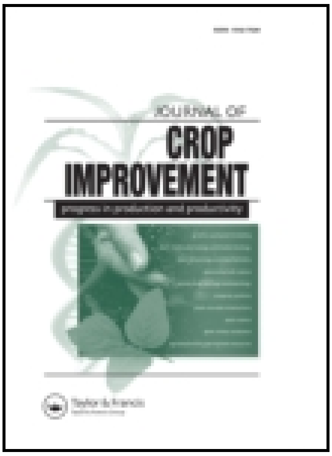

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Onion Growth, Yield, and Production Costs as Affected by Irrigation System

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*Onion (*Allium cepa*) production in California's San Joaquin Valley (SJV) typically involves intensive tillage and sprinklers for crop establishment followed by drip irrigation (DR). Studies were conducted at Five Points, California, in 2011 and 2013 to compare minimum tillage (MT) practices under overhead irrigation (OH) and DR relative to crop growth, yield, and costs. The experimental design was a randomized complete block with four replications of each irrigation treatment. Crop growth in both systems was similar; however, there was a year X irrigation system interaction for crop yields. In 2011, yields were not affected by irrigation, but in 2013, irrigation type affected yield with the OH system having 15.4 t/ha higher production than the DR system (78.6 t/ha vs. 63.4 t/ha). Onion size was not affected by irrigation system. Cost estimates indicated that onion production could be $564 per hectare lower with the OH system compared with the DR system, if yields were maintained. Because of cost savings from OH, in both years the OH system was more profitable than DR. The study showed that onions could be successfully grown with MT using the OH system in the SJV and similar amounts of water.*

KEYWORDS Allium cepa*, onion, minimum tillage, overhead irrigation*

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INTRODUCTION

Developing economically viable and more efficient onion production systems is a challenging goal of farmers in California's San Joaquin Valley (SJV) because of tight returns on investments that result from high costs for seed and pest management. Most current onion farming in the SJV relies on considerable intercrop tillage operations (Wilson et al. 2011) and the use of surface or shallow buried drip tape in combination with sprinklers for crop establishment (Smith et al. 2011). A possible means for reducing onion production costs in these systems is the coupling of controlled traffic and minimum tillage seeding practices with mechanized overhead irrigation (Pelter et al. 2004).

Controlled traffic farming is a way of growing crops that permanently separates crop growth areas from traffic lanes, thereby providing optimal conditions for both (Wang et al. 2009; Vermeulen and Mosquera 2009). A number of benefits of controlled traffic farming systems have been reported, including decreased soil bulk density (Wang et al. 2009), reduced crop growth zone traffic-induced soil compaction that occurs under random traffic farming systems (Gasso et al. 2013), lower energy requirements (Tullberg et al. 2007), increased available water capacity in the crop root zone (McHugh et al. 2009) and water-use efficiency (Wang et al. 2009), and higher crop yields (Wang et al. 2009). Controlled traffic farming is thus now seen as a 'more environment-friendly' system (Gasso et al. 2013) with 'enthusiastic farmer adoption' in Australia and Europe (Tullberg et al. 2007; Tullberg 2010; Kingwell and Fuchsbichler 2011). Minimum or reduced-pass tillage management may further reduce production costs in CTF vegetable production systems (Mitchell et al. 2009; Mitchell et al. 2012).

An additional potential means for increasing efficiencies and reducing costs in SJV onion production is overhead mechanized irrigation, which is commonly used on an estimated 80% of production acreage in Washington State because of the ability of automated center pivot systems to reduce labor costs and provide economical production (Pelter and Sorensen 2003; Pelter et al. 2004). Pivot irrigation of onions is also a means for providing frequent irrigations to maintain high surface soil moisture levels that are necessary to optimize yields and the percentage of single-centered onions, which is an important marketing attribute of onions used in food products such as onion rings (Shock et al. 1998, 2007). The use of pivot irrigation on SJV onions, however, is extremely rare with fewer than five systems currently in use in the region.

Because no studies from the SJV have been published on the merging of controlled traffic farming, minimum tillage, and overhead pivot irrigation, there is a need to compare the performance and profitability of these coupled technologies with local standard (surface drip with minimum or reduced pass tillage) production practices in the SJV (Mitchell et al. 2009). Therefore, the objective of this study was to compare crop growth, yield, size, and production costs of minimum tillage onion production under overhead and drip irrigation. Our specific goal was to test the hypothesis that overhead-irrigated minimum tillage onion production can match the standard SJV drip irrigated onion system in terms of productivity and profitability.

MATERIALS AND METHODS

A two-year (2011 and 2013) field study was conducted at the University of California's West Side Research and Extension Center (WSREC) in Five Points, Calif. (36°20′29″N, 120°7′14″W). The field size was 394 m by 100 m, and the soil type was Panoche-clay loam (fine-loamy, mixed superlative, thermic Typic Haplocambids) (Arroues 2000). The onion studies were part of a four-year intensive vegetable crop rotation: tomato (2010); onion (2010/2011); broccoli (2011); tomato (2012); onion (2013); broccoli (2014). The irrigation and tillage systems were maintained similarly for all the crops in the entire rotation. The MT management consisted of two intercrop preplant tillage passes using a Wilcox *Performer* bed-reworking implement (Wilcox Agriproducts, Walnut Grove, CA) that was fitted with chisel-point shanks set at about 20 cm deep to loosen soil on the shoulders of beds, a rolling rotor blade to chop and mix residues, and a shaping shroud to reform beds. The experimental design was a randomized complete block with four replications of each irrigation type. Controlled traffic was used throughout the study in all the plots, which meant that only certain furrow areas were trafficked while the onion crop growth zones or beds were not trafficked. Each plot consisted of thirty 150-cm beds. Buffer zones of at least three beds on either side of the plots were maintained during the data collection process. Data on reference evapotranspiration (ETo), precipitation, and soil temperature at 10-cm were acquired from the California Irrigation Management Information System (CIMIC) (Department of Water Resources 2014).

The intermediate day-length yellow-onion cultivar, Caballero (Seminis, Oxnard, CA), was planted on November 3, 2010 and January 10, 2013 in eight lines across the bed tops using a 3-row Monosem precision seeder (Edwardsville, KS) and irrigated using a hose-fed lateral-move system (Model 6000, Valmont Irrigation, Valley, NE) with eight 30-m wide spans. The area under each span of the overhead system was used as one of the plots. The OH system was fitted with rotator-type nozzles with 360° spray patterns except at the edges of each plot where 180° center-facing nozzles were used to prevent overlap with the DR system. Irrigation amounts for the overhead systems were determined by various combinations of the lateral-move system speed and application nozzles and an in-line flow meter (Seametrics, Kent, WA). The DR irrigation system used two lines of 0.15 GPH 2.2 cm ID drip tape with 30 cm spacing between emitters placed about 33 cm apart to divide the bed surface into thirds on each bed surface. Water application amounts were determined using a McCrometer in-line flow meter (Hemet, CA). Because little locally derived performance data on overhead irrigation are available in the SJV, a catch-can analysis of the application uniformity of the overhead linear move system was conducted by placing 10 rows of 17 #10 cans spaced in a 1 m grid under one span of the system and measuring the amount of water collected following an irrigation event. The Christiansen coefficient of uniformity (CU) was then calculated (Harrison and Perry 2013). Application uniformity of the drip irrigation system was not determined.

All plots received several sprinkler irrigations via the overhead system (24 in 2011 and 7 in 2013) for onion seedling germination and establishment, after which drip tape was used for the drip system (Figures 1 and 2). Irrigation application amounts for both the DR and OH systems were determined using evapotranspiration (ETo) data from a CIMIS (http://wwwcimis.water.ca.gov/cimis/welcome.jsp) weather station located about 50 m from the study field with crop coefficient (Kc) values based on crop canopy estimates. Commonly applied onion herbicides for the SJV, oxyfluorfen (GoalTender at 292 ml/ha), 3,5-bromoxynil (Buctril 4EC at 584 ml/ha), and oxyfluorfen (Goal 2XL™ at 584 ml/ha) were applied by a ground spray-rig and sprinkler-incorporated on 18 January, 3 February, and 23 February, respectively in 2011, and 7 March, 25 March, and 18 April in 2013. In 2013, an additional application of dimethyl tetrachloroterephthalate (Dacthal at

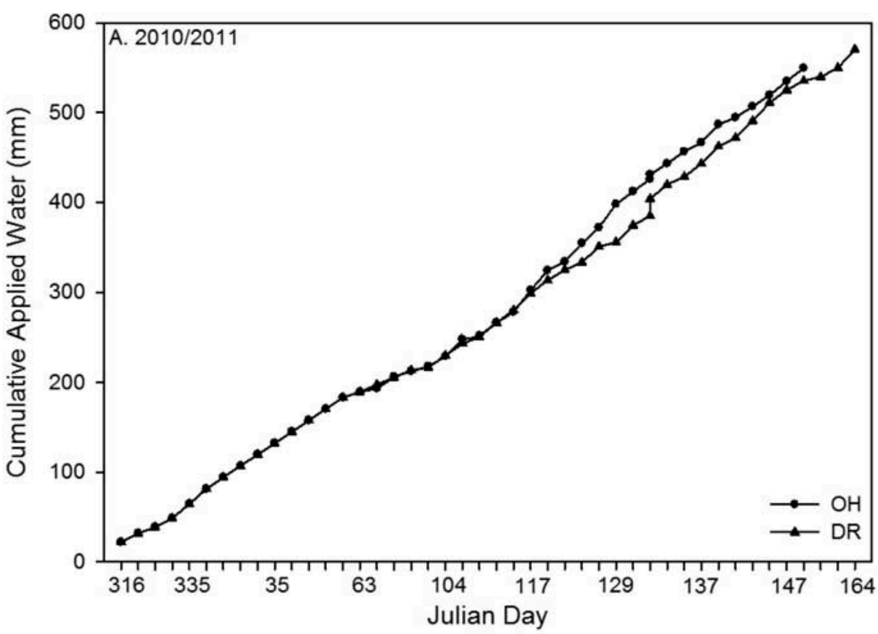

FIGURE 1 Cumulative water applied for drip and overhead irrigated onion in 2011.

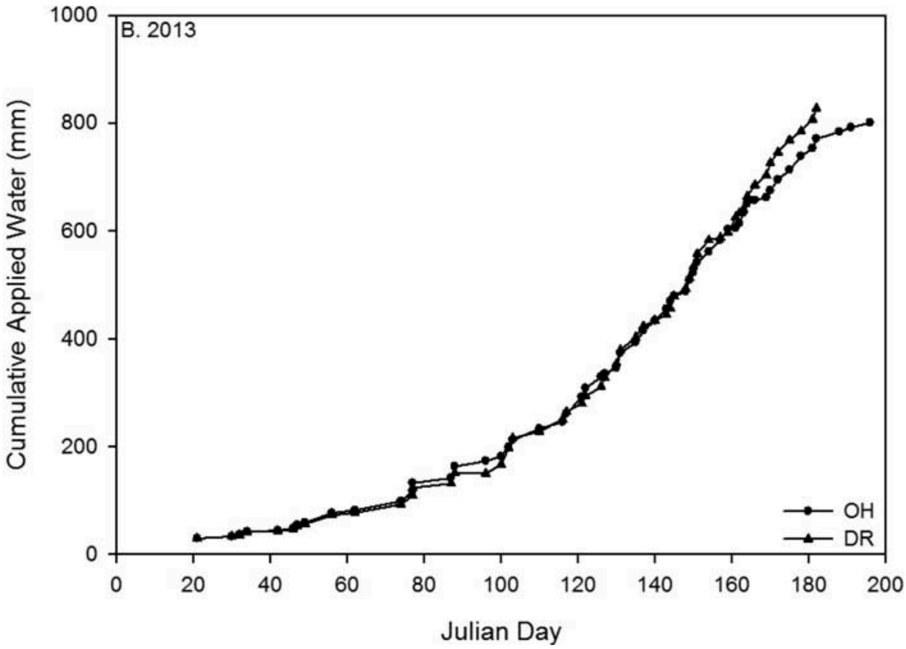

FIGURE 2 Cumulative water applied for drip and overhead irrigated onion in 2013.

14 l/ha) was made on 15 January. Different formulations of the herbicide, oxyfluorfen, were used in the two years due to their different weed growth-stage registrations and the relative weed maturities that were targeted at the time of applications in the two years. Hand weeding was done in both years by labor crews. Also, in 2013 spinetoram (Radiant SC) was applied at 438 ml/ha on April 19 for control of thrips (*Thrips tabaci*). Weekly fertigation applications of UAN32 totaling 302 kg N/ ha were made from late March to early June in both years to both the overhead and drip systems.

Similar amounts of water were applied to the overhead and drip treatments within each year, but more water was applied in 2013 because of the higher cumulative ET and a longer onion growing season than in 2011 (Figures 1 and 2 and Table 1). Total growing season ETo was 759 mm in 2011 and 1115 mm in 2013. Rainfall was also lower in 2013 with considerably less precipitation falling in January through June than in 2011. Soil temperatures at 10-cm depth were also higher during the early months of 2013 than 2011. Soil volumetric water content was determined in the top 20-cm soil layer using a Campbell Scientific CD620 HydroSense system (Logan, UT) in 2011 and to a depth of 0.9 m at 15, 30, 60, and 90 cm increments in all replications and averaged in 2013 using a 503 DR Hydroprobe neutron moisture gauge (Campbell Pacific Nuclear, Martinez, CA). HydroSense and Hydroprobe readings were converted to soil volumetric water content using calibration curves developed at the site.

TABLE 1 Reference evapotranspiration (ETo), precipitation, and soil temperatures at 10 cm depth for onion study site in Five Points, California, in 2011 and 2013

	ETo (mm)	Precipitation (mm)	Soil temperature (°C)
2011			
November 2010	50.7	58.9	13.4
December 2010	26.5	112.6	11.4
January	16.9	56.5	9.7
February	57.2	29.1	9.7
March	80.5	53.4	12.1
April	145.4	7.8	15.5
May	186.3	3.5	18.1
June	195.6	17.6	22.4
Total	758.9	339.4	
2013			
January	45.1	13.3	8.2
February	65.9	13.6	9.7
March	122.4	22.9	13.4
April	193.3	1.5	16.3
May	224.7	1.1	19.8
June	233.5	0	22.0
July	230.9	0.5	24.7
Total	1115.2	52.9	

These water applications corresponded to similar patterns of soil volumetric water content in the top 20–23 cm of soil in both years, though there was more in-season fluctuation between irrigation treatments in 2011 (Figures 3 and 4). In general, surface soil volumetric water content was maintained in the 30% to 40% range in both seasons; however, in 2011, levels in the OH system were lower during Julian days 100–115 and in the DR system at the very end of the season. Frequent irrigations and avoiding interruptions between irrigation are required for high onion yields (Shock et al. 2007). Both the OH and the DR irrigation systems were able to frequently apply precise, small amounts of water to avoid interruptions between irrigations that may be associated with furrow-irrigated onion systems because of the need to allow drying periods for tractor operations (Shock et al. 2007). The Christiansen CU for the OH irrigation system was determined to be 93.3% (data not shown), indicating excellent uniformity (Letey et al. 2007).

In this study, we used the functional approach to crop-growth analysis (Hunt 1982), relying on very frequent sampling with small sample sizes in an effort to gain a more detailed, season-long assessment of crop growth in the experimental treatments. Whole-plant onion biomass was determined by harvesting, rinsing, drying, and weighing five plants in 2011, and by harvesting, rinsing, and weighing 10 plants in 2013 from random locations throughout the center 10 beds of each plot. Biomass measurements were made 45 times during the 2011 trial and 53 times during the 2013 trial.

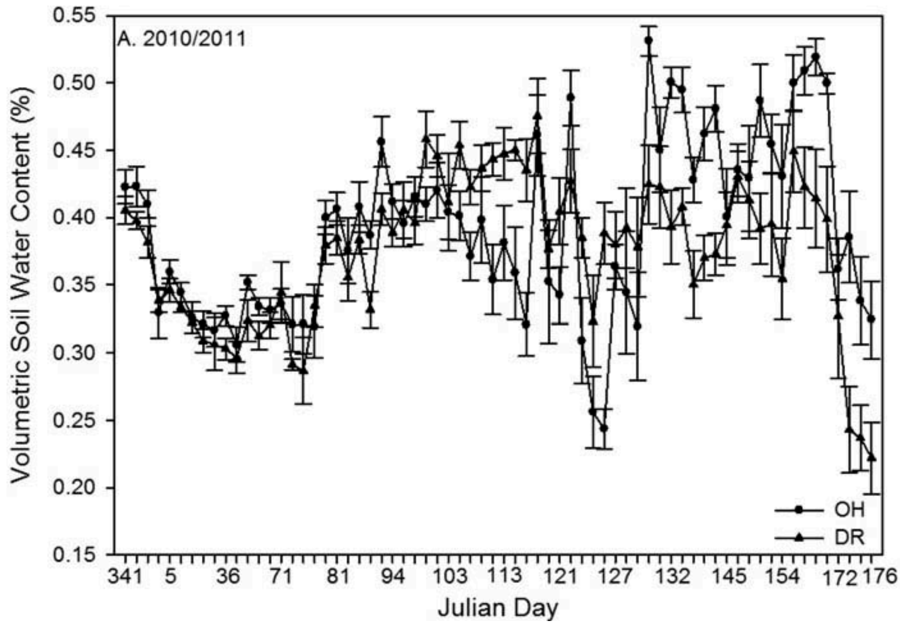

FIGURE 3 Soil volumetric water content in surface 8 inches of soil measured by HydroSense TDR in 2011.

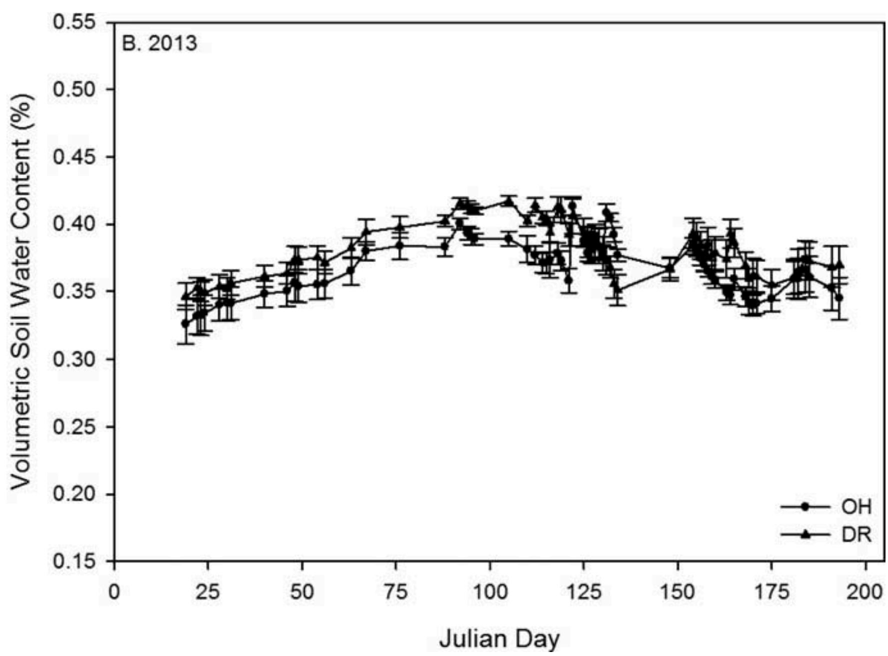

FIGURE 4 Soil volumetric water content in surface 9 inches of soil measured by neutron hydroprobe in 2013.

Onions were harvested in both years using a commercial single-row Top Air harvester (Parma, ID), and yields were determined using weighing gondola trailers equipped with electronic scales for six 100-m beds per plot. Roughly 45 kg subsamples were then sorted by size using an electric-belt sorter according to local custom diameter size classes: culls (<5.87 cm), small (5.87–6.17 cm), medium (6.17–6.50 cm), large (6.50–8.26 cm), extra large (8.26–10.16 cm), and oversize (>10.16 cm). Partial onion production budgets were calculated for each of the irrigation systems.

An economic model of a hypothetical farm was created for each of the irrigation systems to determine the revenue, costs of production, and net returns (profitability) that would be realized by a farm adopting each of the irrigation systems in each of the two years of the study. The yields, equipment, and materials (fertilizer, pesticides, and seed) used are included in the farm model. A calendar of operations was maintained for the trials including the date, equipment, and materials for each operation. We obtained costs from local input suppliers for each of the inputs and labor rates. Obviously, the time required to complete an operation on a per hectare basis is much higher for a small research trial than on a commercial scale. Instead, we used the model to estimate the hours for each operation on an actual farm. For each operation the amount of fuel and labor was calculated. Also, the repair costs on the equipment and the depreciation and interest on equipment are calculated using engineering equations and accounting methods. The total cultural costs for each system were calculated by adding together the costs of each operation including labor, fuel, repairs, and materials. Total costs include cultural costs, irrigation system costs, and equipment costs. The gross revenue was calculated by multiplying the trial yields by a typical market price. The net returns were calculated by subtracting the total costs from the total revenue.

Weed biomass in the plots was estimated only in 2011 (May 3). In each plot, weeds within a 0.25 m^2 quadrat were sampled at four random spots. The weeds were clipped at the soil surface, put in paper bags, dried in a forced-air oven at 70°C for 72 h, and dry weight was taken.

Data were subjected to analysis of variance (ANOVA) using SAS v. 9.2 (SAS Institute Inc., Cary, NC). Assumptions of ANOVA were checked by testing for normality and homogeneity of variance. The GLM procedures were used at a significance level of 0.05 to evaluate differences between the years, treatments, and interactions between years and treatments. Replications and years were considered random effects and irrigation treatments fixed effects. When there was no interaction between year and treatment, the data from the two years were combined and analyzed; otherwise each year was analyzed separately. Treatment effects on onion size categories did not vary by year, so data from the two years were combined and analyzed.

RESULTS AND DISCUSSION

Growth, Development, and Yield

Onion growth and development were generally similar in both production systems in both years (Figure 5). Growth in the 2013 overhead system was lower than in the drip system on a number of sampling dates; however, it

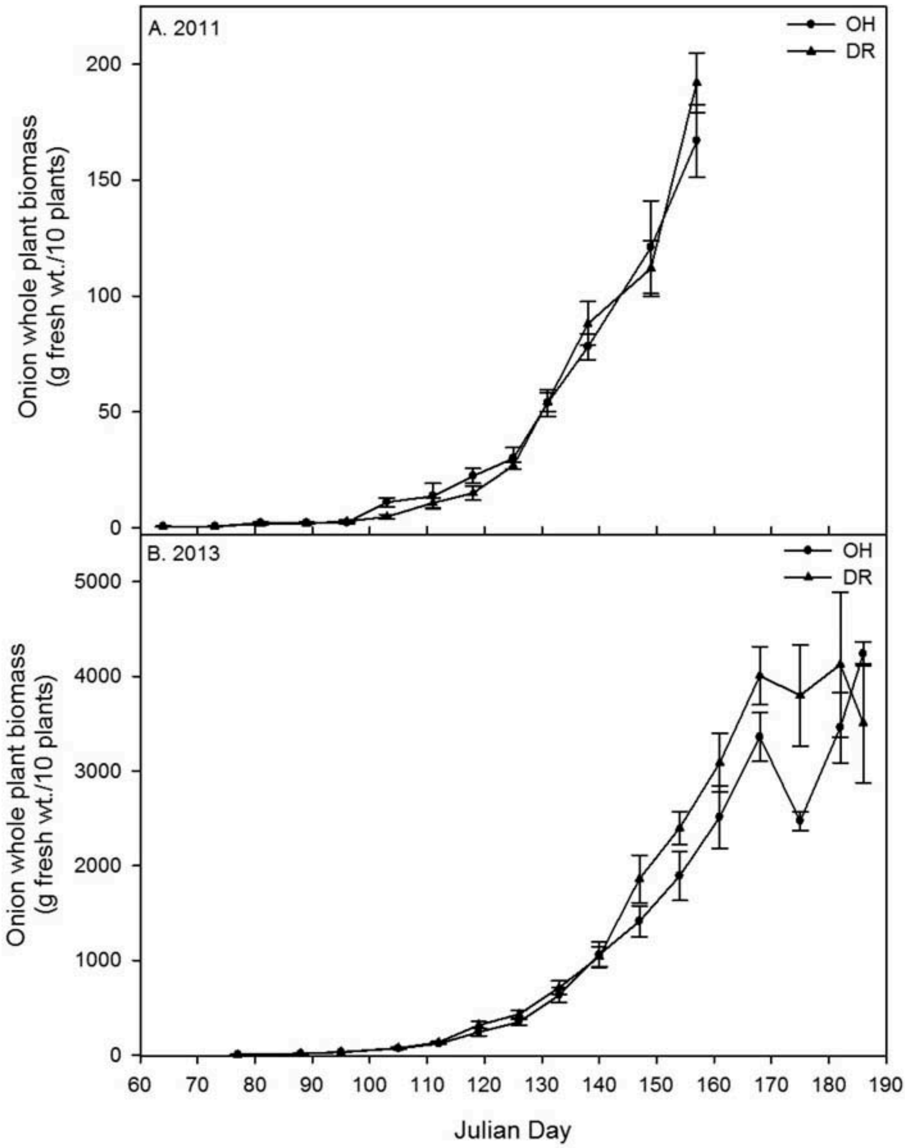

FIGURE 5 (A) Onion growth and development in 2011 in the four production systems. (B) Onion growth and development in 2013 in the four production systems.

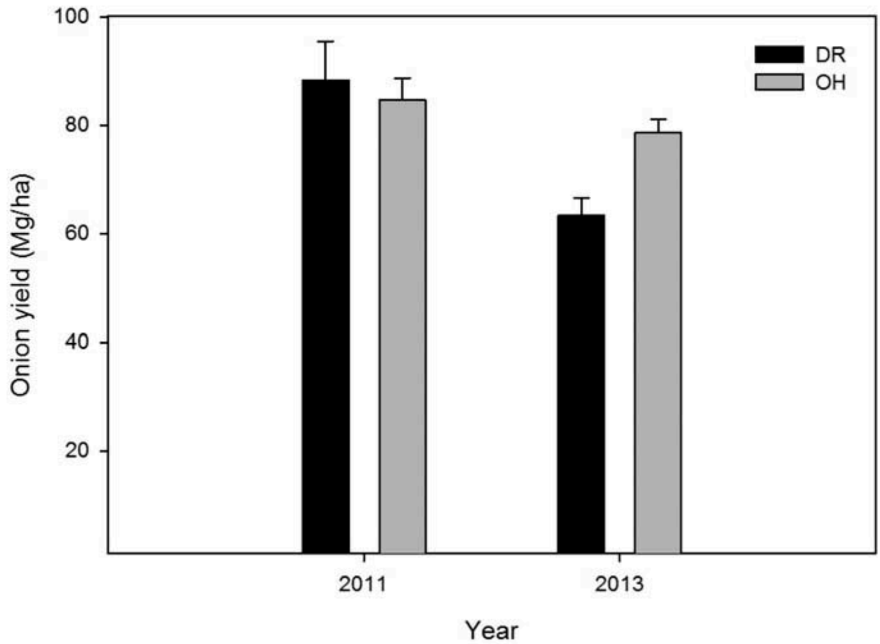

FIGURE 6 Effects of irrigation and tillage systems on onion yield for 2011 and 2013 at the WSREC in Five Points, California.

was similar between the two systems at harvest. The effect of irrigation on onion yields varied by year. In 2011, there was no difference in onion yield (Figure 6), but in 2013, onion yields were almost 15.7 t/ha higher in the overhead than in the drip system (Figure 6). Commercial farm onion yields for Fresno County in the SJV from 2010 through 2012 averaged 66.1 t/ha (Wright 2011 and 2012). Therefore, yields in our study were above the county average and even in the DR system in 2013 yields were in line with commercial production levels.

Because water and fertilizer applications and crop growth were relatively similar between the irrigation systems in 2013, factors other than these may explain this difference. While similar amounts of water were applied to the two irrigation systems throughout the season, a possible explanation for the lower drip system yields may have been a loss of applied water to lower depths in the soil profile under the drip system because of water in this system being applied in a more concentrated area, which may have more readily leached through the profile faster than in the overhead system in which water was applied across a larger area. This was, however, not the case as indicated in Figure 7, which shows the change in soil volumetric water content at 120 cm depth during the 2013 season. While there was a slightly earlier increase in water content at this depth in the DR system, there tended to be an overall greater accumulation of water by the end of the

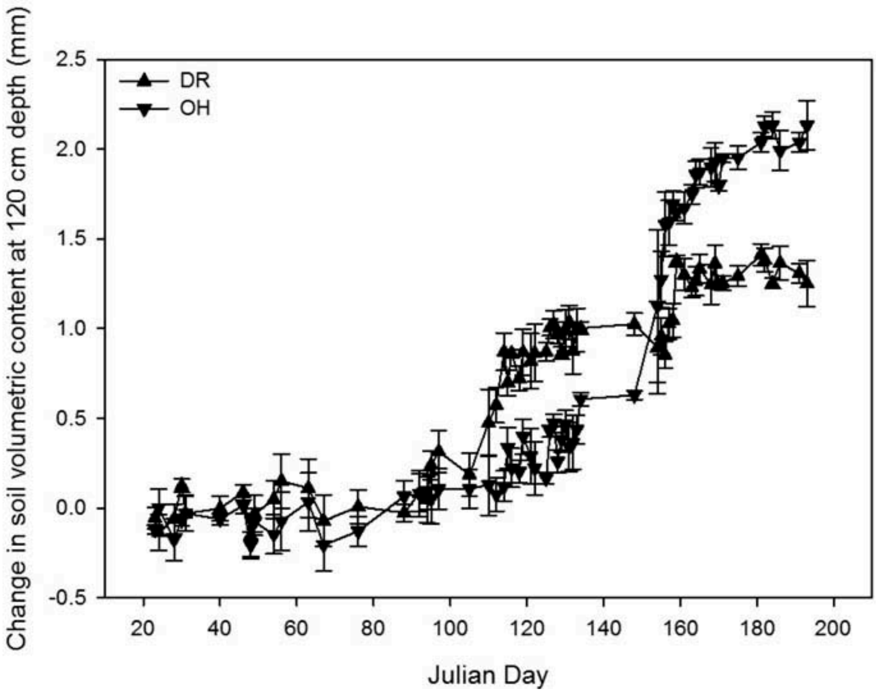

FIGURE 7 Changes in volumetric soil water content at 120 cm depth under drip and overhead irrigation at Five Points, California, study site in 2013.

season in the OH system, though the actual amount of water that reached this depth was quite small in both systems. These data thus do not support the hypothesis that more water was lost below the onion root zone in the DR system.

One problem that occurred in the drip system that did not occur in the overhead plots that was also observed in commercial onion production fields in the region during 2013 and that may have resulted in damage to the drip onion plants was the reinstallation of the surface drip tape, which was dislodged and scattered randomly throughout the plots by rather severe winds that occurred in April 2013. Considerable hand labor was required to reposition the tape and although attempts were made to avoid damage to the onions, damage may not have been entirely avoided and this replacement of the tape within the onion beds by hand may not have been as uniformly done as when the season started following tape installation using tractor-mounted spools.

A final factor that may have contributed to the reduced DR yields in 2013 is the fact that the placement of the two lines of drip tape across the eight lines of onions plants on a bed may have resulted in onions on the outer edges of the eight rows receiving less water and thus growing less than plants in the center of beds. The precedent for DR onions to underperform at 100% ETc relative to higher ETc rates and for yields to actually continue to increase up to 160% of ETc has been noted by Hanson and May (2004) and provides additional evidence for this water distribution issue, with not all lines of onions adequately tapping into optimal soil moisture due to limited lateral water movement with DR. When greater amounts of water are applied by DR, better wetting near the edge of the bed is thought to enhance bulb development and yield. This suspected more variable surface water content under DR may also be seen in the 2011 data that were collected at various locations across the entire bed using TDR (Figure 3) rather than in 2013 when neutron probe readings were made at single, fixed locations in the centers of beds (Figure 4). To overcome this concern, some onion producers use three drip tapelines for wide bed production, but this system results in additional cost.

There was no year by treatment interaction for onion size data and thus the data for the two years of the study were combined (Table 2). There were no significant differences between the irrigation treatments for any of the onion sizes.

Economic Performance

To calculate the gross returns we assumed an average fresh market price of \$193 per ton. We also assumed that price did not vary by year, and that all production would go to fresh market. Using the actual trial yield results and the assumed price, the gross returns are \$2,979 per hectare higher for OH than DR in 2013 (\$15,196 versus \$12,216 per hectare) but \$696 per hectare lower in 2011 (\$16,359 versus \$17,055 per hectare) (Table 3). The farming practices other than irrigation were kept identical between the systems. Therefore, the costs for land prep, planting, fertilization, and pest control are identical for both systems and both years estimated to be \$3,030 per hectare. The cost of irrigation varies in water, labor, energy, and the irrigation system itself. Typically, overhead irrigation uses more water than drip irrigation. However, the research trial was designed to keep the water use for the two systems as close as possible. In fact, the water use was slightly

TABLE 2 The effect of irrigation and tillage treatments on onion size percentages (%)[a]

	Onion size[b]					
Treatment[a]	Culls (<5.9 cm)	Small (5.9–6.2 cm)	Medium (6.2–6.5 cm)	Large (6.5–8.3 cm)	Extra-large (8.3–10.2 cm)	Oversize (>10.2 cm)
DR	0.6 ± 0.2	0.6 ± 0.2	4.1 ± 1.0	19.5 ± 3.7	53.1 ± 3.5	21.9 + 4.2
OH	0.8 ± 0.3	1.1 ± 0.3	4.7 ± 1.2	21.0 ± 2.3	50.5 ± 2.3	21.7 ± 2.9

[a](OH) overhead irrigated; (DR) drip irrigated.
[b]Means and standard errors of the means.

TABLE 3 Gross returns, costs, and net returns by system and year ($ per hectare)

	2011		2013	
	OH	DR	OH	DR
Yield (tonnes/hectare)	84.8	88.4	78.8	63.3
Price ($/tonne)	193	193	193	193
Revenue ($/hectare)	16,359	17,055	15,196	12,216
Costs:				
Water	267	277	389	402
Irrigation labor	59	203	59	203
Irrigation energy	306	193	306	193
Irrigation system maintenance	30	185	30	185
Other cultural costs	3,030	3,030	3,030	3,030
Harvest costs	9,455	9,774	8,923	7,561
Irrigation system	217	583	217	583
Equipment	168	168	168	168
Total cost ($/hectare)	13,533	14,412	13,123	12,325
Net returns ($/hectare)	2,826	2,643	2,073	(109)

lower for overhead than drip in both years, 54.9 cm compared with 57.0 cm in 2011 and 80.0 cm compared to 82.7 cm in 2013. Assuming a water cost of $1.96 per cm, the cost of water is $5.11 per hectare lower for overhead than drip in 2013 and $3.84 per hectare lower in 2011. In addition, the irrigation labor is lower for overhead than drip ($143 per hectare) as is the system maintenance ($156 per hectare). The energy cost is higher for overhead ($114 per hectare). Summing the water, energy, irrigation labor, and system maintenance, the annual operating cost in 2011 for overhead is $785 per hectare and $983 per hectare for drip, $199 per hectare higher for drip. Similarly, in 2013 the difference was $196 per hectare higher for drip. Of course, the cost of water varies tremendously across growers. The installation costs of the systems themselves are estimated to be $217 per hectare for overhead and $583 per hectare for drip, a difference of $366 per hectare higher for drip than overhead. For 2011, the result is a total cost per hectare for irrigation of $880 for OH and $1,441 per hectare for drip or a difference of $561 per hectare per year more for drip in 2011. In 2013, the result is a total irrigation cost per hectare of $1,002 per hectare for overhead and $1566 for drip for a difference of $564 per hectare higher for drip.

The harvest cost varies with yield so that harvest costs per hectare increase with yield because of the additional costs of bags, boxes, grading, packing, loading, and hauling. As a result, harvest costs were higher in 2013 than 2011 for both systems as the yields were higher. The net returns are calculated as total revenue minus total costs. Both systems showed a positive net return except drip in 2013. The 2011 net returns were higher than in 2013 for both systems due to higher yields. The net returns for overhead and drip were comparable in 2011 ($2,826 per hectare and $2,643 per hectare, respectively), with OH showing a net return \$183 per hectare higher than drip despite slightly lower yields. This result is attributable to the fact that the revenue for drip is \$696 per hectare higher than overhead but the costs are \$880 per hectare higher for drip because of the higher irrigation and harvest costs. In 2013 the overhead yields were significantly higher than DR, 15.4 tons per hectare. Consequently, the gross revenue is \$2,979 per hectare higher for overhead than drip. The harvest costs are also higher for overhead but the irrigation costs are lower with a net effect of a higher cost of \$798 per hectare for overhead. The bottom line is higher net returns for overhead of \$2,182 per hectare in 2013 (\$2,073 per hectare for overhead compared with a loss of \$109 per hectare for drip).

Weed Biomass

Although weed biomass was sampled only once in this study, heavy weed pressure was observed in all the plots and required frequent hand weeding. Data taken in May 2011 showed that weed biomass was lower ($P = 0.02$) in the overhead than in the drip plots (68.7 vs. 204.4 g/m^2 in the drip and overhead plots, respectively).

In conclusion, this field study affirms the hypothesis that the alternative overhead irrigation system can successfully and efficiently produce onions in California's San Joaquin Valley. Furthermore, it demonstrates that overhead irrigation may be a viable means for reducing production costs.

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