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Drip Irrigation and Water Conservation in Onions; An Economic Analysis

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DRIP IRRIGATION AND WATER CONSERVATION IN ONIONS; AN ECONOMIC ANALYSIS

by

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of

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in

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ABSTRACT

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by

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Utah State University, 2024

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Water diversions for irrigated agriculture have contributed to increased water stress in drought prone areas across the globe. Previous research finds that farmers increase irrigation intensity per unit of product grown, increase total area under irrigation, and switch to more water intensive crops to increase yields and compensate for the cost of drip irrigation installation. Other studies have shown that drip irrigation can produce yields that parity surface irrigated yields or even surpass them using less water and increasing profits. Ultimately this plot trial showed drip irrigated onion yields were 6.31% greater than surface irrigated onion yields using an average of 61.46% less in water diversions. A Monte Carlo analysis conducted on yield and price found drip irrigated onions had a mean yield per acre of 25,434 pounds, a mean return of $13,134 and a median return of $8,711 while surface irrigated onions had a mean yield per acre of 22,193 pounds, a mean return of $23,416 and a median return of $7,994. Drip onions had a standard deviation of $24,665 and surface irrigated onions had a standard deviation of $127,427. Similar to Halvorsen et al., Enciso et al., Gupta et al., Naravanamoorthy et al., and Jha et al. papers, greater yields were found in drip irrigated onions than surface irrigated onions. Further studies are needed to investigate the efficacy of drip irrigation as a viable water conservation tactic in the arid west.

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INTRODUCTION

Droughts have become more commonplace and continue to wreak havoc across the western United States and other parts of the world. As water stress increases, different methods to tackle water consumption are evaluated. Many methods are directed at the water consumption in irrigated agriculture since it accounts for a majority of worldwide water use. Among water conservation methods in agriculture, drip irrigation has been heavily investigated. Theoretically drip irrigation should decrease water consumption through targeted, efficient watering. Studies, however, have found compensative behavior can increase total water consumption under drip irrigation. This raises the issue that drip irrigation may not be a viable water conservation method unless other factors are taken into consideration.

The purpose of this study is to investigate the economic efficacy of drip irrigation and the efficacy of drip irrigation as a potential water conservation tactic. In order for drip irrigation to be considered a viable solution, it must be able to produce yields that are greater than or equal to yields of surface irrigated onions while using less water and increasing profits. Producing yields greater than surface irrigated onions while using less water would show the economic viability of drip irrigation as an increase in yield translates to an increase in farm profits. These increased profits, however, would need to more than offset the install costs of the drip tape. Producing yields equal to surface irrigated onions while using less water would show the possible viability of drip irrigation as a water conservation method if installation were to be subsidized.

There are a couple questions this study aims to answer. Can drip irrigated onions produce an increased yield compared to surface irrigated onions? Can drip irrigation be implemented and use less water than traditional surface irrigation? Can drip irrigated onions produce an increased net profit compared to surface irrigated onions? It is hypothesized that greater onion yields and profit can be found in drip irrigated onions than surface irrigated onions using less water.

Some basic assumptions can be made about this study. One assumption is that the sensors set up to measure field irrigation inflow, field irrigation outflow, soil moisture, and soil temperature were accurate and reflective of the entire area measured. Another assumption is that the yield measurements were accurate and reflective of the area studied. Additionally, it is assumed that Weber County and Box Elder County are similar enough in climate to be compared against each other. It is also assumed that the water budget equation used fully reflects water use and infiltration. It is also assumed the data used for the economic analysis from outside sources is legitimate and similar to data that was-not or could-not-be collected from the original plot trial.

There are some limitations when it comes to this study. One limitation in this study is that it was conducted in the arid west and conclusions from this study may not be easily carried across different regions. Another limitation is the overall sample size of this study. The greater the size, the more accurate analysis would be. Additionally, the lack of water pressure compensating emitters may affect the ability for the drip tape to evenly distribute water across each field.

This research is significant because it will contribute to a body of work on drip irrigation. The implications of this study may contribute to the adoption of drip irrigation in arid regions for the purpose of conserving water, increasing profits, or both. It may also be concluded that drip irrigation is a candidate for governmental subsidization in the water conservation space if yields are not substantial enough to compensate for the cost of drip tape installation, but considerable water use reduction is achieved.

LITERATURE REVIEW

Irrigated agriculture has become a contentious point of water conservation. Global water scarcity has intensified placing higher pressure on agriculture since it accounts for more than 70% of water usage worldwide (Zilberman et al., 2017). On top of that, irrigated agriculture increased by more than 76% since 1970 (Zilberman et al., 2017). This stark increase is due to irrigated agriculture yields outproducing precipitation reliant agriculture yields by two to four times (Zilberman et al., 2017). Water conservation in agriculture is important and necessary. Many attempts have been made to increase water conservation through different mechanisms including federal policy, region-specific policy, and the implementation of irrigation technologies such as drip irrigation.

Governments have many objectives when it comes to agricultural management. Some of these objectives include providing resources such as water and land, expanding total agricultural production, providing affordable and safe food to the public, and protecting the environment. As time passes and available resources surge and dwindle, different objectives hold various priorities over time. The changing priorities of the United States government has had an impact on water conservation that spans hundreds of years.

In the 1800s the government prioritized agricultural expansion due to the high demand of agricultural products and the abundance of land and water. This led to the homestead act which set a precedent of putting a resource to use in order to claim it (Zilberman et al., 2017). Water laws soon mimicked the homestead act with the prior appropriation doctrine. The doctrine of prior appropriation served the priority of expanding agricultural land at the expense of water use efficiency and overall water conservation (Wescoat, 1985). This use-it-or-lose-it policy did not incentivize farmers to conserve water, rather, it encouraged farmers to use their full allowances regardless of if they were needed or not (Wescoat, 1985).

In the 1900s the acreage of agricultural cropland peaked, and the objective of increasing farmland efficiency became top priority (Zilberman et al., 2017). Some efficiency measures such as sprinkler irrigation and canal lining were adopted at low rates due to the fear their potential reduction in water use would lead to the loss in water rights (Wescoat, 1985). The goal to increase farmland efficiency also led to a vast expansion into federal water projects which proved to be monetarily intensive and economically inefficient whilst ignoring the water conservation problem (Zilberman et al., 2017).

In the 1990s and early 2000s environmental side effects started to be taken into account when proposing governmental projects, this served as a turning point in water conservation prioritization. Large legislative changes that prioritize water conservation have followed major droughts. After the 1987-1991 drought, ten percent of the Central Valley Project water was reallocated to environmental purposes (Zilberman et al., 2017). After the 2011-2015 drought, the Sustainable Groundwater Management Act was introduced, monitoring and reducing the amount of groundwater pumped (Zilberman et al., 2017).

While governmental policies often achieve the intended objective, there are several unintended consequences produced by the policy. Often times these externalities directly affect lower prioritized objectives such as water conservation. Since the introduction of water conservation policies, water in agriculture has been used more efficiently but it has not necessarily reduced water consumption (Grafton et al., 2018). In addition, conservation policies have been reactionary in nature and may be working as more of a band-aid than a solution. For these reasons, it appears federal policy alone might not achieve sufficient water conservation levels.

The United States is a large country comprised of many different climates. These climates dictate the growth of different crops and in turn use various irrigation systems. Some of the irrigation systems used across the United States include center pivot sprinkler irrigation, drip irrigation, flood irrigation, furrow irrigation, moveable sprinkler irrigation, and bog irrigation (Wallander, 2017). The creation of a single federal policy to promote water conservation across the diversely irrigated country becomes extremely difficult.

This problem has been addressed by the U.S. Department of Agriculture’s Environmental Quality Incentives Program (EQIP). EQIP promotes region-specific irrigation technology to promote water conservation. This program divides the United States into five regions: the Midwest/Northeast, the Southeastern Coastal Aquifers, the Southern Alluvial Aquifers, the Central Plains, and the Mountain West (Wallander, 2017). The regions were divided based on factors such as climate, soil, crop choice, water supply, and irrigation technology.

Among these regions, cropland is irrigated by a mix of direct precipitation, surface water allocation, and groundwater. The proportion of the irrigation source varies widely by region. The reliability of each source is different with direct precipitation being the least reliable to groundwater being the most reliable (Wallander, 2017). The rising significance of groundwater in proportion to other irrigation sources and groundwater’s reliability through years of drought has begun to quickly deplete aquifers beyond rechargeable rates. This has created a need for greater efficiency in irrigation.

Irrigation efficiency technology adoption is one of the main goals of EQIP. The program gives financial assistance to farming operations that invest in water saving technology that is optimal for the given region. For example, the irrigation practices most commonly supported by EQIP in the Mountain West are micro and drip irrigation.

In contrast, the High Plains region focuses mostly on low pressure sprinkler irrigation that minimizes water evaporation loss (Wallander, 2017).

While EQIP has found success in transitioning previous irrigation systems to more efficient systems, it has caused unintended consequences. The efficiency of water on irrigated agricultural land has increased which means the marginal cost per unit of water used by the crop has decreased. This has resulted in compensative behavior such as increasing the acreage of irrigated land or the switching to more water intensive crops (Wallander, 2017). Programs and technology that increase water use efficiency don't necessarily lead to water conservation and, conversely, often lead to more water consumption (Grafton et al., 2018). One example can be found in India where the goal was to reduce groundwater demand by increasing water efficiency. India provided subsidization programs to farmers in Rajasthan which doubled the area irrigated under drip irrigation from 2010 to 2015 (Birkenholtz, 2017). As a result, farmers reduced fallow times, increased production per unit area, and increased the total area under irrigated production (Birkenholtz, 2017). While this improved farm income and yields, it resulted in an overall increase in water volume, the opposite of the intended effect (Birkenholtz, 2017).

Another example can be found in the Rio Grande Valley where subsidies on overall water depletion were analyzed. Ward & Pulido-Velazquez showed that subsidies do indeed encourage adoption of more water efficient technologies such as drip irrigation (2008). This study found that as subsidies increase, the ratio of water depletion to stream diversion increases from 61% to 80% under full subsidy (Ward &

Pulido-Velazquez, 2008). Under these conditions farm profits and yields both increased, as did total irrigated acres of production and subsequently total water depletion (Ward & Pulido-Velazquez, 2008).

In yet another example, the effects of subsidization of water efficiency technologies such as drip irrigation on water depletion were observed in the Tensfit and Souss areas of Morocco. In less than a decade, subsidies for drip irrigation increased from 17% to 80-100% with the intention of a reduction in the overexploitation of aquifers, a reduction of overall water use, an increase in farm yields, and an increase in farm profits (Molle & Tanouti, 2017). This resulted in farmers converting to more water-intensive crops, densifying orchards with already intensive irrigation needs, and expanding the total area under irrigation (Molle & Tanouti, 2017). While the subsidization increased yields and profits for many farmers, it also increased the overexploitation of aquifers and increased overall water use by an average of 20% (Molle & Tanouti, 2017).

Vast literature on the increase in overall water usage when converting to technologies implementing a greater irrigation efficiency such as drip irrigation begs the question; how can drip irrigation be used to promote water conservation and decrease total water use in crop production? One strategy explored is the implementation of deficit irrigation, the intentional application of less irrigation water than the full plant requirement resulting in less than maximum evapotranspiration (Trout et al., 2020). This strategy focuses more on water reduction and water use efficiency than yield optimization (Trout et al., 2020). Though the goal is frequently defined as yield stabilization under less use of water, deficit irrigation can come at the expense of overall yields and, consequently, farm profits (Trout et al., 2020).

A study conducted in New Mexico's Mesilla Valley analyzed irrigation efficiency, yield, and economic return under base and deficit irrigation conditions for three different types of irrigation systems: sprinkler, furrow, and drip (Al-Jamal et al., 2001). The base irrigation efficiencies under sprinkler, drip, and furrow irrigation were 80, 77, and 82% respectively. The deficit irrigation efficiencies under sprinkler, drip, and furrow irrigation were 54, 45, and 79% respectively (Al-Jamal et al., 2001). Though sprinkler irrigation had the higher irrigation efficiency of the three, it also used the most water overall (Al-Jamal et al., 2001). While drip irrigation had lower irrigation efficiencies under base and deficit irrigation conditions, it also had higher yields than sprinkler and furrow under both base and deficit irrigation (Al-Jamal et al., 2001). Though yields were greater under drip irrigation, it was not economically efficient under deficit irrigation conditions (Al-Jamal et al., 2001). For this reason, deficit irrigation may not be the best tactic when trying to conserve water with drip irrigation.

Another strategy used to promote water conservation while increasing irrigation efficiency is the use of more detailed water accounting budgets (Grafton et al., 2018). Water accounting involves more scrutiny on the inflows and outflows of water at both basin and watershed levels (Grafton et al., 2018). The use of technology such as remote soil sensors can aide in the estimation of water inflows, consumption, and recoverable and non-recoverable return flows (Grafton et al., 2018). Water accounting budgets will allow for a more accurate analysis on water depletion and the evaluation of whether irrigation efficiency policies are within public interest or not (Grafton et al., 2018).

A study conducted in Colorado's Arkansas River Valley used sensor technology and water accounting to analyze the conversion from furrow to drip irrigation and its effect on overall water usage, irrigated water use efficiency, and yield in onions. In the first year of this two-year experiment, the drip irrigated onions saw a total gross application of 68.6 cm over 20 irrigation periods while the furrow irrigated onions saw a total gross application of 243.8 cm over 13 irrigation periods (Halvorson et al., 2008). The second year of the experiment, the drip irrigated onions saw a total gross application of 87.9 cm over 17 irrigation periods while the furrow irrigated onions saw a total gross application of 202.7 cm over 12 irrigation periods (Halvorsen et al., 2008). The average yield over both years produced a statistically significant increase in the yield of drip irrigated onions, 91.9 Mg ha^{-1}, compared to that of the furrow irrigated onions, 79.9 Mg ha^{-1} (Halvorson et al., 2008). This also led to the irrigated water use efficiency of onions under drip irrigation to be greater than that of furrow irrigated onions at a statistically significant level (Halvorson et al., 2008).

Another study using a water accounting budget was conducted in Los Ebanos and Weslaco, Texas analyzed total water use, irrigation efficiency, and yield in onions under drip and furrow irrigation. The first year of the experiment, total water demands for the crop were calculated at 409mm with 359mm being applied over 17 irrigation periods for the drip irrigated onions and 677mm being applied over 6 irrigation periods for the furrow irrigated onions (Enciso et al., 2015). This resulted in an irrigation efficiency of 88.5% for drip irrigation compared to 54.1% for furrow, and a yield approximately 119% higher for drip irrigated onions (Enciso et al., 2015). The second year of the experiment, total water demands for the crop were calculated at 411mm with 211mm being applied over 14 irrigation periods for the drip irrigated onions and 318mm being applied over 5 irrigation periods for the furrow irrigated onions (Enciso et al., 2015). This resulted in an irrigation efficiency of 81.4% for drip irrigation compared to 67.1% for furrow, and a yield approximately 95% higher for drip irrigated onions (Enciso et al., 2015).

A water accounting budget study was conducted during two seasons in Nashik, India to analyze overall water use, yield, and water use efficiency in onions under drip and furrow irrigation. In the first season, 60.29cm ha^{-1} of water were applied to the drip irrigated onions and 85.35cm ha^{-1} were applied to the furrow irrigated onions resulting in a gross increased yield of 13.64% for drip irrigated onions (Gupta et al., 2018). Additionally, drip irrigation resulted in a 17.49% increase in A grade bulbs, a 10.51% increase in B grade bulbs, and an increase in water use efficiency of 60.87% for the first season (Gupta et al., 2018). In the second season, 55.65cm ha^{-1} of water was applied to the drip irrigated onions and 76.35cm ha^{-1} was applied to the furrow irrigated onions resulting in a gross increased yield of 14.27% for drip irrigated onions (Gupta et al., 2018). Additionally, drip irrigation resulted in an 81.24% increase in A grade bulbs, a 5.94% increase in B grade bulbs, and an increase in water use efficiency of 56.79% for the second season (Gupta et al., 2018).

Ultimately, farmers respond to incentives, and they will only install drip irrigation if it is economically advantageous to do so. A farmer in Tamil Nadu, India conducted an economic study on drip irrigated vegetable production and showed just that. When comparing drip irrigation to surface irrigation, it was found that there was a 40% savings in water, 31% savings in fertilizer, and 629 kwh/acre savings in electricity (Narayanamoorthy et al., 2018). There ended up being 52% increase in crop yield and 54% higher net returns using drip irrigation (Narayanamoorthy et al., 2018).

Another economic study of vegetable production was conducted in the Eastern Plateau and Hill Region of India. Comparing drip irrigation to surface, the drip system increased yields, increased water application efficiency, reduced labor costs, reduced fertilizer application, and led to higher returns (Jha et al., 2017). Net returns for drip irrigated tomatoes were 145,358 Rs ha^{-1}, net returns for drip irrigated potatoes were 86,422 Rs ha^{-1}, net returns for cauliflower were 198,336 Rs ha^{-1}, net returns for drip irrigated French beans were 43,786 Rs ha^{-1}, and net returns for peas were 84,343 Rs ha^{-1} (Jha et al., 2017). In contrast the net returns under furrow irrigation were 63,912 Rs ha^{-1} for tomatoes, 39,562 Rs ha^{-1} for potatoes, 102,636 Rs ha^{-1} for cauliflower, 13,312 Rs ha^{-1} for French beans, and 25,203 Rs ha^{-1} for peas (Jha et al., 2017).

The last example also found profits in an economic analysis on drip irrigation in vegetable production in Turkey. Under drip irrigation the net returns for tomatoes were $6,960 and the net returns of peppers were $7,614 (Kuscu et al., 2009). The net returns for green beans under drip irrigation was $3,436 and the net returns for eggplant was

$6,188 (Kuscu et al., 2009). These examples show there can be alignment between conserving water and making greater profits with drip irrigation.

There have been many attempts to increase water conservation across the United States without avail. In the past, federal policies exacerbated water scarcity and only prioritized water conservation as a reactionary measure after major drought periods. Even after these policies were implemented, the success of water use efficiency did not necessarily translate into water conservation. While regional focus was very effective at transitioning and adopting water-saving technology across the country, it also was not successful in increasing water conservation, it instead created unintended consequences of compensative behavior. This compensative behavior includes switching to more water intensive crops, increased intensification on crops, and increased overall acres under irrigation causing net increases in water depletion. In order to meet the goal of water conservation using drip irrigation technology, tactics such as depletion irrigation or the use of water accounting budgets must be used. Only then can increased yields and farm profits be properly balanced against water depletion and public interest.

METHODS

This study was conducted in years 2019 and 2020 to evaluate consumptive water use and yield in onions under drip and surface irrigation. In the attempt to accurately measure the study's objectives, this paper will only be evaluating the 2020 portion of the study due to the fact the 2019 study compared drip and surface irrigated onions of different varieties (Joaquin and Garnero) and the plant and harvest dates differed by up to a month.

Four fields comprised the 2020 northern Utah onion study: drip irrigation in Weber County (Field 1), surface irrigation in Weber County (Field 2), drip irrigation in Box Elder County (Field 3), and surface irrigation in Box Elder County (Field 4). In an attempt of greater uniformity than the 2019 study, all fields were planted between March 21^{st}-25^{th}, harvested between September 2^{nd}-5^{th}, and used the Hamilton variety of onion. In the drip irrigated fields, drip tape was placed two to three inches below the soil surface in the furrow.

Measurements collected in this study were field irrigation inflow, field irrigation outflow, soil moisture, soil temperature, yield. A field irrigation inflow meter was installed in each of the four fields and a field irrigation outflow meter was installed on each of the surface irrigated fields. There were three water measurement stations in each of the four fields. Each station had 10 soil temperature and water sensors taking readings every 30 minutes. Yield was measured by onion size and weight at the time of harvest.

The study used a water accounting budget characterized by the equation:

ET = irrigation + precipitation + groundwater contribution – deep percolation ± change in soil moisture

Irrigation was measured using rain gauges, flow meters, and soil water sensors. Precipitation was measured using rain gauges. Groundwater contribution, deep percolation, and change in soil moisture were all measured using soil moisture sensors.

Other sources were used to conduct the economic analysis. The water and drip system costs come from a California drip corn budget. The water cost was estimated at $93 per acre for the drip irrigated onions and $128 per acre for the surface irrigated onions (Oregon State University, 2022). The drip system and technology were estimated at $42 per acre and the drip lines were estimated at $28 per acre per (Oregon State University, 2022). Both the labor time and labor cost came from the farmers in the plot trials. Labor costs was $20 an hour and was 75 minutes an acre for drip and 100 minutes an acre for surface irrigated onions. Monthly onion pricing from December of 2018 to December of 2023 was collected from releases of AMS' National Potato and Onion Report (USDA, 2023).

Using these inputs, the program @RISK was used to perform a ten thousand draw Monte Carlo simulation on yield and on price. This program uses the input data to determine the best fit distribution for each variable (in this case marketing size), then uses the best fit distribution to project possible outcomes within a degree of certainty. Net present value per acre curves were then constructed for drip and surface irrigated onions and stacked for comparison.

RESULTS

As seen in Figure 1, irrigation application was 19.8 inches for Field 1, 64.5 inches for Field 2, 25.1 inches for Field 3, and 52 inches for Field 4. Irrigation application was the total amount of water applied to each field of onions. Irrigation consumptive use was 19.8 inches for Field 1, 26.1 inches for Field 2, 24 inches for Field 3, and 25.1 inches for Field 4. Irrigation consumptive use is the irrigation application minus the soil water depletion. Total consumptive use was 24.3 inches for Field 1, 28.8 inches for Field 2, 26.7 inches for Field 3, and 27.8 inches for Field 4. Total water consumptive use is irrigation application plus precipitation minus soil water depletion. The surface irrigated fields had a higher water consumptive use of 1.1-4.5 inches.

Figure 1

Irrigation Application, Irrigation Consumptive Use, and Total Consumptive Use on Drip and Surface Irrigated Fields

Field	Irrigation Method	Irrigation Application (in.)	Irrigation Consumptive Use (in.)	Total Consumptive Use (in.)
Field 1	Drip	19.8	19.8	24.3
Field 2	Surface	64.5	26.1	28.8
Field 3	Drip	25.1	24	26.7
Field 4	Surface	52	25.1	27.8

Yields were measured in pounds per acre and categorized by size. Onions two-and-a-quarter to three inches were classified as Medium, onions three to three-and-a-half inches were classified as Jumbo. Onions three-and-a-half to four inches in diameter were classified as Colossal and onions greater than four inches were classified as Super Colossal.

Figure 2

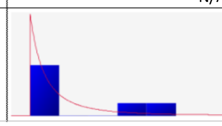
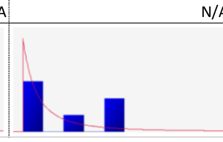
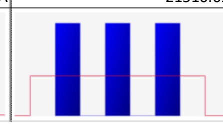
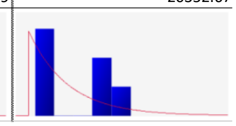
Field Level Pounds Per Acre Yield by Marketing Size

	Field 1	Field 2	Field 3	Field 4	Drip Avg	Surface Avg
Super Colossal avg lbs/acre	-	26,111	40,705	6,181	20,353	16,146
Colossal avg lbs/acre	20,576	54,928	49,294	21,582	34,935	38,255
Jumbo avg lbs/acre	49,616	28,444	15,289	27,247	32,453	27,845
Medium avg lbs/acre	12,609	5,957	4,467	10,679	8,538	8,318

Figure 2 contains the average yield observations from the plot trial organized by field and averaged by irrigation type. Drip irrigated onions measured more pounds per acre than surface irrigated onions in the Super Colossal, Jumbo, and Medium sizes. Total drip average from the plot trial was 24,070 pounds per acre and the total surface average was 22,641 pounds per acre. These observations were then used as inputs for the Monte Carlo simulation.

Figure 3

Simulated Drip Onion Yield by Marketing Size

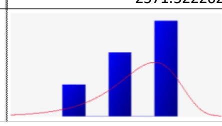
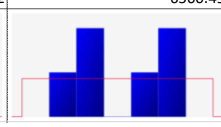
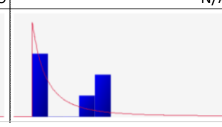
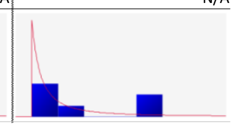
Name	Medium	Jumbo	Colossal	Super Colossal
Range	Yield lbs. acre!D26:D32	Yield lbs. acre!E26:E32	Yield lbs. acre!F26:F32	Yield lbs. acre!G26:G32
Best Fit (Ranked by AIC)	RiskPareto(1.7459,3946)	RiskPareto(1.5041,13999)	RiskUniform(-3500,71036)	RiskExpon(20352,RiskShift(-339
Function	4116.598568	146160.4546	29746.87849	71026.29546
AIC	119.5514	137.6409	142.6285	141.0516
Minimum	3946	13999	-3500	-3392.11
Maximum	+∞	+∞	71036	+∞
Mean	9236.185	41770.05	33768	16960.56
Mode	3946	13999	-3500	-3392.11
Median	5869.177	22194.15	33768	10715.28
Std. Deviation	N/A	N/A	21516.69	20352.67
Graph				

Correlation	Medium	Jumbo	Colossal	Super Colossal
Medium	1.000			
Jumbo	0.696	1.000		
Colossal	-0.928	-0.486	1.000	
Super Colossal	-0.647	-0.880	0.455	1.000

As seen in Figure 3, @RISK used the plot trial yields to simulate drip irrigated onion yields. Medium onions were simulated using a Pareto distribution, had a mean yield of 9,236 pounds per acre, had a median yield of 5,869 pounds per acre, and were strongly negatively correlated with Colossal yields. Jumbo onions were simulated using a Pareto distribution, had a mean yield of 41,770 pounds per acre, had a median yield of 22,194 pounds per acre, and were strongly negatively correlated with Super Colossal yields. Colossal onions were simulated using a Uniform distribution, had a mean yield of 33,768 pounds per acre, and had a median yield of 33,768 pounds per acre. Super Colossal onions were simulated using an Exponential distribution, had a mean yield of 16,960 pounds per acre, and a median yield of 10,715 pounds per acre.

Figure 4

Simulated Surface Onion Yield by Marketing Size

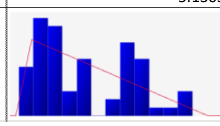
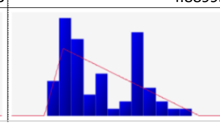
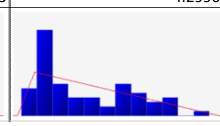
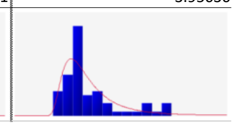
Name	Medium	Jumbo	Colossal	Super Colossal
Range	Yield lbs. acre!D34:D40	Yield lbs. acre!E34:E40	Yield lbs. acre!F34:F40	Yield lbs. acre!G34:G40
Best Fit (Ranked by AIC)	RiskExtValueMin(9567.7446,20	RiskUniform(16187,38913)	RiskPareto(1.7864,19602)	RiskPareto(0.88905,3798)
Function	7343.267951	35890.03459	32710.87387	7975.241331
AIC	118.7216	128.3753	138.3556	133.8155
Minimum	−∞	16187.4	19602	3798
Maximum	+∞	38913.6	+∞	+∞
Mean	8410.422807	27550.5	44528.12	N/A
Mode	9567.74465	16187.4	19602	3798
Median	8832.883428	27550.5	28894.3	8282.32
Std. Deviation	2571.522262	6560.49	N/A	N/A
Graph				

Correlation	Medium	Jumbo	Colossal	Super Colossal
Medium	1.000			
Jumbo	0.200	1.000		
Colossal	-0.886	-0.257	1.000	
Super Colossal	-0.943	-0.371	0.943	1.000

As seen in Figure 4, @RISK used the plot trial yields to simulate surface irrigated onion yields. Medium onions were simulated using an Extreme Value Min distribution, had a mean yield of 8,410 pounds per acre, had a median yield of 8,832 pounds per acre, and were strongly negatively correlated with Colossal and Super Colossal yields. Jumbo onions were simulated using a Uniform distribution, had a mean yield of 27,550 pounds per acre, and had a median yield of 27,550 pounds per acre. Colossal onions were simulated using a Pareto distribution, had a mean yield of 44,528 pounds per acre, had a median yield of 28,894 pounds per acre, and were strongly correlated with Super Colossal yields. Super Colossal onions were simulated using a Pareto distribution, did not have a mean yield, and had a median yield of 8,282 pounds per acre.

Figure 5

Simulated Onion Price by Marketing Size

Name	Super Colossal	Colossal	Jumbo	Medium
Range	Onion Price!B2:B65	Onion Price!C2:C65	Onion Price!D2:D65	Onion Price!E2:E65
Best Fit (Ranked by AIC)	RiskTriang(5.6527,7.5000,28.28	RiskTriang(4.5755,7.2500,26.52	RiskTriang(4.3992,6,23.386)	RiskPearson5(4.4060,20.902,Ris
Function	19.317558	17.08906856	22.90125702	8.563669074
AIC	370.189	362.7891	343.6723	302.7478
Minimum	5.65268	4.57549	4.39917	2.7748
Maximum	28.2835	26.52926	23.38596	+∞
Mean	13.81206	12.78492	11.26171	8.91166
Mode	7.5	7.25	6	6.64128
Median	12.94812	11.98188	10.53871	7.90099
Std. Deviation	5.1303	4.88993	4.29901	3.95636
Graph				

Correlation	Super Colossal	Colossal	Jumbo	Medium
Super Colossal	1.000			
Colossal	0.983	1.000		
Jumbo	0.961	0.982	1.000	
Medium	0.502	0.590	0.651	1.000

As seen in Figure 5, @RISK used USDA's AMS prices to simulate price by marketing size. Medium onion prices were simulated using a Pearson distribution, had a mean price of $8.91, and had a median price of $7.90. Jumbo onion prices were simulated using a Risk Triangle distribution, had a mean price of $11.26, had a median price of $10.54, and was strongly correlated with Colossal and Super Colossal prices. Colossal onion prices were simulated using a Risk Triangle distribution, had a mean price of $12.78, had a median price of $11.98, and were strongly correlated with Super

Colossal and Jumbo prices. Super Colossal onion prices were simulated using a Risk Triangle distribution, had a mean price of $13.81, had a median price of $12.95, and were strongly correlated with Colossal and Jumbo prices.

Figure 6

Simulated Drip and Surface Net Profit Per Acre

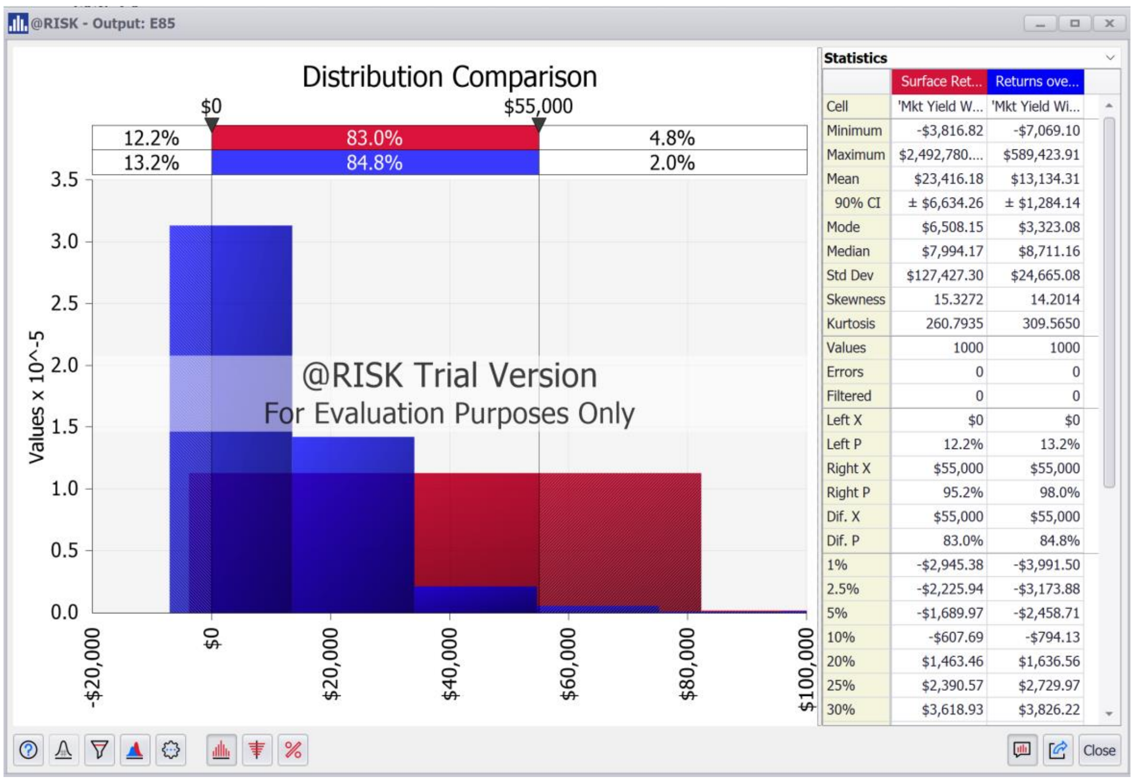


Figure 6 shows the simulated net present value of both drip and surface irrigated onions. The net present value was between zero dollars an acre and fifty-five thousand dollars 84.8% of the time in drip irrigated onions and 83% of the time in surface irrigated onions. Drip onions had a mean NPV of $13,134, a median NPV of $8,711, and a standard deviation of $24,665. Surface onions had a mean NPV of $23,416, a median NPV of $7,994, and a standard deviation of $127,427.

DISCUSSION

The findings of this study confirm the hypothesis that greater onion yields can be found in drip irrigated onions than surface irrigated onions using less water, however a greater average NPV was not found. The observed drip yield from the experiment was 6.31% greater than surface onions and the simulated drip yield was 14.6% greater than surface onions. Drip irrigated onions used on average 9.89% less water than surface irrigated onions and decreased water diversions on average by 61.46%. While the simulated mean drip NPV was 44% lower than surface, the median drip NPV was 9% higher, and the drip standard deviation was just $24,665 compared to the surface standard deviation of $127,427. With such a large reduction in the standard deviation of returns, risk-averse farmers may be willing to overlook the decrease in average NPV.

Similar to the Halvorsen et al., Enciso et al., and Gupta et al. papers, greater onion yields in drip irrigation versus surface irrigation were found. Also, using a water accounting budget to encourage water conservation was achieved in this study. This analysis supports the theory that onion yields can reach parity with surface irrigated onions with lower irrigation diversions. Unlike in the Narayanamoorthy et al. and Jha et al. papers, greater average profits in drip irrigation versus surface irrigation were not found. However, this analysis supports the theory that drip irrigation can be profitable and attractive to risk-averse farmers.

There were some limitations when it came to this study including equipment functionality, measurement, and sample size. Although the goal was to apply an even amount of water across each field, this didn't always turn out to be the case. A drip irrigation system without pressure compensating emitters causes a different rate of water application across the field. This combined with clogged emitters can affect water uniformity which in turn affects yields. This can most easily be seen in Field 1 where there were no Super Colossal sized onions.

Measurement and sample size were also limitations to this study. Though there were three sensing stations with 10 sensors in each field, these were used to estimate field-level water consumptive use. This means one data point for water was used across each field even though it became evident that different parts of each field were receiving different amounts of water due to the pressure differential in the drip tape. Additionally, the small sample size collected may have limited the results of the experiment and as well as the Monte Carlo simulation.

The implications of this study are the need for more research into the economic viability of drip irrigation and the efficacy of drip irrigation as a water conservation tactic. While the drip irrigated onions diverted and consumed less water than that of surface irrigated onions, yields were only 6.31% larger and the average NPV was smaller. This highlights why the paradox of increased water use after implementing drip systems pointed out by Grafton et al. is prevalent. Farmers attempt to recoup costs of the drip irrigation systems with higher water application for significantly larger yields.

The 6.31% increase in yield combined with 61.46% decrease in water usage opens the possibility for drip irrigation to be considered as a water conservation method. The median NPV and dramatic reduction in the standard deviation of returns shows the possibility of drip irrigation being economically viable in Northern Utah. Consequently, further replication is needed to explore the increase in onion yields and profit while consuming less water than that of surface irrigated onions in the arid west. As more literature becomes available, a more complete decision on drip irrigation as independently economically viable or as a subsidized water conservation method can be made.

CONCLUSION

Continued water depletion in the arid, drought-ridden west has become an issue particularly in the agricultural sector. Efforts have been made to reduce water consumption using technologies such as drip irrigation. Without being combined with stringent water budget accounting, this often had the result of increasing water diversions. This research explored the question: Can drip irrigated onions produce an increased yield and profit compared to surface irrigated onions while using less water? It was found that average drip onion yields were larger while using less water, however farm profits were not greater.

In this study four fields were evaluated, two drip irrigated fields and two surface irrigated fields. Average water diversions were 22.45 acre-inches per acre for the drip irrigated fields and 58.25 acre-inches per acre for the surface irrigated fields. The average observed yield was 24,070 pounds per acre for the drip irrigated onions and 22,641 pounds per acre for surface irrigated onions in the plot trial. The average simulated yield 25,434 pounds per acre for the drip irrigated onions and 22,193 pounds per acre for surface irrigated onions in the simulation. Net profit was $13,134 per acre for the drip irrigated onions and $23,416 per acre for the surface irrigated onions.

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