Project Title: Evaluation of Drip Irrigation in Organic Spinach Production and Downy Mildew Management

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Abstract: This project is aimed at evaluating the viability of drip irrigation for organic spinach production and the management of spinach downy mildew. The experiment was conducted over two crop seasons (fall 2018 and winter 2019) at the UC Desert Research and Extension Center. Various combination of dripline spacing (three and four lines per 80-in bed) and installation depth (driplines on the soil surface and at the 1.5-in depth) was studied versus sprinkler irrigation as control treatment. A comprehensive data collection was carried out to fully understand the differences between the irrigation treatments.

Statistical analysis indicated a very strong evidence (P= 0.001) for an overall effect of irrigation system on spinach fresh yields. The results demonstrated a significant fresh yield difference between sprinkler irrigation and each of the drip irrigation treatments (P values of 0.0001 to 0.0009), while the number of driplines in bed had a considerable impact on the fresh yield. A wide range of yield reduction as resulted by using drip irrigation was observed (7% - 25% compared to sprinkler irrigation), which was likely due to use of irrigation and nutrient practices that were not optimized for drip-irrigated. The results revealed an overall effect of irrigation treatment on downy mildew, in which downy mildew incidence was lower in plots irrigated by drip following emergence when compared to sprinkler. The likely mechanism for this effect is reduction of leaf wetness under drip irrigation. For instance, during a 12-day period in November and December 2018, the total amount of time that the canopy experienced wetness in the sprinkler treatment was 24.3% more than that in the drip treatment. The preliminary conclusion of the project is that drip irrigation has the potential to produce organic spinach, conserve water, enhance the efficiency of water use, and manage downy mildew, but further work is required to optimize system design, the impacts of irrigation and nitrogen management practices in different soil types and climates, and strategies to maintain productivity and economic viability of spinach.

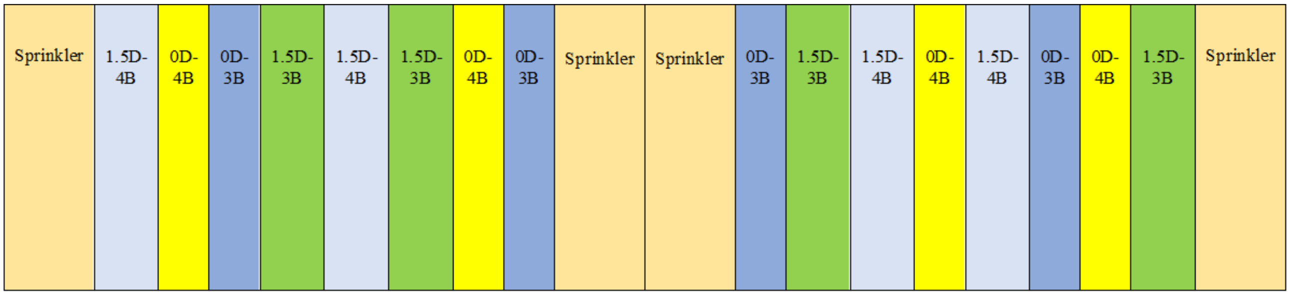
Objectives: The objective of this project was to evaluate the viability of adapting drip irrigation for organic spinach production. The project particularly aimed to understand the optimal dripline spacings and depth to successfully produce spinach, while to conduct a preliminary assessment on the impact of drip irrigation on the management of spinach downy mildew.

Procedures: The field experiments were carried out over two crop seasons at the UC Desert Research and Extension Center in a silty clay soil (UC DREC, Figure 1).

Fall 2018 experiment: Land preparation was started in late September, and untreated Viroflay spinach seeds were planted at a rate of 33 lbs. per acre on October 31st. For the research trial (Figure 2), five irrigation system treatments consist of two drip depths (driplines on the soil surface and driplines at the 1.5-in depth), two dripline spacings (three driplines on an 80-in bed and four driplines on an 80-inch bed), and sprinkler irrigation (80-in bed). The experiment was arranged in a randomized complete block with four replications. Each drip replication had three beds and each sprinkler replication had five beds to use two sprinkler laterals for irrigation (providing a better water distribution uniformity). The beds were 200 feet long. All treatments were germinated by sprinklers (two sets of five-hour irrigations).

Figure 1. Planting spinach seeds at the experimental field (planter and crew provided by Jack Vessey)

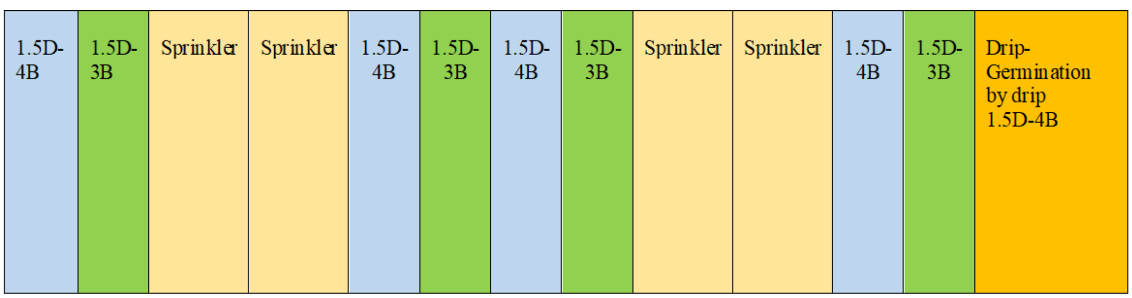
True 6-6-2 (a homogeneous pelleted fertilizer from True Organic Products) was applied at a rate of 80 lbs. of N per acre as pre-plant fertilizer, and True 4-1-3 (a liquid fertilizer from True Organic Products) was applied as complementary fertilizer through injection into irrigation system. For the drip treatments, True 4-1-3 was applied three times after germination (through crop harvest) at a rate of 40, 30, and 40 lbs. of N per acre. This liquid fertilizer was applied at a rate of 50, 38, and 45 lbs. of N per acre for sprinkler irrigation system. Following crop ET and using soil moisture data, it was tried to irrigate spinach trials more than crop water requirements to make sure there is no water stress the entire crop season, however this led to over-irrigation at some points in early and mid- crop season according to our data.



Sprinkler: treatment irrigated by sprinklers
1.5D-3B: treatment with three driplines in each bed installed at 1.5 in. depth
1.5D-4B: treatment with four driplines in each bed installed at 1.5 in. depth
0D-4B: treatment with four driplines in each bed on soil surface
0D-3B: treatment with three driplines in each bed on soil surface

Figure 2. Fall field experiment layout (not to scale)

Winter 2019 experiment: Untreated Viroflay spinach seeds were planted at a rate of 34 lbs. per acre on January 28th. For the research trial (Figure 3), three irrigation system treatments consisted of two dripline spacings (three driplines on an 80-in bed and four driplines on an 80-in bed), and sprinkler irrigation (80-in bed). All driplines were installed at the 1.5-in depth. The experiment was arranged in a randomized complete block with four replications. Each drip and sprinkler replication had three beds. The beds were 200 feet long. All treatments were germinated by sprinklers (two set of five-hour sprinkler irrigation). In addition, six beds located in the south side of the trial were germinated and irrigated the entire crop season by drip irrigation (four driplines in 80-in bed).



Sprinkler: treatment irrigated by sprinkler
1.5D-3B: treatment with three driplines in each bed installed at 1.5 in. depth
1.5D-4B: treatment with four driplines in each bed installed at 1.5 in. depth

Figure 3. Winter field experiment layout (not to scale)

True 6-6-2 was applied at a rate of 70 lbs. of N per acre as pre-plant fertilizer, and True 4-1-3 was applied as complementary fertilizer through injection into irrigation system. For the drip system, True 4-1-3 was applied four times after germination (by crop harvest) at a rate of 30, 40, 30, and 40 lbs. of N per acre. This liquid fertilizer was applied at a rate of 40, 40, 45, and 40 lbs. of N per acre for sprinkler irrigation system.

Flow control drip tape of Toro company was used for the both trials with a hose diameter of 5/8-inch, wall thickness of 6 mil, emitter spacing of 8-inch, and emitter flowrate of 0.13 gph (@8 psi).

Field measurements: The actual crop ET (evapotranspiration) was measured using Tule Technology sensor (www.tuletechnologis.com). Using the actual crop water use data measured and spatial CIMIS data (http://wwwcimis.water.ca.gov/SpatialData.aspx), the actual crop coefficient curves was developed for each crop season. Images were taken on weekly basis utilizing an infrared camera (NDVI digital camera) to quantify the development of the crop canopy of each treatment. NDVI assigns for Normalized Difference Vegetation Index, a measurement of plant health. A combination of Watermarks and Decagon 5TE sensors were installed at three depths to monitor soil moisture on a continuous basis. The applied water for the irrigation treatments was measured throughout the crop season using a magnetic flowmeter. and plant leaf wetness values were measured using Spectral Reflectance Sensors and dielectric leaf wetness sensors, respectively, from Meter Group Company on a continuous basis. Leaf chlorophyll and SPAD were measured with atLEAF CHL STD sensor.

Yield biomass measurements at the final harvests were carried out in three sample areas of 6 ft^2 (3 ft × 2 ft) per replicate and treatment. The bed located in the center of each replication in each of the treatments was selected as the sample bed (four sample beds per each treatment, for a total of 20 sample beds in the fall trial and 14 sample beds in the winter trial). Fresh weight was measured in order to determine biomass accumulation. The statistical significances were performed using general linear mixed model in SAS statistical analysis package.

Downy mildew scouting: Both replicate runs of the experiment were visually scouted by walking down arbitrarily selected rows of all treatments. When disease symptoms were observed, the number of plants exhibiting downy mildew symptoms was counted by walking down one side of the bed. Due to overall low disease incidence, the entirety of the bed was counted. Two of the three beds in each plot were rated. To calculate disease incidence, or the percentage of plants affected by downy mildew, the number of plants in each bed was divided by the estimated plant population. The estimated plant population was determined from the seeding rate and the germination rate averaged over each treatment at emergence. Disease incidence was analyzed using a generalized linear mixed model in SAS. Plots that were germinated by drip were excluded from analysis because they had an insufficient number of replications and were not randomized among plots with other treatments.

Results and Discussion

Air temperature and relative humidity: The daily air temperature and relative humidity variations were different over the fall and the winter experiments (Figure 4). At the fall trial, we observed a mean daily air temperature of 63 ^{o}F at the early – and - mid-season when the temperature stayed above 40 ^{o}F during nights. The mean daily temperature decreased to 58 ^{o}F at the late season and relative humidity dramatically increased over the last 10 days before final harvest.

While more variable air temperature was observed at the winter experiment, the mean daily temperature was 55 ^{o}F during the first two weeks after planting and the temperature fell below 37 ^{o}F in a couple of nights. A higher day-time air relative humidity than the fall trial was observed during early- and mid-season at the winter trial.

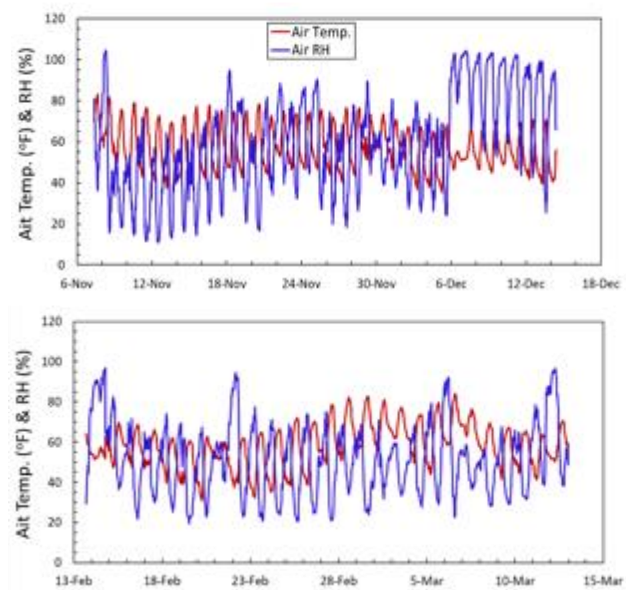


Figure 4. Daily air temperature and relative humidity variations, fall season (top) and winter season (bottom)

Canopy crop over the season: Ground crop cover is defined as the percentage of plant material which covers the soil surface and can be very useful tool in irrigation scheduling. Here, the canopy cover percentage was developed for each of the irrigation treatments (Figure 5). Even though there were not accurate measurements of canopy cover during the first 10-15 days after planting, the canopy cover percentages show that the leaf density of drip irrigation treatments was slightly behind (1-4 days depending upon the irrigation treatment and crop season) that of sprinkler irrigation treatments in time. The individual canopy cover curves for each season show that spinach crop water requirements and irrigation scheduling were different in the fall and winter seasons. For instance, an average of 52% and 70% of canopy crop coverage was observed 30 days after planting in the winter and the fall crop season, respectively. We expect a longer crop season for spinach in winter planting than fall planting in the Imperial Valley, while it may change depending on weather condition of year.

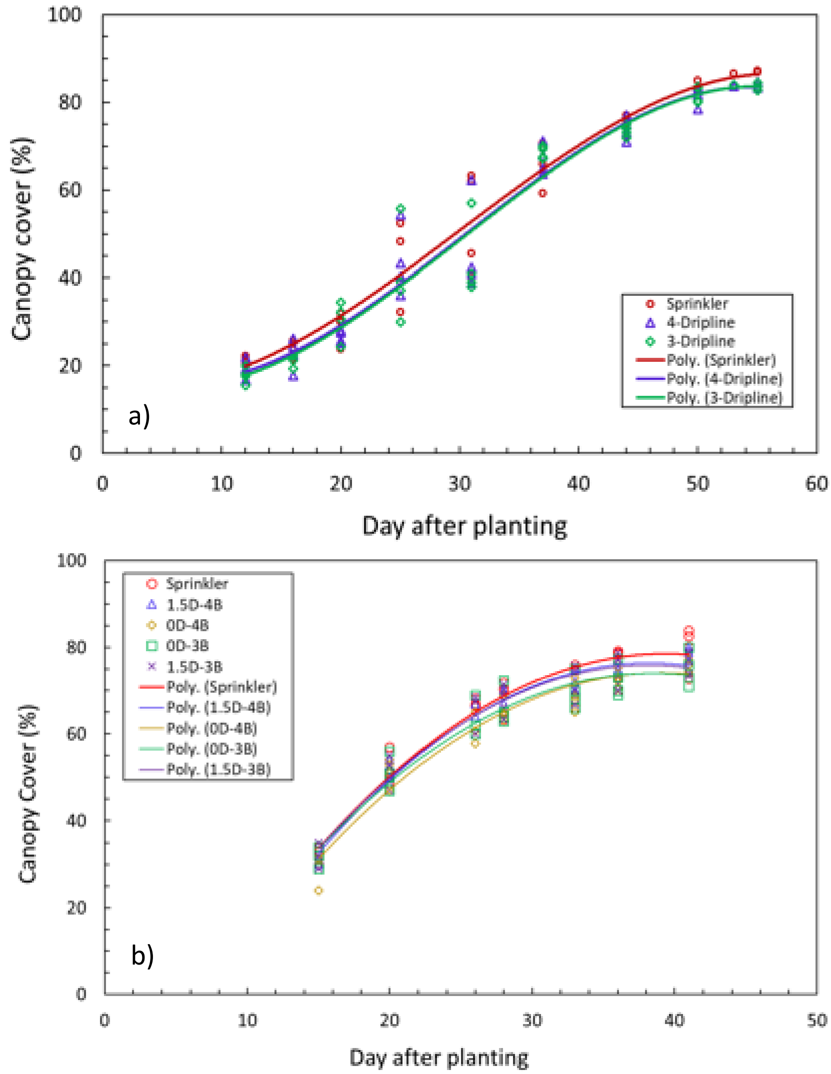


Figure 5. Canopy crop curve for the different irrigation treatments in (a) winter 2019 crop season and (b) fall 2018 crop season

Crop growth and greenness: Figure 6 shows crop growth status in drip and sprinkler trials in two different dates. Few differences between drip and sprinkler treatments are visible which means crop growth at these treatments were very similar while we observed the leaf density of drip irrigation treatments was 1-4 days behind that of sprinkler irrigation treatments in time in several of the beds.

Figure 6. Visual comparison of drip treatments versus sprinkler treatments on two different dates of 18 days after planting (three top pictures) and 38 days after planting (three bottom pictures) in the fall 2018 experiment.

In late November, more differences were observed among the treatments in several of the beds (Figure 7), mainly yellowing of leaves in between driplines (especially the three driplines in bed at the 1.5-inch depth). A possible reason may be that the fertigation did not move the N in between the driplines. The total plant tissue nitrogen content of the drip treatments with three driplines in bed was 1.5% less than sprinkler treatment in November 30th, while it was 0.5% less than sprinkler treatment for the drip treatments with four driplines in bed (Figure 8). Overall, a higher plant tissue nitrogen content was observed in sprinkler treatment compared to drip treatments.

Figure 7. Leaves yellowing issue (one of the beds with three surface driplines, 12/9/2018)

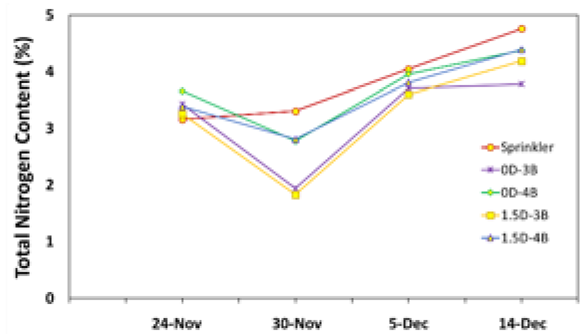


Figure 8. Total plant nitrogen content at different irrigation treatments over the fall crop season

The leaf chlorophyll content (Figure 9) was also higher in the sprinkler treatments (both crop seasons) compared to the drip treatments, meanwhile the drip treatment with four driplines at 1.5 in. depth was numerically lower about 1 μg cm^{-2} but similar compared with other drip treatments. A greater level of leaves chlorophyll content in late season was observed at the winter experiment than the fall experiment for both sprinkler and drip treatments. For instance, the total leaf chlorophyll content of sprinkler treatment two days before the final harvest at the

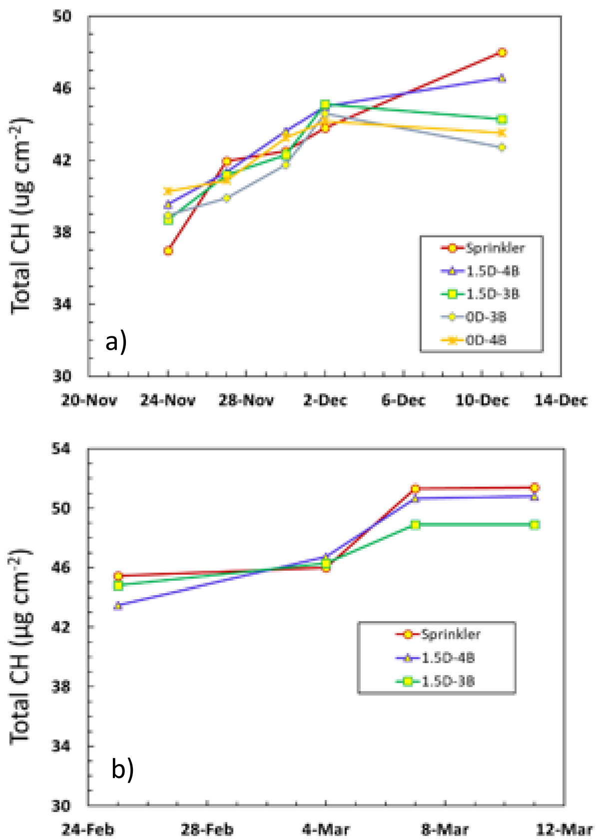


Figure 9. Average leaves chlorophyll content at different irrigation treatments over the crop season of (a) fall 2018 season and (b) winter 2019 season.

winter trial was 4 μg cm^{-2} more than leaves chlorophyll content of sprinkler treatment two days before plant final harvest at the fall trial.

Figure 10 shows the NDVI values (a simple graphical indicator that can be used to analyze remote sensing measurements and assess whether the target being observed contains live green vegetation or not. Greener and healthier crop canopy has a higher value of NDVI) for the drip treatment with four driplines and sprinkler treatment for the fall season experiment. The results indicate that the NDVI values varied from 0.2 (two weeks after planting) to 0.83 (the day before final harvest). By the late November, the NDVI values were very similar in both irrigation treatments, even in a short period, this index had higher values in the drip treatment (4-drpline on the soil surface). The results demonstrate lower NDVI values in the drip treatment than sprinkler treatment over the last two weeks crop season by final crop harvest

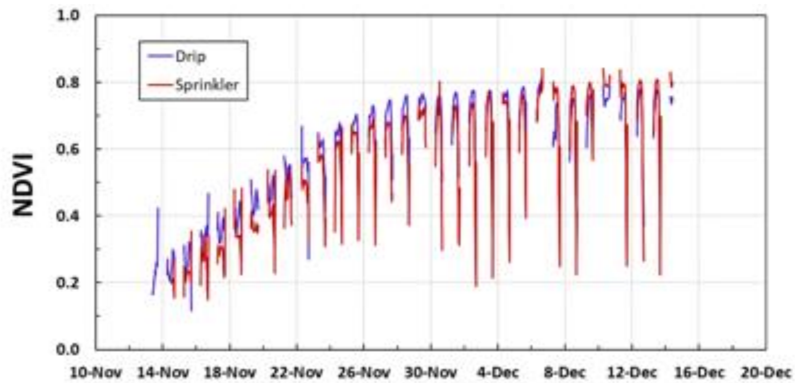


Figure 10. NDVI values of sprinkler and drip (four driplines in bed) treatments over the fall crop season

The values of total plant nitrogen content, leaves chlorophyll content, and NDVI confirmed that N uptake at the drip treatments was not as effective as the sprinkler treatment, particularly in the fall experiment. Nutrient management issue in spinach drip irrigation in combination with water management is likely a critical issue that we need to learn more about since it may affect the adoptability and viability of drip for spinach production.

Fresh biomass yield: The effects of various irrigation treatments on spinach fresh biomass yield over the two experimental seasons are summarized in Table 1 and Figure 11. In the fall trial, mean fresh yield in the sprinkler treatment was 12,406 lb/ac approximately 9% more than 1.5D-4B treatment (four driplines per bed installed in 1.5-in depth). The lowest mean fresh yield (9,935 lb/ac) was observed in the 0D-3B treatment (three driplines per bed installed on the soil surface). Statistical analysis indicated a very strong evidence (P= 0.001) for an overall effect of irrigation system on spinach fresh yield. Significant difference between the individual treatments was investigated using Tukey-HSD analysis. The results demonstrated a significant fresh yield difference between the sprinkler irrigation and each of the drip irrigation treatments (P values of 0.0001 to 0.0009). Even though no significant yield difference was obtained between surface drip and subsurface drip (driplines at 1.5-in depth) with the same dripline number in bed (P value of 0.8276 for three driplines and 0.1995 for four driplines, the number of dripline in bed had a very significant impact on the fresh yield (P values of 0.0001 to 0.0009).

Table 1. Mean spinach fresh yield values of each irrigation treatment in each of the fall and winter experiments. Yields with different letters significantly differ ($p < 0.05$) by Tukey's test.

Fall 2018		Winter 2019	
Irrigation treatment	Fresh yield (lb/ac)	Irrigation treatment	Fresh yield (lb/ac)
Sprinkler	12,406 a	Sprinkler	13,281 a
1.5D-4B	11,378 b	1.5D-4B	12,414 ab
0D-4B	10,950 b	1.5D-3B	12,116 b
0D-3B	9,935 c	-	-
1.5D-3B	10,127 c	-	-

In the winter trial, mean fresh yield in the sprinkler treatment was 13,281 lb/ac approximately 7% more than 1.5D-4B treatment. Statistical analysis indicated strong evidence (P= 0.0424) for an overall effect of irrigation system on spinach fresh yield. While we couldn't find a significant difference between the impact of the sprinkler and the 1.5D-4B irrigation treatments on spinach yield (P= 0.1161), there was statistically significant yield difference between the sprinkler and the 1.5D-3B irrigation treatments (P= 0.04147).

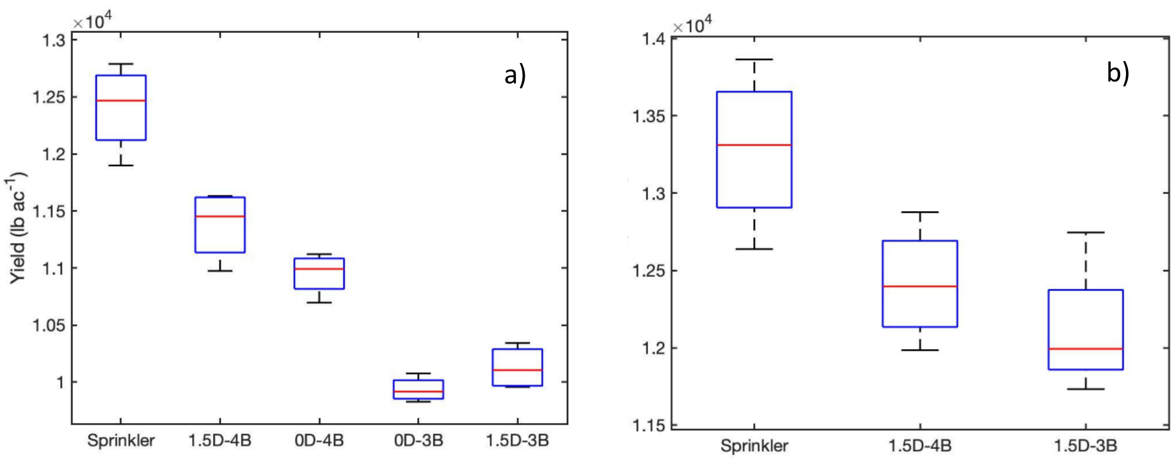


Figure 11. Mean yield data of the sample beds in each of the irrigation treatments at (a) the fall 2018 experiment and (b) the winter 2019 experiment. Horizontal red lines indicate the average for each treatment.

The yield reduction in the drip irrigation treatments varied from 7% to 25% in comparison with the sprinkler irrigation. This could be likely caused by suboptimal irrigation and nutrient management, because there are no standard recommendations for amount and timing of irrigation and nutrients for spinach produced under drip, and these practices had to be adjusted in real time as the study progressed. Since drip irrigation was tested for the first time for spinach, subsequent trials need to plan for improvements and be conducted in different aspects. However, a yield difference of only 7% between the best drip treatment (1.5D-4B) and sprinkler treatment demonstrates the potential of drip for profitable spinach production. Further work is required to optimize drip system design, and irrigation and nitrogen management practices of the system in various soil types, farming practices, and climate, and strategies to maintain productivity and economic viability at spinach production.

We noticed that the surface drip treatment is not practical. The driplines moved around due to wind until the crop canopy was fully developed. In addition, the surface drip might be problematic for growers since the driplines would need to be removed before harvest and would pose a food safety risk. This was the main reason that we eliminated the surface drip treatments from the project at the winter 2019 trial.

Leaf Wetness (LW): The LW measures leaf surface wetness by measuring the dielectric constant of the sensor's upper surface. Figure 12 shows the probe outputs of the sensors placed in the sprinkler treatment and one drip treatment (four driplines in bed) for a period of 12 days during the fall season experiment. At this period, there were two irrigation events in each of the treatments and two rainy days. The sensor output from dew was typically lower (less than 700 counts) than that from the rain or the irrigation event. It is concluded that duration or the total amount of time that the canopy experiences wetness at the sprinkler treatment had been 24.3 % [(70 hours / 288hours) ×100] more than that at the drip treatment at the period.

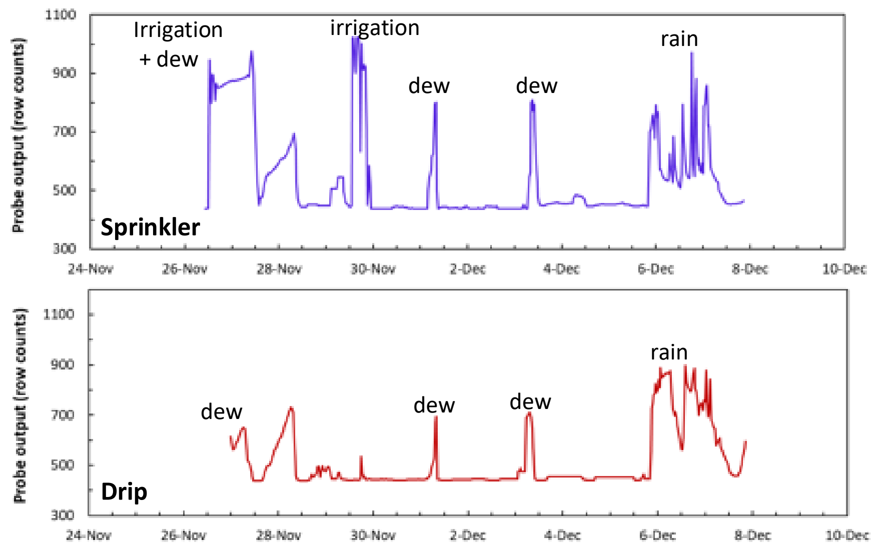


Figure 12. The row counts of leaf wetness sensors at the sprinkler and drip (four driplines in bed) treatments over a 12-day period in the fall crop season

Spinach downy mildew requires cool, wet conditions for infection and disease development. The dense canopy of spinach retains much moisture and creates ideal conditions for infection and disease development. Sprinkler irrigation could contribute to the speed and severity of downy mildew epidemics within a field when other conditions such as temperature are favorable. Considering the above analysis and in case that the weather and farming conditions are similar, there is higher risk for infection and downy mildew disease development in spinach irrigated by sprinklers in comparison with spinach irrigated by drip. The air temperature and relative humidity pattern (Figure 7) indicate that there was a desirable weather condition and more possibility for downy mildew disease in late December 2018, but the fall trial has been already terminated.

Downy mildew: Downy mildew was not observed in the fall 2018 trial. In the winter 2019 experiment, downy mildew activity was first confirmed in the study area on March 5. Disease incidence was rated on March 11. Downy mildew incidence was low on this date, with only two beds (0.12% and 0.20%) exhibiting incidence values above 0.1% (Figure 13). Mean downy mildew incidence in plots irrigated with sprinklers following emergence was 0.08%, approximately 3 to 11 times higher than treatments irrigated with drip following emergence. Statistical analysis indicated strong evidence (P = 0.0461) for an overall effect of irrigation treatment on downy mildew. The separation of individual treatments in this analysis was somewhat weaker but the trend suggests (P = 0.0671 and 0.1139) that downy mildew incidence was lower in plots irrigated with drip following emergence when compared to sprinkler.

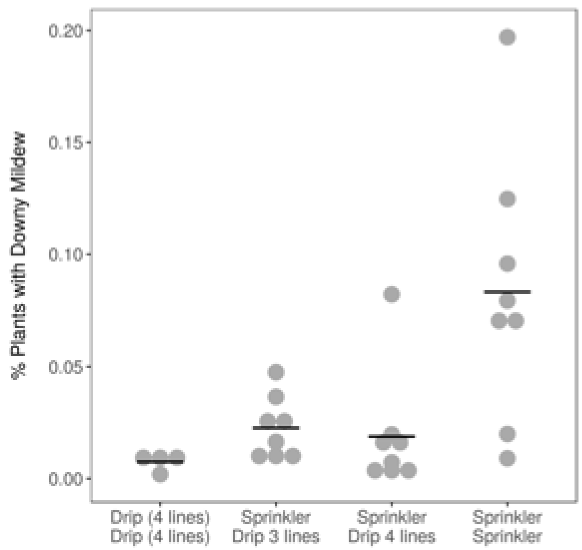


Figure 13. Raw data (all plots and beds within plots) of downy mildew incidence. Horizontal bars indicate the average for each treatment. The top line of x-axis labels indicates what the plot was germinated with, and the bottom row indicates the irrigation used following emergence.

Data from a single replicate run of this study showed a reduction in downy mildew in drip-irrigated spinach when compared to irrigation by sprinkler. The likely mechanism for this effect is a reduction under drip irrigation of leaf wetness, which is critical for infection and sporulation by the downy mildew pathogen. Additional repetitions of this experiment in higher disease pressure situations are needed for further evaluation of the ability of drip irrigation to reduce downy mildew. Figure 14 shows an area and plants infested by downy mildew at the sprinkler treatment in the winter trial.

Another mechanism that could partially account for the observed differences among the treatments is that the leaf density in drip-irrigated plots was slightly behind that of sprinkler irrigated plots in time. A less dense canopy could reduce the leaf wetness potential, and in turn disease incidence potential. However, the magnitude of differences in density likely could not account for the magnitude in differences in downy mildew incidence between sprinkler and drip irrigated treatments.

Other observation and lessons learned: At the winter trial, a germination rate test was conducted 10 days after planting to evaluate the germination rate of sprinkler treatments, treatments with drip that were germinated by sprinkler, and the beds germinated and irrigated by drip. Even though plots that were germinated by drip had an insufficient number of replications and were not randomized among plots with other treatments, it was worth to have an initial idea of germinating spinach by drip for the future experiment. The plot germinated by drip was approximately three days behind in comparison with plots germinated by sprinkler. While the germination rate was 95-97% in beds germinated by sprinkler, there was an average of 3% lower germination rate for the beds germinated by drip (Table 2).


Figure 14. Area and plants infested by downy mildew at the sprinkler treatment in the winter trial

Table 2. Germination rate of the different irrigation treatments

Germinated by	Irrigation (post-germination)	Germination rate (%)
Sprinkler	Sprinkler	96
Sprinkler	4 driplines	97
Sprinkler	3 driplines	95
4 driplines	4 driplines	93

Preliminarily conclusions: Drip irrigation demonstrated the potential to produce organic spinach, conserve water, enhance the efficiency of water use, and reduce/manage downy mildew. Statistical analysis indicated a strong evidence for an overall effect of irrigation system on spinach fresh yield and downy mildew disease. Lower spinach yield could be likely caused by irrigation and nutrient management in drip at this point while using drip for spinach is an initial trial and improvements need to be conducted in different aspects. Observing only a 7% yield difference between the best drip treatment and the sprinkler treatment demonstrates the potential of drip for profitable spinach production. The yield difference between spinach in drip and in sprinkler could be reduced through optimal system design and better irrigation and nutrient management practices in drip system. The likely mechanism for less downy mildew reduction under drip irrigation is a lower duration of leaf wetness, which is critical for infection and sporulation by the downy mildew pathogen. Further work is needed to evaluate the viability of utilizing drip (optimal system design, the impacts of irrigation and nutrient management practices), and strategies to maintain spinach productivity and economic viability at spinach.

Future work: For the next year, the research team will continue investigating the viability of drip irrigation in organic spinach production in the Imperial Valley. Surface drip irrigation treatment will be eliminated, and two nitrogen levels will be included to the drip-treatment trials.

The team will also evaluate utilizing drip irrigation for the whole crop season (germination and remainder of crop season). The team plan to continue this project in the Salinas Valley where the climate and dominant soil type are different from the Imperial Valley.