Experimental Design and Results of Deployment of SproutLabs Moisture Sensors in a Control and Experimental Bed[1]

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I. Introduction

Water availability in the state of California and many other parts of the world is affected by droughts and by the accelerating depletion of underground water resources. This brings its toll on agriculture where success is very much dependent on sufficient irrigation.

Farmers themselves often contribute to the water scarcity problem by excessive use of water resources available to them, on the theory that more irrigation is better than less. In particular, they may not know how to assess the amount of moisture in their soils in order to make appropriate irrigation decisions. Digital moisture sensors are available, but most are unaffordable for small-scale farmers facing small financial margins.

The main objective of this project was to conduct longitudinal research on and demonstration of a smart irrigation sensor developed by SproutLabs (http://sproutlabs.io/) a small engineering startup in Santa Cruz, California. The sensors include WIFI/Cellular enabled irrigation control valves and use of artificial neural networks that take in real time sensor data, satellite weather forecast, and evapotranspiration and come up with precise irrigation control (Figure 1, below).

The research was designed to determine whether an inexpensive soil moisture sensor device could reduce water usage in small-scale agriculture settings without affecting produce yields and quality.

Project objectives were:

1. Determine if the soil moisture sensors are effective in reducing water usage in small-scale agriculture settings without affecting plant health, yields, and produce quality.

2. Determine if irrigation controlled by water moisture sensors will significantly decrease nutrient runoff to deeper soil levels.

3. Demonstrate to small-scale farmers techniques that would help them reduce their water use and introduce them to the sensor setup from the research.

[1] This research was conducted with support from a Farmer-Rancher Research and Education grant from the Western Sustainable Agriculture, Research and Education Program at Montana State University and the Sustainable Systems Research Foundation in Santa Cruz, California. Dave Blume of Whiskey Hill Farms in Watsonville, California is the principal investigator on this project. Thanks to him and Robert Re for helping with this project..

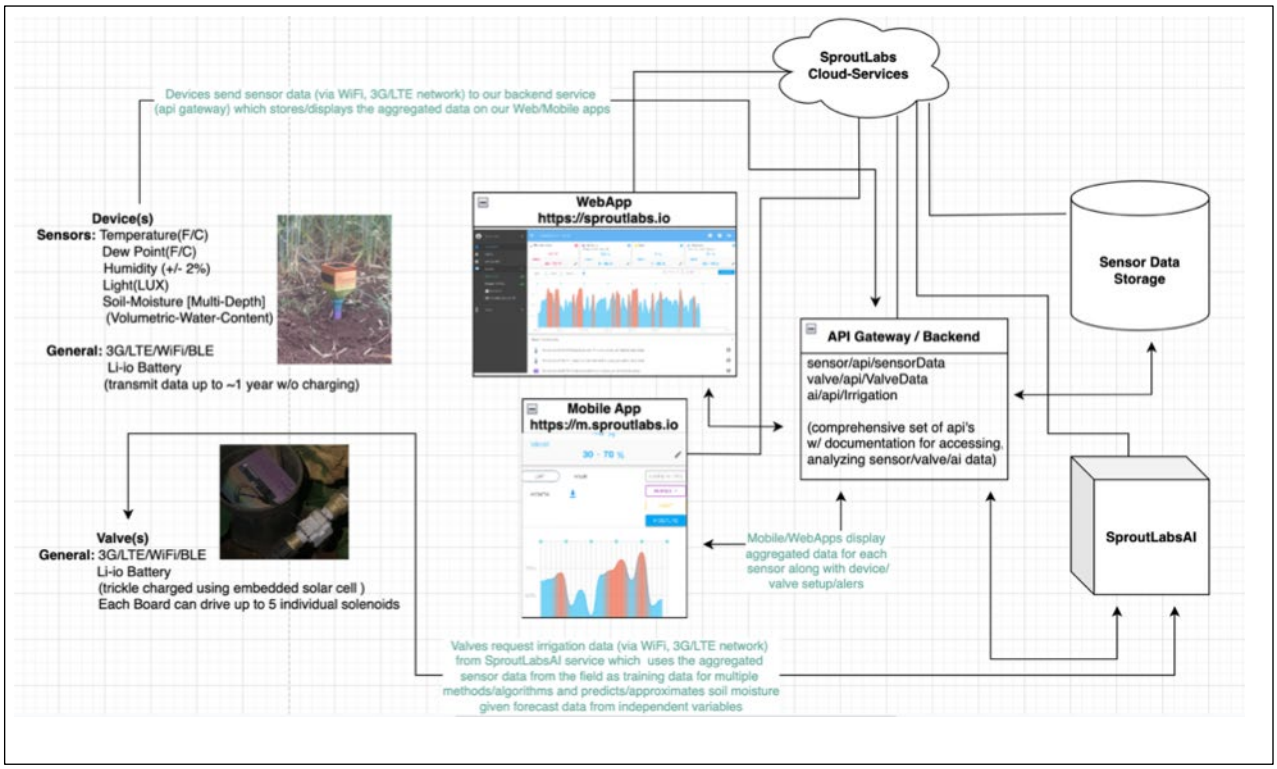


Figure 1: Moisture sensor configuration

The research was conducted at Whiskey Hill Farms, a regenerative organic farm in Watsonville, CA. Control and treatment beds were established in one of the greenhouses with SproutLabs sensors installed on each. The farm has all the equipment and infrastructure necessary to host the research. It prepared plots for the experiment (shallow tillage, application of organic fertilizer, laying drip-tape irrigation, and supplying water) and provided a workforce to help us plant the crops. We planted "Rainbow" carrots, "Napa" cabbage, and "Astro" arugula as they are commonly grown in the area and come to maturity quickly.

Although we had to scale down the research due to the unexpected crop damage by wildlife on the farm, we found no significant difference in crop yields and their quality between our control and treatment plots. The treatment bed used about one-third of the water applied to the control bed, without significant impacts on plant health and crop yields.

II. Project schedule

July 2022: Order and receive seeds and transplants for the experiment

August 2022: Install soil moisture sensors and connect them with the irrigation system to implement automation. Plant crops. Begin observations.

September 2022: Continue observations and harvest arugula.

October 2022: Continue observations and harvest carrots.

November 2022: Harvest cabbage and finish observations.

December 2022: Analyse collected data. Present to farmers. Write the final report.

III. Research materials and methods:

1. **Compare scheduled and automated irrigation in the context of water usage and crop yields.**

Control and test bed design

For this experiment, we arranged two beds, three feet wide and 135 feet long, separated by a one-bed space. Four sensors were available. Two were installed on each bed.

Inside the SproutLabs device is a resistive soil moisture sensor that works by measuring the relationship between electrical resistance and water content to gauge the moisture level in the soil at 6 inches and 12 inches. The sensor is attached to the bed's irrigation valve and controls its opening and closing. Data on moisture content are sent to a cloud server, and the experimental bed was irrigated based on moisture levels.

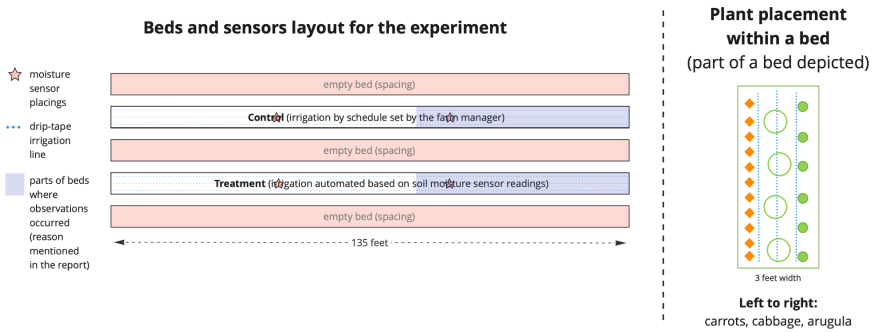
The control bed was irrigated on a regular schedule.

To establish target VWC (volumetric water content) levels at which the system should start and stop irrigation, we collected a combined soil sample from the two beds and measured particle size. The results were "loamy sand" and which allowed us to establish a field capacity point at 21% VWC and wilting point at 12% VWC.

As we placed sensors in the soil and conducted several rounds of irrigation to test the setup, we observed that VWC readings were consistently higher than 21% on both beds, with each stabilizing around 30% VWC. We attributed this to high organic matter content, between 8.5% and 13.3% in both beds based on an agrochemical soil test. Therefore, we set a slightly higher water moisture target point for the test bed, instructing the automatic irrigation system to operate when the reading dropped below 25% and to continue until reaching 25% VWC.

Three drip-irrigation lines were placed on both beds. The irrigation rate was measured on a few randomly picked emitters on all six lines before and after the experiment. The readings were consistent on both beds with an average of 11 ml/min or .0029 gal/min delivered per emitter.

Figure 2



Observation protocol

In order to assess plant health throughout the experiment we established a protocol whereby we weekly observed and counted stress signs in plants on both beds. These signs included slow growth, wilting, bolting/spines, and insect damage.

The initial plan was to randomly select ten plants of each type on each bed and run the assessment. However, we had to change that at the very beginning of the experiment - carrot and arugula transplants on the control bed suffered significant damage from farm wildlife (gophers) in the second week after transplanting. The damage mostly occurred on the left and central parts of the control bed.

We then limit the experiment to the far 51 feet of both beds as these sections were undamaged. We installed traps and scarecrows to prevent further damage, but towards the very end of the experiment, the wildlife returned. With 2x51 feet left for the experiment at, we decided to spend a bit more time each week and assess each plant on those segments of both beds rather than conducting random plant assessments.

Calculating the total amounts of water used

The control bed was irrigated twice a week for 1-hour long intervals based on the farm manager's experience with growing vegetables in that greenhouse. This irrigation was turned on and off by timers.

For the first two weeks, both beds were irrigated on the same schedule. Then the automated irrigation on the treatment bed was engaged.

Each irrigation event and its length in minutes was recorded in a journal, separately for each of the two beds. Final water usage numbers were calculated by multiplying the length of the section (51 feet) by the number of emitters per foot (2) by the emitter drip rate (.0029 gal/min) and by the total irrigation time for each bed.

Harvesting and total yield calculations

We were able to harvest arugula three times, throughout September. Carrots were harvested in October. Cabbage was harvested in November, 78 days after planting. We weighed yields from both beds separately and recorded these numbers in a journal.

We then graded the produce—marketable, edible (but not marketable), and cull, using the following USDA charts:

Cabbage: https://www.ams.usda.gov/grades-standards/cabbage-grades-and-standards
Carrots: https://www.ams.usda.gov/grades-standards/bunched-carrots-grades-and-standards
Arugula*: https://www.ams.usda.gov/grades-standards/bunched-spinach-grades-and-standards . (Because USDA has no separate inspection instructions for arugula, another similar leafy green plant, spinach, was chosen for reference).

The edible grade was assigned for produce with visual imperfections or noticeable wilting, but no other type of damage. Cull was used for yields damaged by insects or with imperfections that rendered it not suitable for human consumption.

2. **Comparing scheduled and automated irrigation in the context of nutrient runoff (leaching)**

   It has been established that because of its chemical characteristics, nitrogen is most susceptible to leaching by percolating water. Although potassium, phosphorus, magnesium, calcium, and sulphur are much less susceptible to leaching, they do leach more in sandy and organic soils: the exact constitution of the two beds. Because of the properties of our soil, we decided to compare the depletion of nitrogen, potassium, phosphorus, calcium, sulfur, and magnesium between both beds.

   In an ideal research setup, we would use lysimeters to collect and analyze liquids percolated through the soil, but given the limitations of our research capabilities, we used standard agrochemical soil tests instead, knowing that this way we would be simultaneously measuring nutrient depletion from leaching and from other natural processes in the soil.

   We performed agrochemical soil analysis for each bed separately at the beginning of the experiment and one more at the end. We sampled soil at three depth intervals - 0-6 inches, 6-12 inches, and 12-18 inches. For each sample, 15 sub-samples were collected from random spots on each bed using an auger and thoroughly mixed.

3. **Passing knowledge to farmers and helping them to implement sensor technology**

   As a separate part of this project, we committed to installing SporutLabs sensor devices on several farms in Central California, teaching farmers how to use them, and learning about difficulties that farmers face when establishing irrigation practices and when implementing our technology specifically.

III. Results and discussion

1. **Comparing scheduled and automated irrigation in the context of water usage and crop yields**

   One important event that accounts for some of the changes in the research protocol was the unexpected presence of gophers in the greenhouse which ate carrots and cabbages. Figure 3 illustrates the damage three weeks after transplanting carrots and arugula and seeding cabbage. The front and middle portion of the control bed (on the left) has significantly fewer carrots and arugula plants remaining while the treatment bed (on the right) is almost intact.

Figure 3: Crop damage in week three due to gophers

As noted above, this damage led to the foreshortening of both beds. Traps and scarecrows were installed to prevent further incursions but, after carrot and arugula had been harvested, a significant amount of cabbage in the treatment beds was devoured in new attacks by gophers.

Another unfortunate occurrence was the malfunctioning of the unit that controlled the valve on our treatment bed. Because of that we only did a couple of automated irrigations, and the rest had to be done by research staff based on reading VWC numbers through the SproutLabs online dashboard.

Because research staff was not present on the farm throughout the full day, sometimes this resulted in late irrigations on the treatment bed (1/2 - 1 day since the drop below 25% was discovered at the top 6” reading). However, even when being late, we never reached a wilting point, and readings at 12” depth shown enough water available to already established plants.

Plant stress

Carrots didn’t exhibit any visual stress and grew well (from a visual observation) on both beds (Figure 4).

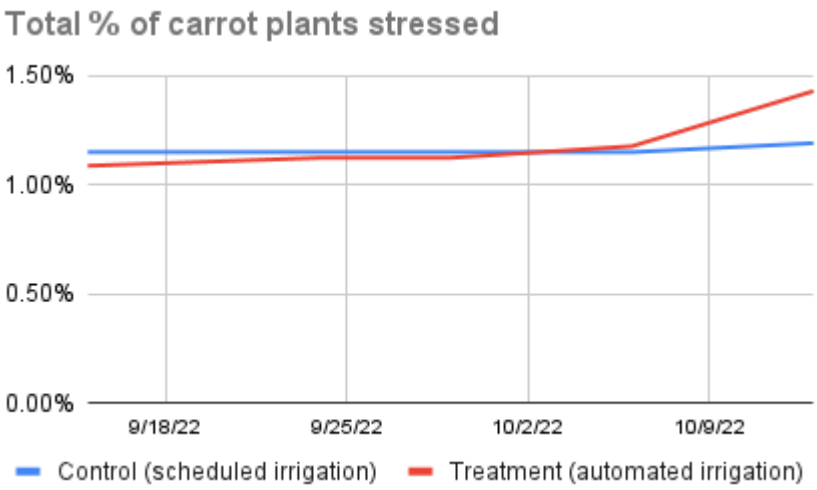


Figure 4

Arugula was susceptible to wilting and insect damage on both beds but, because of its shorter growth period, this damage did not have much effect on yields. Insect presence and wilting for arugula were comparable both for treatment and control beds (Figure 5).

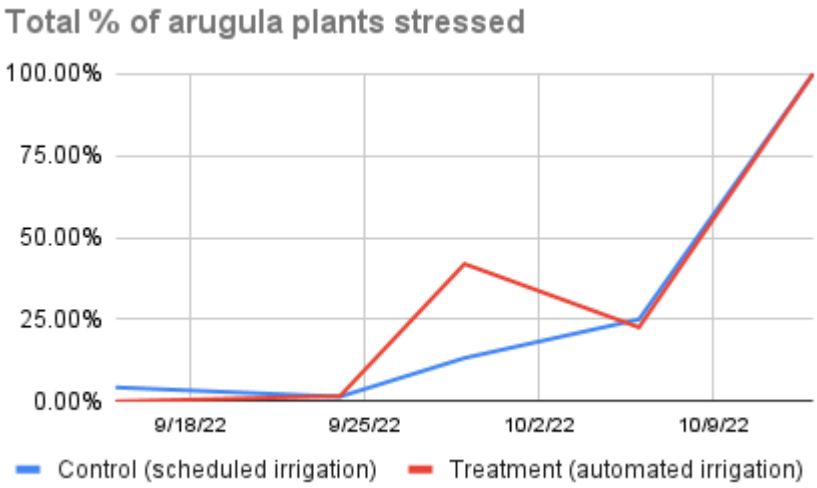


Figure 5

Cabbage, needing to establish itself from seed and with a lengthier growing period, showed a variety of different stress signs. We saw a lot of plants going through slow growth, showing signs of wilting and insect damage. We learned that prior to our experiment, brassicas and cabbage specifically were grown on those same beds, which may have caused the increased presence of aphids and caterpillars on arugula and cabbage throughout the experimental period.

Figure 6 to 8 illustrate stress, wilting and insect damage to cabbage plants.

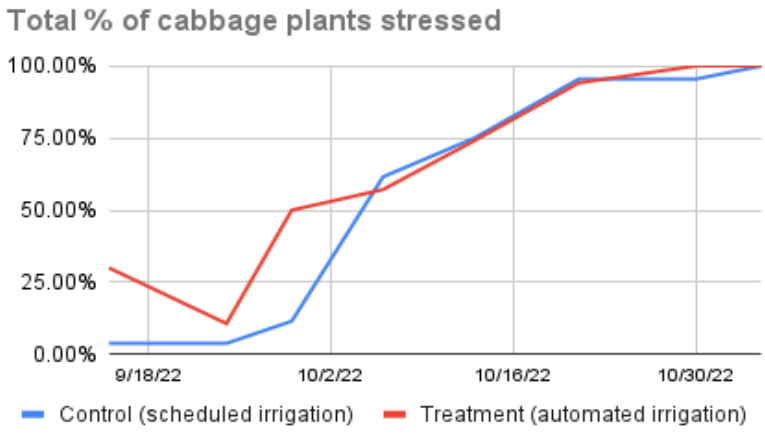


Figure 6

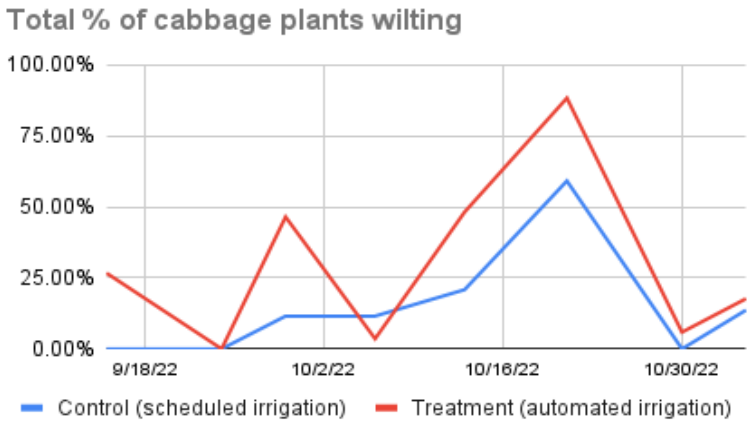


Figure 7

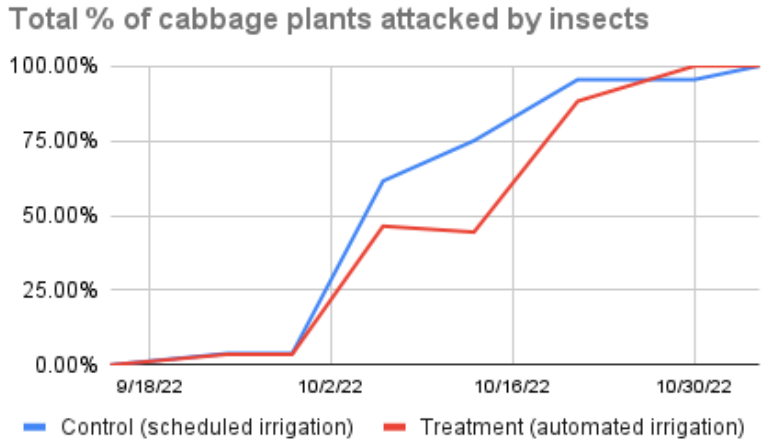


Figure 8

Where managing plant stress was concerned, both irrigation schedules performed the same way. More plants were observed wilting in the treatment bed, which we attribute to difficulties of irrigating the bed immediately after dropping below our established 25% VWC target.

Total yields

The tables below illustrate comparative produce yields from the two beds.

Carrots		Averages yield per plant (several seeds growing together)		
Single harvest	**Total plants harvested**	**Marketale yield**	**Edible (non-marketable)**	**Cull and carrot tops**
Control (scheduled irr.)	84	0 oz	1.37 oz	11.05 oz
Treatment (sensor-based irr.)	70	0 oz	1.33 oz	6.47 oz

Cabbage		Averages yield per plant		
Single harvest	**Total plants harvested**	**Marketale yield**	**Edible (non-marketable)**	**Cull**
Control (scheduled irr.)	22	7.72 oz	0 oz	Unknown
Treatment (sensor-based irr.)	17	7.88 oz	0 oz	Unknown

Arugula		Averages yield per plant		
3 harvests	**Total plants harvested**	**Marketale yield**	**Edible (non-marketable)**	**Cull**
Control (scheduled irr.)	66	4.52 oz	.26 oz	.72 oz
Treatment (sensor-based irr.)	61	4.4 oz	1.48 oz	.7 oz

Table 1

Harvested carrots were small and stunted, which we attribute to late transplanting and inadequate thinning. None were marketable but they were edible and consumed. We did observe a significantly bigger volume of carrot tops on the control bed, which we attribute to a greater irrigation of that bed.

Cabbage yields were very similar between the two beds as well. We did not weigh the cull correctly and cannot report that number. But from the visual observation, the numbers of cabbage we had to consider as cull were comparable between the two beds, primarily due to heavy insect damage and damage by wildlife.

Arugula, which was harvested three times, also showed comparable yields between the two beds. If that harvest had been done when arugula was not under stress due to missed irrigation window, the treatment bed would have outperformed the control bed in total marketable yield per plant

Overall, yields were comparable between control and treatment beds, and the irrigation management technique did not affect yields significantly.

Irrigation results

The most important result of this experiment was the total amount of water used to irrigate the remaining 51 foot segment of each bed: 898 gallons for the control bed, 301 gallons for the experimental bed (66% less).

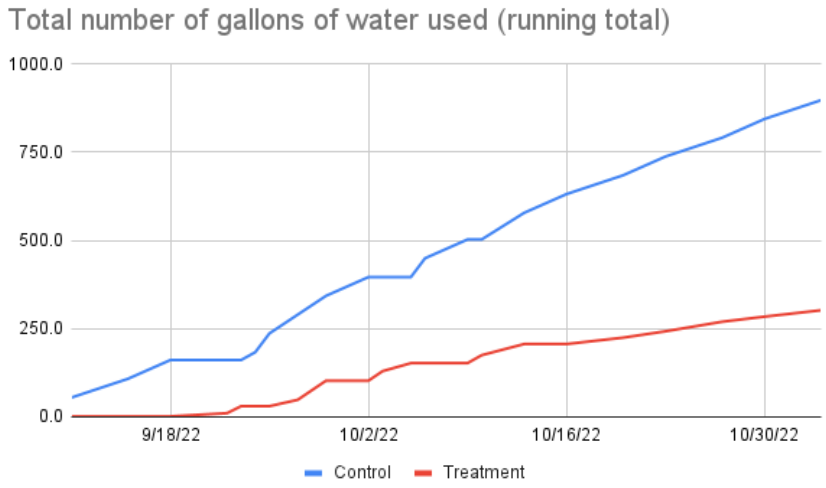


Figure 9

On two occasions, it was necessary to intervene manually in control bed irrigation due to equipment malfunction, but 15 other irrigation events occurred on schedule. The total number of irrigation events on the control bed was 17 with an average length of 59 minutes. The experimental treatment bed was irrigated 13 times with an average irrigation time of 26 minutes.

Overall, the soil moisture sensors resulted in significantly less irrigation for moisture determined irrigation in comparison to time irrigation, without significant difference in plant stress or yields, with the exception of carrot tops in the control bed.

2. **Comparing scheduled and automated irrigation in the context of nutrient leaching**

Standard agrochemical soil analysis is not a decisive measurement with respect to nutrient leaching by water percolation as there are many other factors affecting concentrations of nutrients in extracted soil cores. For example, the fact that parts of the control bed were left without living plants due to their damage by animals is probably a factor in seeing the difference in nutrient runoff measurements. However, we still decided to take a look and compare results (Table 2).

		Nitrogen (NO3-N ppm)			**Phosphorus** (Weak Bray ppm)			**Potassium** (K ppm)			**Calcium** (Ca ppm)			**Magnesium** (Mg ppm)			**Sulfur** (SO4-S ppm)		
		0-6"	6"-12"	12"-18"	0-6"	6"-12"	12"-18"	0-6"	6"-12"	12"-18"	0-6"	6"-12"	12"-18"	0-6"	6"-12"	12"-18"	0-6"	6"-12"	12"-18"
Control	start	56	57	31	291	271	205	532	508	363	4400	4432	2528	433	434	284	634	612	527
scheduled irrigation	end	21	19	8	281	284	221	287	183	315	4092	3782	2684	427	314	266	555	515	216
	change %	-62.50%	-66.67%	-74.19%	-3.44%	4.80%	7.80%	-46.05%	-63.98%	-13.22%	-7.00%	-14.67%	6.17%	-1.39%	-27.65%	-6.34%	-12.46%	-15.85%	-59.01%
Treatment	start	72	71	39	274	255	246	513	489	336	4376	4140	2664	503	477	309	536	594	478
sensor-managed irrigation	end	22	30	21	284	288	269	373	440	369	4126	4164	2928	443	447	344	480	585	467
	change %	-69.44%	-57.75%	-46.15%	3.65%	12.94%	9.35%	-27.29%	-10.02%	9.82%	-5.71%	0.58%	9.91%	-11.93%	-6.29%	11.33%	-10.45%	-1.52%	-2.30%

Leader at the start
Leader at the end
Biggest loss in % compared to the start

Table 2

At the beginning of the experiment, notwithstanding that the two beds were adjacent to each other and prepared using the same equipment and techniques, nitrogen levels were slightly higher, by about 20%, in the treatment bed. Both beds scored “high,” indicating sufficient nitrogen for the growth of good crops. Other nutrients that we compared

(phosphorus, potassium, sulfur, magnesium, and calcium) were also present in different but sufficient quantities in both beds.

At the conclusion of the experiment, in 17 out of 18 measurements, the experimental bed retained more nutrients than the control bed. In all but two measurements, the control bed lost a greater percentage of its nutrients that the experimental bed.

As expected, nitrogen was the most depleted nutrient, with both beds losing around 60% of their plant-available nitrogen when compared to beginning values. The control bed also lost a significant amount of potassium and a noticeable amount of magnesium.

We also observed that some levels increased, although insignificantly. This is especially the case with phosphorus in the treatment bed, which confirms the limited precision of the agrochemical soil test for this kind of experiment.

3. **Passing knowledge to farmers and helping them to implement sensor technology**

As of the date of publication, seven SproutLabs soil moisture sensor devices have been installed on three different farms in Monterey and San Benito Counties. Farmers were provided with soil tests which established field capacity and wilting point boundaries and were led through the first few weeks of using sensors and the online dashboard where they can see individual measurements and graphs. Results and additional installations are pending.[2]

[2] The torrential rains and flooding in Monterey and San Benito Counties during December 2022 and January 2023 will probably postpone further installations and monitoring until such time as affected farms are restored.