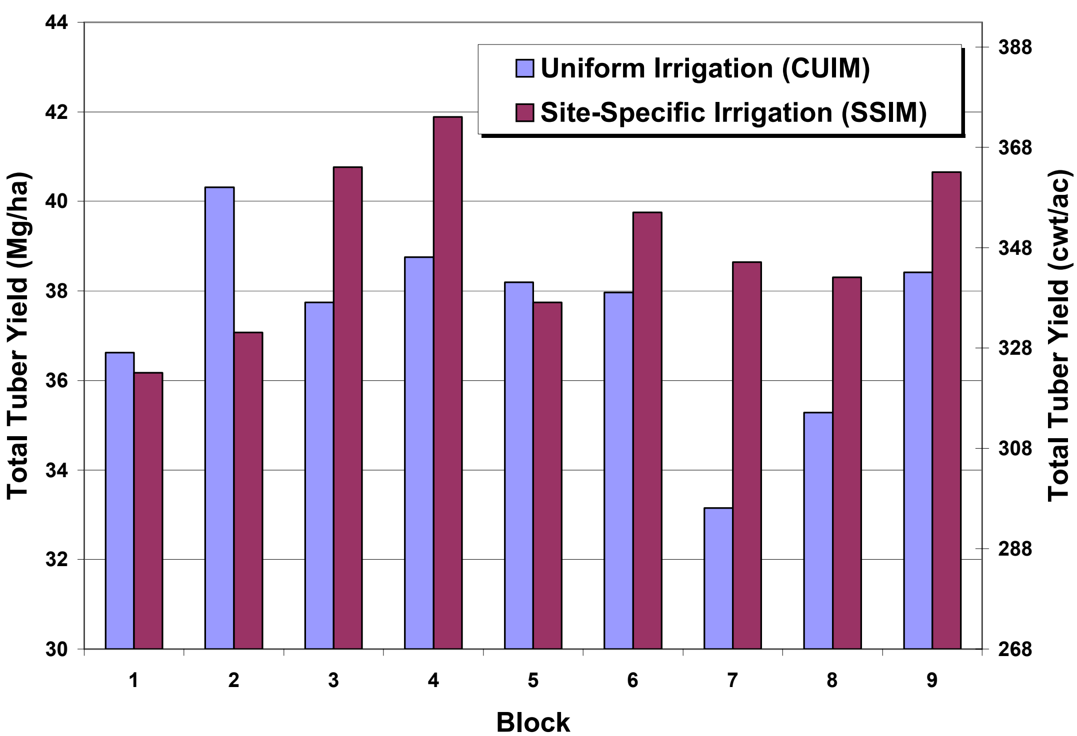

Fig. 1. Total tuber yields measured in each block of the 2001 field study.

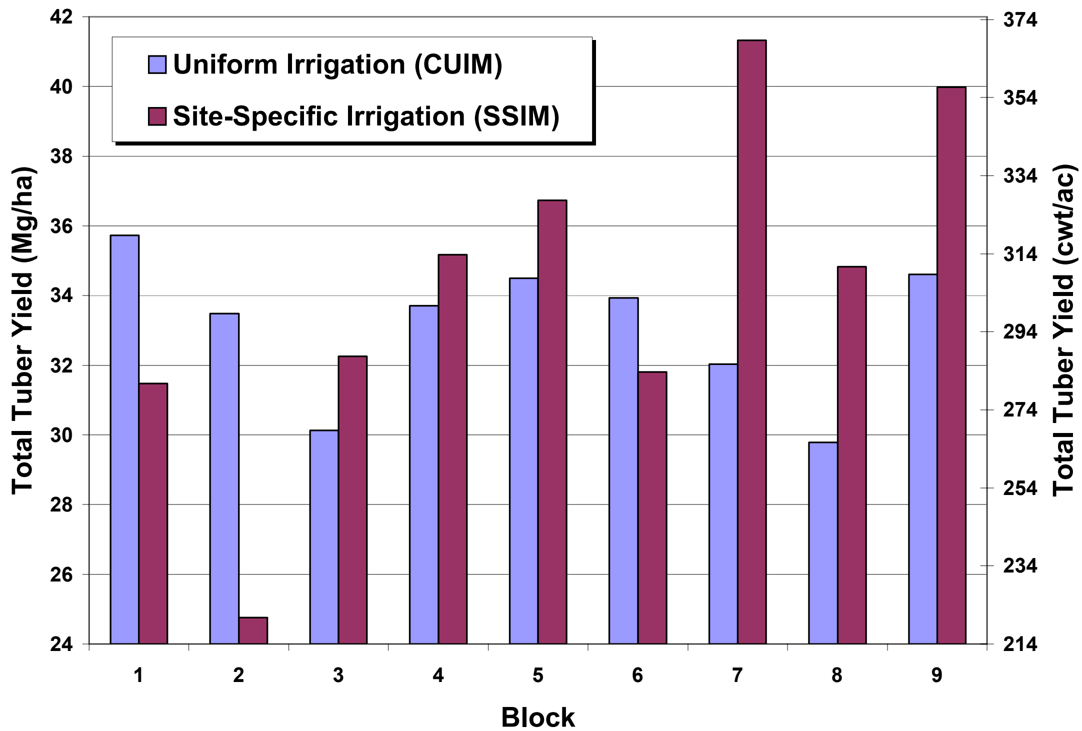

Fig. 2. Total tuber yields measured in each block of the 2002 field study.

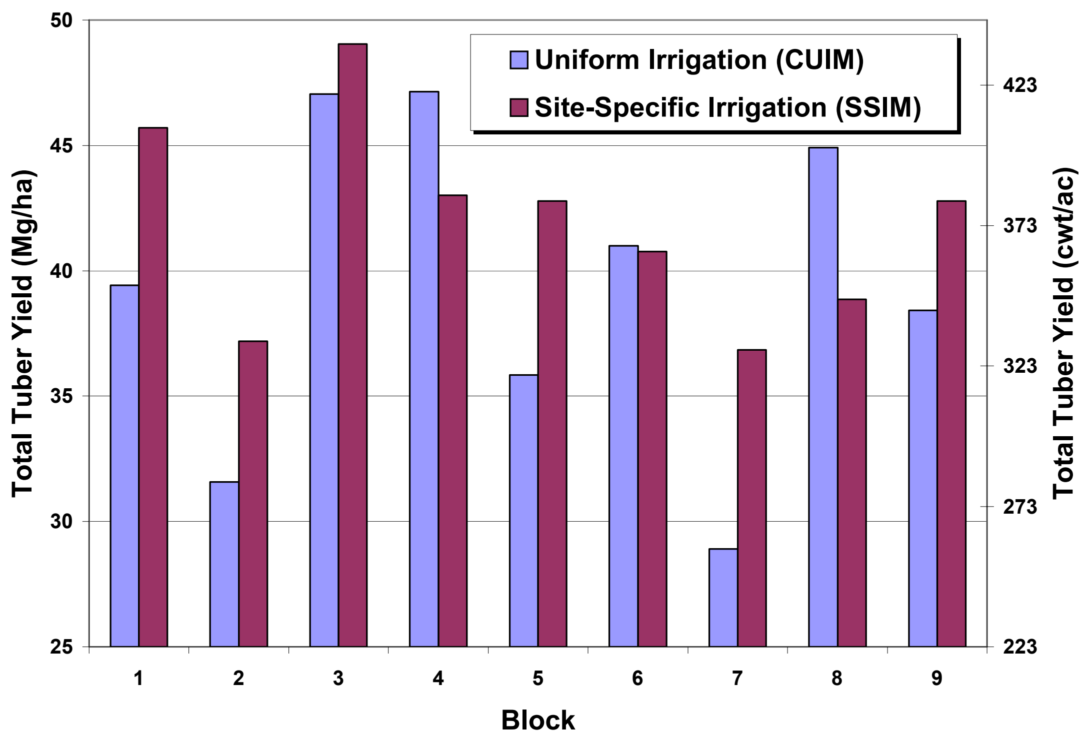

Fig. 3. Total tuber yields measured in each block of the 2004 field study.

Total tuber yields for both irrigation treatments for each block in 2001, 2002, and 2004 are shown in Figs. 1, 2 and 3, respectively. In 2001, total tuber yield was greater under the SSIM treatment in 6 of the 9 blocks. Only in block 2 was total tuber yield substantially greater under the CUIM treatment. Total tuber yield averaged across the field site was 37.4 Mg ha^{-1} (334 cwt ac^{-1}) for the CUIM treatment and 39.0 Mg ha^{-1} (348 cwt ac^{-1}) for the SSIM treatment. Total tuber yield was not significantly different between treatments at the 95% confidence level. In 2002, total tuber yield was again greater under the SSIM treatment in 6 of the 9 blocks. Total tuber yield averaged across the field site was 33.1 Mg/ha (296 cwt/ac) for the CUIM treatment and 34.3 Mg/ha (306 cwt/ac) for the SSIM treatment. However, again total tuber yield was not significantly different between treatments at the 95% confidence level. In 2004, total tuber yield was greater under the SSIM treatment in 6 of the 9 blocks. Total tuber yield averaged across the field site was 39.4 Mg/ha (351 cwt/ac) for the CUIM treatment and 41.0 Mg/ha (374 cwt/ac) for the SSIM treatment. Total tuber yield was not significantly different between treatments at the 95% confidence level.

Irrigation water use efficiency calculated as seasonal irrigation depth plus precipitation divided by total yield was 0.070 Mg/ha-mm (15.9 cwt/ac-in) and 0.073 Mg/ha-mm (16.6 cwt/ac-in) for CUIM and SSIM treatments, respectively in 2001. It was nearly equal in 2002 at 0.068 Mg/ha-mm (15.3 cwt/ac-in) and 0.071 Mg/ha-mm (16.2 cwt/ac-in) for CUIM and SSIM treatments, respectively. Irrigation water use efficiency was 0.082 Mg/ha-mm (18.6 cwt/ac-in) and 0.093 Mg/ha-mm (21.2 cwt/ac-in) for CUIM and SSIM treatments, respectively in 2004. Irrigation water use efficiency was not significantly different at the 95% confidence level in any study year. However, irrigation water use efficiency averaged over 2002 and 2003 study years trended 5% higher under the SSIM treatment and was 14% greater under the site-specific water and nitrogen treatment in 2004.

Computed gross income was calculated using a local tuber quality incentive based potato processing contract price structure. In 2001, gross income averaged across the field site was $3690/ha ($1494/ac) for the CUIM treatment and $3856/ha ($1561/ac) for the SSIM treatment, a non-significant trend difference of $165/ha ($67/ac) greater under SSIM. In 2002, gross income averaged across the field site was $3283/ha ($1329/ac) for the CUIM treatment and $3435/ha ($1391/ac)) for the SSIM treatment, a non-significant trend difference of $152/ha ($62/ac) greater under SSIM. While non-significant, demonstration of a trend showing an average increase in gross return of $159/ha ($65/ac) under the SSIM in the field experiment is encouraging. In 2004, gross income average across the field site was $3544/ha ($1435/ac) for the CUIM treatment and $3867/ha ($1566/ac) for a non-significant trend difference of $324/ha ($131/ac) in the one-year study.

SUMMARY AND CONCLUSIONS

Potato total tuber yield, gross income, and water use efficiency were increased under site-specific irrigation management relative to conventional uniform irrigation management for the study field site. However, total yield and water use efficiency were not significantly greater ($p \leq 0.05$) under site-specific irrigation management. Based on a local tuber quality adjusted potato processing contract price structure, the trend in gross income averaged across the field site for study years 2001 and 2002 was $159/ha ($65/ac) greater under site-specific irrigation management compared to conventional uniform irrigation management. In 2004, the non-significant trend in gross income averaged over the field site was $324/ha ($131/ac) greater under conjunctive site-specific water and in-season nitrogen management compared to conventional uniform water and nitrogen management. The non-significant trend in increased gross return and water use efficiency under site-specific irrigation management and conjunctive in-season nitrogen management is encouraging. Continued research and development is needed to reduce the capital and operational costs of site-specific irrigation and nitrogen management and better understand the factors leading to the development of spatially variable irrigation requirements in center pivot irrigated fields in order to realize a positive net return.

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