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

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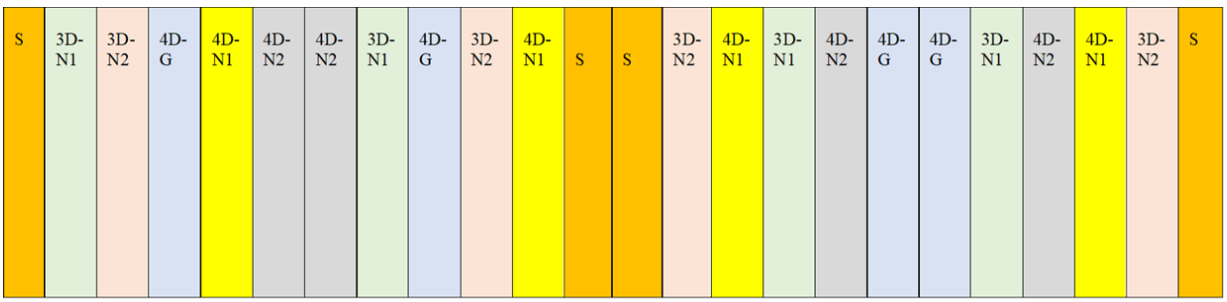
Abstract. This project aims to evaluate the viability of drip irrigation for organic spinach production and the management of spinach downy mildew over a three-year period. In the first year, two trials were conducted in October 2018 and in winter 2019. The second year of the project (this trial) was conducted in winter 2020. The trials were carried out at the UC Desert Research and Extension Center (UC DREC) in Holtville. This project demonstrates the potential for drip irrigation to produce organic spinach, reduce and manage downy mildew, and to germinate seeds. Statistical analysis indicated a very strong evidence (P= 0.012) for an overall effect of irrigation system on spinach fresh yield, lower yield in the drip treatments. This could be likely caused by suboptimal nutrient management, while the practices had to be adjusted in real time as the study progressed. Mean downy mildew incidence in plots irrigated by sprinklers following emergence was 4%, approximately 10 times higher than the treatment germinated by drip and 2-4 times higher than treatments that irrigated by drip following emergence. The germination rate was 94% in beds germinated by sprinkler, while there was an average of 4% points lower for the beds germinated by drip. Further work is needed to evaluate nutrient management practices, and strategies to maintain spinach productivity and economic feasibility in spinach.

Objectives. The objective of this project is to evaluate the viability of adapting drip irrigation for organic spinach production. The project particularly aims to understand the optimal dripline spacings, and irrigation and nitrogen management practices to successfully produce spinach. The efforts attempt to assess germination by drip and the impact of drip irrigation on the management of spinach downy mildew.

Procedures. The field experiment was carried out in winter 2020 at the UC DREC in a silty clay soil (Fig. 1). Untreated Viroflay spinach seeds were planted at a rate of 2,650,000 per acre on January 8th. The experiment was arranged in a randomized complete block with four replications (each replication had three beds). Beds were 200 ft. long and on 80 in. center spacing. Irrigation treatments were sprinkler, 3 driplines per bed, or 4 driplines per bed. The driplines had an emitter spacing of 8 in. and an emitter flowrate of 0.13 gph @8 psi, and were installed at a depth of 1.5 in. For each of the two drip treatments, two nitrogen levels were tested: N1, 110% of N required; and N2, 130% of N required. Only 110% of N required was tested in the sprinkler treatment.

Except for treatment 4D-G that was germinated by the 4 driplines, all treatments were germinated by sprinklers with two five-hour sets.

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 systems. For the drip treatments, True 4-1-3 was applied four times after germination (by crop harvest) at a rate of 30, 30, 30, and 30 lbs. of N per acre for the treatments with nitrogen application rate of N1. For the treatments with nitrogen application rate of N2, True 4-1-3 was applied four times after germination at a rate of 40, 40, 40, and 37 lbs. of N per acre. This liquid fertilizer was applied at a rate of 30, 30, 34, and 30 lbs. of N per acre for sprinkler irrigation system.



S: treatment irrigated by sprinklers and 110%N
3D-N1: treatment with three driplines and 110%N
3D-N2: treatment with three driplines and 130%N
4D-G: treatment with four driplines and 110%N (germinated by drip)
4D-N1: treatment with four driplines and 110%N
4D-N2: treatment with four driplines and 130%N

Fig. 1. Field experiment layout (not to scale)

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.
Field measurements: 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 magnetic flowmeters, and plant leaf wetness values were measured using Spectral Reflectance Sensors and dielectric leaf wetness sensors on a continuous basis. Leaf chlorophyll and SPAD were measured with a LEAF 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 24 sample beds). Fresh weight was measured in order to determine biomass accumulation. Germination rate test was conducted two weeks after planting on January 16th. The number of germinated plants were measured in three samples areas of 1.5 ft ×1.5 ft in each bed. The statistical significances were performed using general linear mixed model in SAS statistical analysis package.

<u>Downy mildew</u>: Downy mildew incidence was assessed over the course of March 4-5 and March 9. Three points along the length of each bed were randomly selected, and at each point the number of plants exhibiting downy mildew symptoms within a 26 in. length of the bed were counted. In addition, the quality of the plant stand/canopy in each rating area was given a qualitative rating of 'good' or 'poor.' The number of plants was converted to percent incidence by dividing by the number of plants in each segment, which in turn was calculated from an estimate of the plant stand determined from the target plant density and adjusting for the difference in germination rate between sprinkler and drip.

Results.

<u>Germination rate</u>: the germination rate test was conducted about two weeks after planting. The plot germinated by drip was approximately 3 to 4 days behind in comparison with plots germinated by sprinkler. While the germination rate was 94% (standard deviation of 4.6%) in beds germinated by sprinkler, there were an average of 4% points (not significant difference) lower germination rate for the beds germinated by drip (Fig. 2d). The grower-cooperator who produces conventional bunched spinach using drip in Imperial County, did not find a difference in the germination rate between sprinkler and drip as well (Fig 2c).

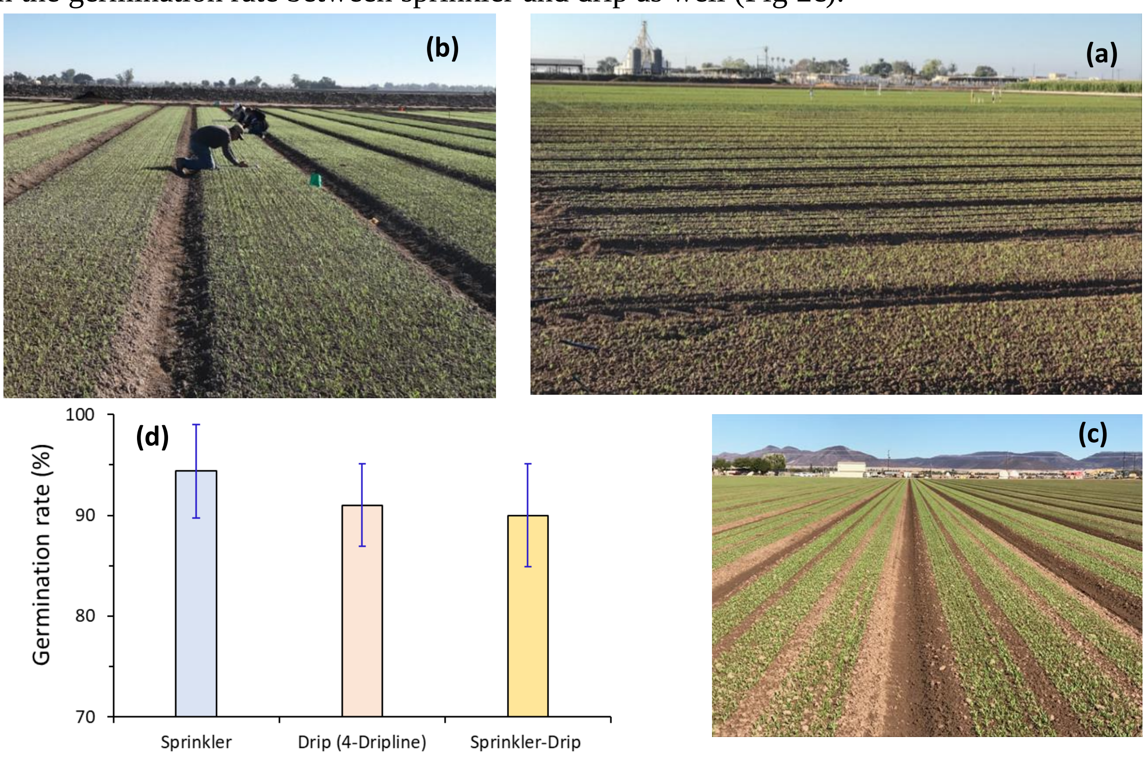


Fig. 2. A view of germinated spinach trial two weeks after planting (a), research staff count plants the number of plant germinated in an area of 2.25 ft^2 in three different spots in each bed (b), a view of conventional bunched spinach field germinated by drip in Imperial County (c), mean germination rates values in different treatments at the DREC trial (d). The error bars in Fig. d show the standard deviation values in each treatment category.

Canopy cover over the season: The percent canopy cover was assessed for each of the irrigation treatments (Fig. 3). Even though there were not accurate measurements of canopy cover during the first two weeks after planting, the data show that the canopy cover of drip irrigation treatments was slightly behind in time (by 1 to 4 days depending upon the irrigation treatment) compared to the sprinkler treatments. This result was also observed in the trials fall 2018 and winter 2019. The 4D-G treatment demonstrated the lowest canopy vegetation cover in time amongst the drip treatments.

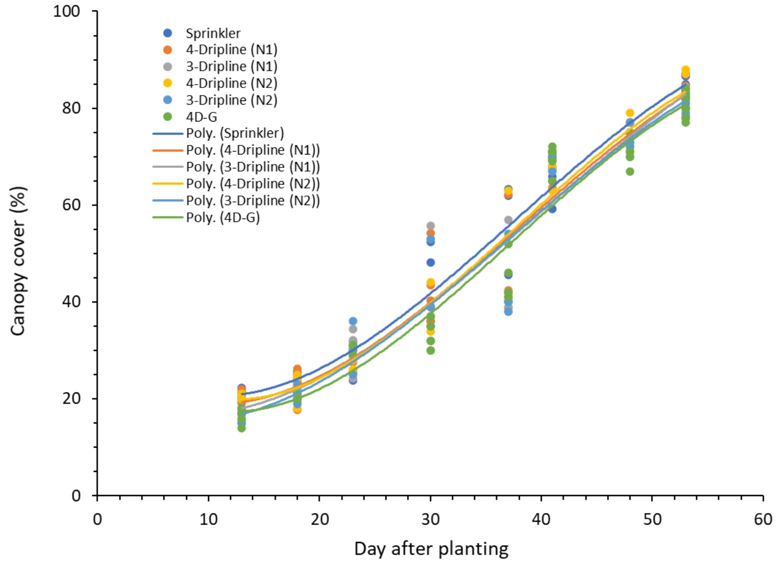


Fig. 3. Canopy crop curve over the crop season in the different irrigation treatments

Crop growth and color: Yellowing of leaves in between driplines was observed again in this trial as the same as the trial fall 2018 (Fig. 4). The fertigation could cause this issue mainly because N was not successfully moved in between the driplines. The total plant tissue nitrogen content in the drip treatments was averagely 1.3-1.7% less than the sprinkler treatment on February 24th.

The leaf chlorophyll content was higher in the sprinkler treatments compared to the drip treatments in the mid- to late-season. For instance, the total leaf chlorophyll content of leaves in the sprinkler treatment was averagely 4.7 μg cm^{-2} more than leaves chlorophyll content of the drip treatments on Feb. 26th. Nitrogen management still stays the most important concern for producing organic spinach in drip while the research team continues investigating for possible practical solutions.

Fig. 4. Leaves yellowing issue in the winter 2020 trial (Feb. 24th)

Fresh yield: The effects of various irrigation treatments on spinach fresh yield is summarized in Fig. 5. The mean fresh yield in the sprinkler treatment was 12,672 lb/ac approximately 9.5% more than the 4D-N2 treatment that had the maximum yield amongst the drip treatments. The lowest mean fresh yield (10,784 lb/ac) was observed in the 3D-N1 treatment. The drip treatments were not significantly different, and/or the only differences were between either 4D-N1 or 4D-N2 and 3D-N1. Statistical analysis indicated a very strong evidence ($P = 0.012$) for an overall effect of irrigation system on spinach fresh yield. Significant difference between the individual treatments was investigated using Tukey-HSD analysis.

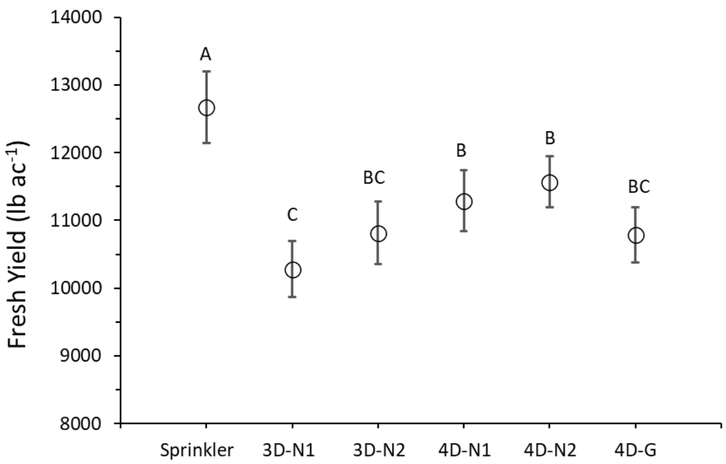


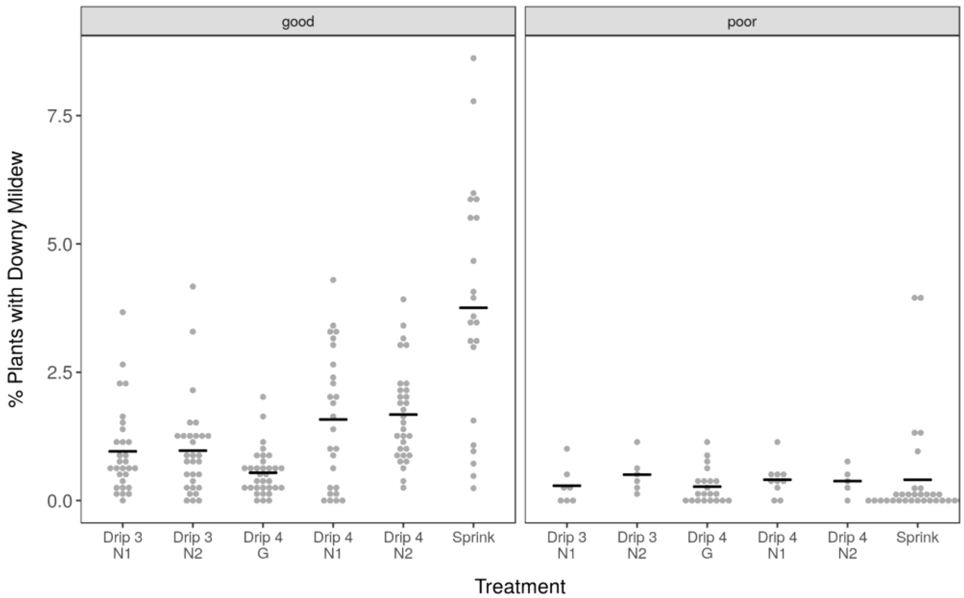
Fig. 5. Mean spinach fresh yield values in each of the irrigation treatments. Yields with different letters significantly differ ($p < 0.05$) by Tukey's test.

The yield reduction in the drip irrigation treatments varied from 9.5% to 23% (3D-N1) in comparison with the sprinkler treatment. This could be likely caused by suboptimal nutrient management, while the practices had to be adjusted in real time as the study progressed. Subsequent trials need to plan for improvements and be conducted in different aspects. However, a yield difference of 7% between the best drip treatment and sprinkler treatment in the previous trial conducted in winter 2019 at the same field demonstrates the potential of drip for profitable spinach production. What the team learned from the cooperative grower in Imperial County shows that the yield productivity in conventional bunched spinach fields under drip can be as the same as sprinkler fields.

Further work is required to optimize irrigation and nitrogen management practices of the system in various soil types, farming practices, and climate, and strategies to maintain productivity and economic viability in organic spinach production.

Downy mildew: Disease activity was first confirmed in the trial on March 4th. Downy mildew incidence was higher than the last two trials conducted in fall 2018 and winter 2019. Mean downy mildew incidence in plots irrigated by sprinklers following emergence was 4%, approximately 10 times higher than the treatment germinated by drip and 2-4 times higher than treatments that irrigated by drip following emergence (Fig. 6). Statistical analysis indicated strong evidence ($P = 0.0028$) for an overall effect of irrigation treatment on downy mildew when rating areas with poor stands were removed. In the plots with poor stands, downy mildew incidence was found very similar across treatments. However, the raw results show that much of the differences between sprinkler and all drip treatments is driven by the 4th block (data not shown), which could be caused by variation in canopy coverage across the study replicates. In addition, canopy coverage could account for the numerical difference in downy mildew incidence among drip treatments, because the treatment germinated by drip had both the lowest canopy coverage percentage and downy mildew incidence.

Fig. 6. Raw data of treatment means and mean separation.. In this analysis, poor canopy ratings have been removed.



Data from this trial and the two previous trials demonstrate 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. The leaf wetness measurements in the trial winter 2019 and winter 2020 indicate that the duration that the spinach canopy experiences wetness at the sprinkler treatment had been averagely 23.7 % more than that at the drip treatment.

A less dense canopy in the drip treatments could also reduce the leaf wetness potential, and in turn disease incidence potential. However, it is unclear if the magnitude of differences in density could account for the magnitude in differences in downy mildew incidence between sprinkler and drip irrigated treatments.

Outreach. An outreach program was developed to disseminate the project findings to growers and stakeholders. The research team held two workshops in the Imperial Valley and in the Salinas Valley, several demonstration tour from the research trials, as well participate in annul and mid-year meetings of the California Leafy Greens Research Board, Imperial County Farm Bureau, and Imperial Vegetable Growers Association to present the findings and receive feedback of growers and stakeholders on the outcome of project. The project outcomes have been presented through several publications and workshops as the following list:

1- Montazar A., Cahn, M., Putman, A. (2019). Research Advances in Adopting Drip Irrigation for California Organic Spinach: Preliminary Findings. Agriculture 9: 177; doi:10.3390/agriculture9080177.
2- Montazar A., Cahn, M., Putman, A. (2019). A Preliminary Evaluation of Using Drip Irrigation in Organic Spinach Production. Organic Farmers: August/September: 10-17.
3- Montazar A., Cahn, M., Putman, A. (2019). Production of Organic Baby Spinach Using Drip Irrigation in the Low Desert. Agricultural Briefs-Imperial County, 22 (2): 18-22.
4- Montazar A., Cahn, M., Putman, A. (2019). Is Drip Irrigation a Potential Tool to Produce Organic Spinach and Manage Downy Mildew? Agricultural Briefs-Imperial County, 22 (6): 122-116.
5- Montazar A., Cahn, M., Putman, A. (2019). Drip irrigation for California organic spinach: We gave it a try for the first time. UC ANR Knowledge Stream Blog: August 2019 https://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=31163
6- Montazar A., Cahn, M., Putman, A. (2019). Production of Organic Baby Spinach Using Buried Drip Irrigation (oral presentation). 2019 Irrigation and Nutrient Management Meeting, UCCE Monterrey, Salinas, February 26th.
7- Montazar A., Cahn, M., Putman, A. (2019). Evaluation of Drip Irrigation for Spinach and Downy Mildew (oral presentation). CLGRB's annual conference, Pismo Beach, March 19th.
8- Montazar A., Cahn, M., Putman, A. (2019). Evaluation of Drip Irrigation in Organic Spinach Production and Downy Mildew Management (oral presentation). CLGRB's mid-year meeting, Salinas, October 8th.
9- Montazar A., Cahn, M., Putman, A. (2020). Evaluation of Drip Irrigation in Organic Spinach Production and Downy Mildew Management (oral presentation). CLGRB's Annual Research Conference, March 17th.

The PI of the project has been also totally interviewed three times about this project by CA AgAlert, Desert Review, and Growing Produce.

Preliminarily conclusions: This project demonstrated the potential for drip irrigation to produce organic spinach, reduce/manage downy mildew, and use for germinating seeds. To date this project has shown that drip irrigation can slightly reduce spinach fresh yield but can also reduce incidence of downy mildew. It is likely at this point that lower yields are caused by nutrient management, which could be improved through better nutrient management practices in drip. Further work is needed to evaluate the impacts nutrient management practices in drip, and strategies to maintain spinach productivity and economic viability at spinach.

Fig 7. Two conventional bunched spinach fields under drip irrigation in Imperial County.