REPORT:

New frontiers in irrigation efficiency

The prevalence and hidden potential of drip irrigation issues

Prepared by **Ceres Imaging**

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Summary

Over the past two decades, a shift from flood irrigation to more precise drip irrigation systems (also called microirrigation systems) has contributed to a reduction in water waste by specialty agriculture in California. However, environmental pressures and new regulations—such as the Sustainable Groundwater Management Act (SGMA)—mean that growers must now become even more efficient.

Ceres Imaging, an aerial imagery and analytics provider, reviewed data from more than 700,000 acres of drip-irrigated specialty crops across California to quantify the extent and impact of drip irrigation issues such as clogs, leaks, and pressure problems. We find that quickly detecting and correcting common irrigation issues represents a farmer-friendly opportunity to conserve water, reduce costs, and improve yields.

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Drip irrigation in context

California's $50 billion agriculture industry employs more than 800,000 people and supplies more than half of the nation's fruits, nuts, and vegetables.[1] Of the state's approximately 8.5 million acres of irrigated farmland in 2017, a USDA census found that 11% was irrigated with sprinkler systems, 43% with flood irrigation, and 46% with drip irrigation.[2]

HISTORY OF ADOPTION

Drip irrigation delivers water directly to the root zone of plants, either on or below the soil surface. Compared to flood irrigation systems—in which water is flooded across the field via a system of furrows or trenches—drip-irrigated fields lose less water to evaporation and runoff.[3]

The first practical surface drip irrigation emitters were developed in Israel in the early 1960s. The University of California Cooperative Extension began experimenting with the new technology on test plots about a decade later, eventually hosting educational events and exhibitions that drew hundreds of interested growers.[4] Drought conditions, rising demand for high-value specialty crops, and steadily improving technology boosted adoption rates: in 1991, the California Department of Water Resources reported that 67% of California farmers used flood irrigation; by 2011 that number had fallen below 45%.[5]

1. California Department of Food and Agriculture. (2019). *California Agricultural Production Statistics.* https://www.cdfa.ca.gov/statistics/
2. United States Department of Agriculture. (2017). *Method of water distribution in fields in the open.* https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Farm_and_Ranch_Irrigation_Survey/fris_2_0028_0028.pdf
3. Water Science School. *Irrigation methods: A quick look.* (n.d.). United States Geological Survey. https://www.usgs.gov/special-topic/water-science-school/science/irrigation-methods-a-quick look
4. Gustafson, C. D. (1979). *History and present trends of drip irrigation.* California Avocado Society Yearbook, 47–49. http://avocadosource.com/CAS_Yearbooks/CAS_63_1979/CAS_1979_PG_047-049.pdf
5. California Department of Food and Agriculture. (2014). *Water and the California farmer: Productivity, conservation, stewardship and innovation in agricultural water use.* https://www.cdfa.ca.gov/drought/docs/FactSheet-Water&CalFarmer2014.pdf

ADVANTAGES

Especially relevant in California, where farming conditions vary widely, drip systems are highly customizable and can be tailored to suit different field shapes, crop spacing, soil conditions, and topography. Drip systems allow for automation and precise applications of water, eliminating the need to overwater some areas of a field simply to meet minimum requirements in another area.[6]

A review of 31 studies across 15 different crop types by researchers at University of California Agriculture and Natural Resources (UCANR) found that, on average, drip-irrigated fields produced 16% higher yields versus flood-irrigated fields, with half of the reviewed studies reporting no statistically significant difference in yield and half reporting positive effects ranging from 12% to 66%.[7]

The adoption of drip irrigation systems by California specialty growers has contributed to greater farming efficiency: today the state produces nearly twice as much food as it did 40 years ago, using only 10% more water. Growers of the state's top crop, almonds, have reduced the amount of water used to produce a pound of nuts by 33%.[8]

ON AVERAGE, DRIP-IRRIGATED FIELDS PRODUCED HIGHER YIELDS BY

16%

CHALLENGES AND OPPORTUNITIES

Although drip irrigation has indisputable advantages over flood irrigation and has significantly improved water efficiency in specialty agriculture, it can be costly to install and labor-intensive to maintain.

Drip tape, tubing, and emitters can become clogged with sediment, algae, or chemical buildup from fertilizers, requiring growers to regularly change filters and flush lines. Damage by rodents, machinery, or even root intrusion can cause leaks. Pressure issues within the system may cause underwatering on uneven terrain.

Compared to comparable maintenance concerns in flood or sprinkler systems, these common drip irrigation issues may be physically small and extremely difficult to detect with the naked eye. Often, it is a resulting crop health issue caused by overwatering or underwatering that is noticeable upon inspection, rather than the equipment issue itself. Growers, especially those managing large farms, rely on a combination of water flow meters, soil moisture probes, and periodic distribution uniformity (DU) testing to supplement field scouting—but these tactics may be too localized or too infrequent to detect common drip irrigation issues before they negatively affect crop health.

Finding and correcting drip irrigation issues more quickly therefore represents an opportunity to prevent water waste and protect yields.

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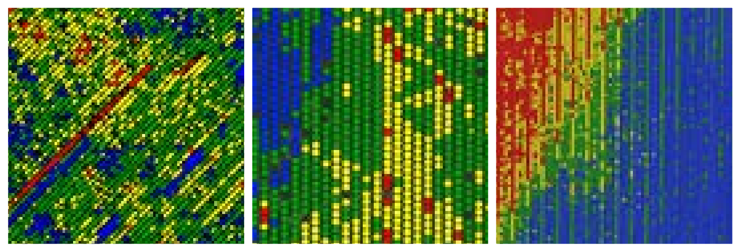
6. Johnson, R., & Cody, B. for Congressional Research Service. (2015). *California agricultural production and irrigated water use*. https://fas.org/sgp/crs/misc/R44093.pdf
7. Parker, D., Zilberman, D., & Taylor, B. (2017, May). *The economic value of drip irrigation in California* [Presentation]. Water in Agriculture Seminar and Discussion, Sacramento, CA, USA. https://secure.cdfa.ca.gov/egov/waterinag/docs/Parker_UC.pdf
8. California Department of Food and Agriculture. (2019). *California Agricultural Production Statistics*. https://www.cdfa.ca.gov/statistics/

Report methodology

Ceres Imaging captures information about customers' crop health using multispectral cameras mounted on fixed-wing planes. The imagery is processed using data models specific to the crop type. Then, a combination of machine learning techniques and human analysis is used to identify patterns in the imagery that are likely to correspond to irrigation issues in the field.

Not all irrigation issues are detectable in imagery. Conversely, not all issues detectable in imagery are irrigation issues. However, imagery in combination with analytics tools consistently reveals the most common drip irrigation issues, including clogs, leaks, and pressure issues.



CLOG | **LEAK** | **PRESSURE ISSUE**

This study evaluates a dataset of 9,401 likely issues flagged in customer data from California specialty crops between March 1, 2020, and September 30, 2020. The study comprises 3,509,263 "flight acres"—or slightly more than 700,000 unique acres—where 1 unique acre flown 5 times over the course of the season is equal to 5 flight acres. The study does not include issues believed to affect an area of less than one acre.

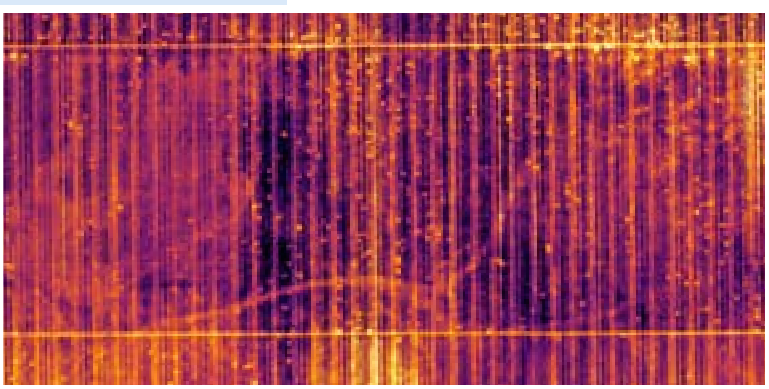
PRECISION THERMAL: THE KEY TO AERIAL IMAGERY FOR IRRIGATION

Thermal imagery captured from the air makes visible the heat emitted from objects on the ground, revealing temperature differences that correspond to crop stress. Ceres Imaging uses scientific-grade thermal cameras capable of detecting temperature differences as small as 0.1 degree Celsius between plants—a level of precision that distinguishes the product from commonly available satellite imagery.

Careful calibration and image correction ensure that irrelevant objects—for example, equipment, ground cover, or soil—don't skew the data. In the resulting imagery, cooler areas appear purple, while warmer areas appear yellow.

Because water cools vegetation, thermal imagery is useful for detecting leaks, clogs, and other irrigation issues. By revealing subtle changes in leaf surface temperature, thermal imagery also helps growers detect pre-symptomatic disease and pest pressures—and respond with more timely and more targeted interventions.

High-resolution thermal imagery →



Report findings

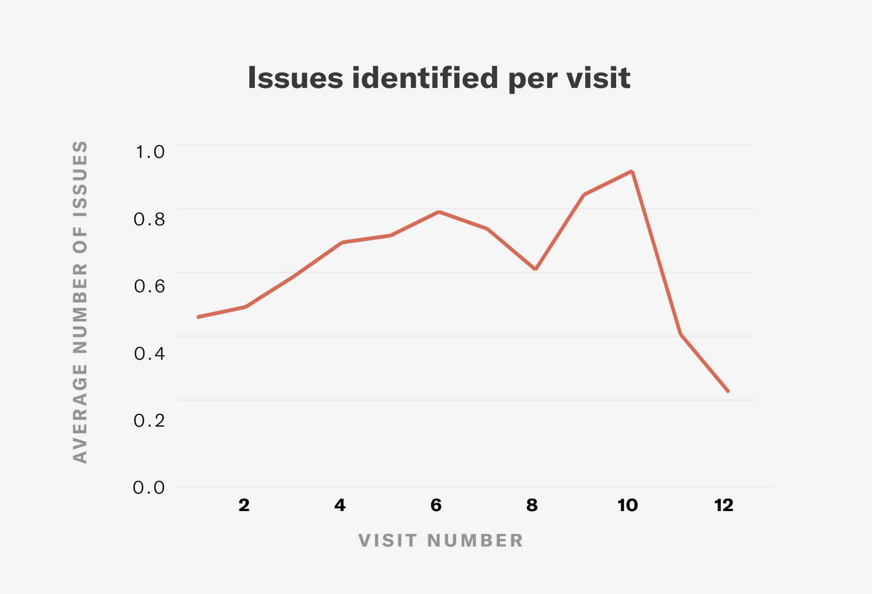
HOW COMMON ARE DRIP IRRIGATION ISSUES?

In drip-irrigated specialty crops in California, Ceres Imaging identifies 27 acute irrigation issues per 1,000 unique acres over the course of a season. We identify an irrigation issue affecting more than 10 acres for every 170 unique acres.

WHEN ARE DRIP IRRIGATION ISSUES MOST COMMON?

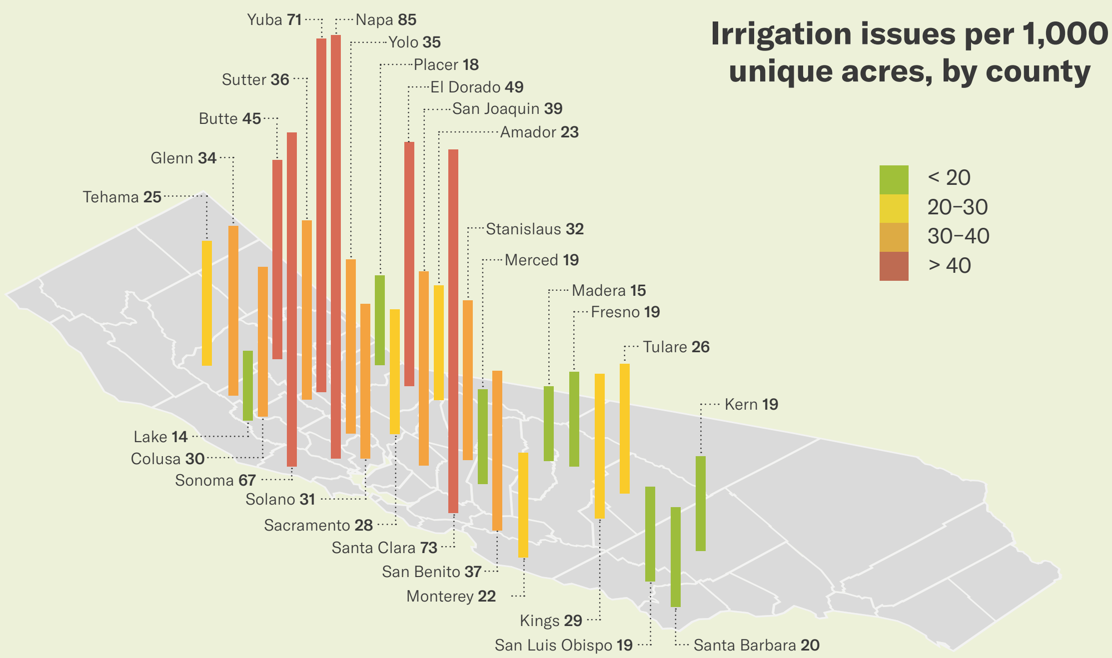
Ceres Imaging captures customer data between 4 and 12 times per season, depending on the customer's service agreement. With some variation by crop and region, California customers' flights typically begin in April and conclude in September.

Irrigation issues may be more easily detected in hot summer months because crops are more vulnerable to stress. However, issues are detected throughout the season—an indication that growers relying on annual or bi-annual distribution uniformity (DU) tests to ensure proper performance of their irrigation system may be missing opportunities to improve efficiency.

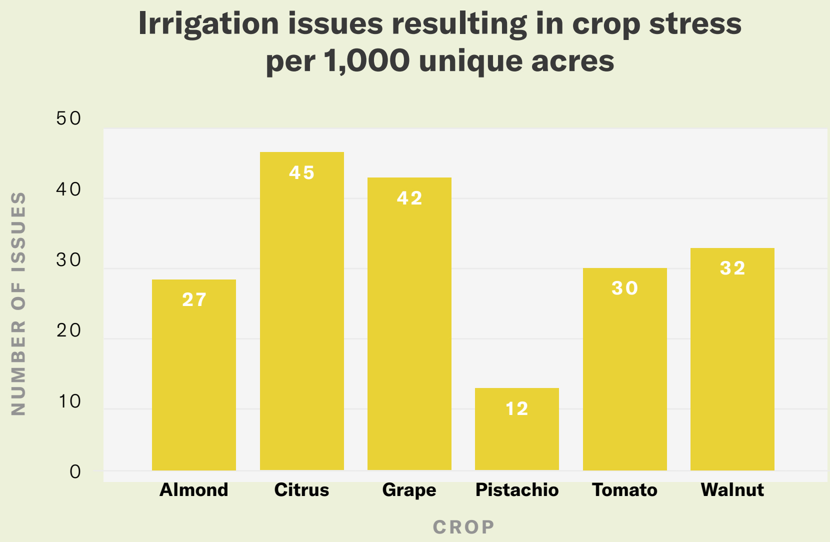


WHERE ARE DRIP IRRIGATION ISSUES MOST COMMON?

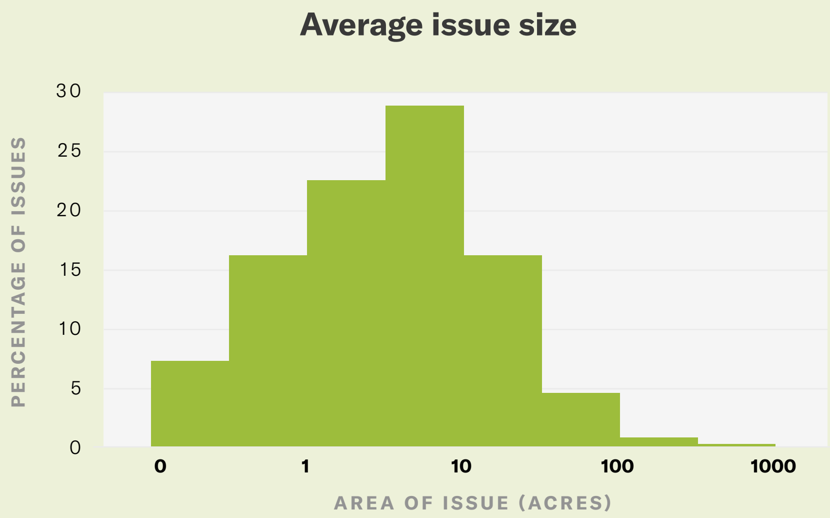
Drip irrigation issues may be more common in regions with more variable topography and soil conditions.



HOW DOES THE IMPACT OF DRIP IRRIGATION ISSUES VARY BY CROP?



HOW LARGE ARE DRIP IRRIGATION ISSUES?



MEAN ISSUE SIZE
9.9 acres

MEDIAN ISSUE SIZE
3.3 acres

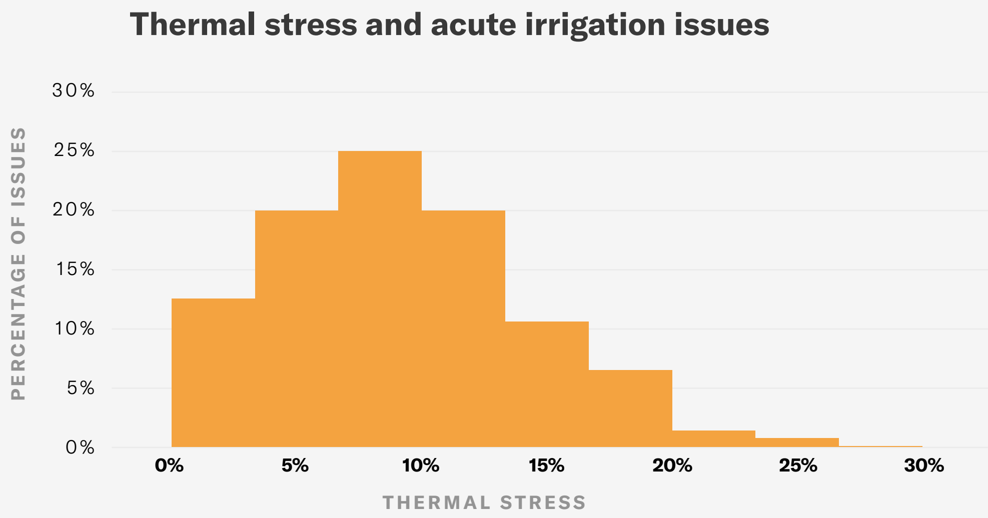
Understanding the impact of drip irrigation issues

CLASSIFYING SEVERITY

For the purpose of our analysis, Ceres Imaging classifies issue severity in terms of thermal stress. Our method is as follows:

- We estimate the crop water stress in a field based on our measurement of canopy temperatures and localized weather data—such as air temperature, humidity, and net radiation—from which we can gauge the differences in plant transpiration rates
- We measure the extent of the suspected issue—i.e., the area of high stress
- We estimate the crop water stress in that area by considering the typical crop water stress we have observed in the issue area, and the crop water stress observed in nearby parts of the field

Using this method, we find that the average issue results in 8.8% more stress on the affected area than the unaffected area.



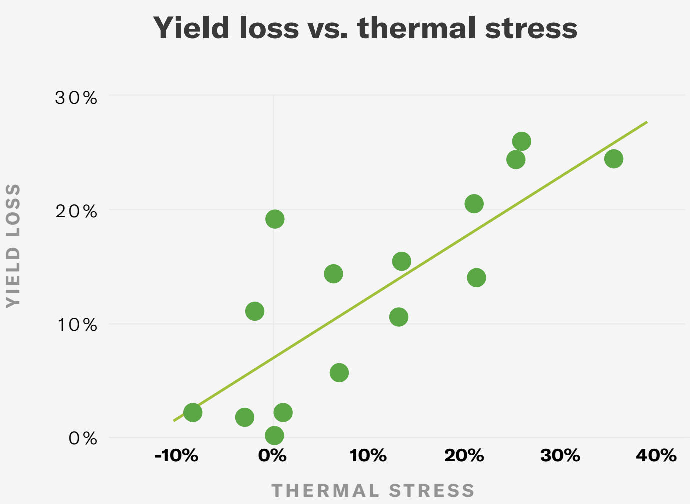
ESTIMATING IMPACTS ON YIELD

This study uses thermal stress measurements to estimate the impact of irrigation issues on yield in drip-irrigated specialty crops.

It's important to recognize that there are inherent limitations to precise quantification of how irrigation issues impact crop yield: many factors affect yield, and isolating the effect of irrigation issues is difficult. Furthermore, the effect of water stress varies by crop.

To estimate the impact on irrigation issues on yield, we therefore consider Ceres Imaging customer data, collected between 2014 and 2020, in combination with findings from a four-year study of almonds in partnership with Blake Sanden at the University of California Cooperative Extension. The results of our work with Sanden and others inform the relationship assumed in this report, that a 10% increase in stress results in a 5.5% decrease in yields.

The figure below shows the relationship between thermal stress and yield within 1-acre plots in the experimental almond orchard investigating the relationship between water and yield in almonds.



EXAMPLE: ESTIMATING IMPACT OF IRRIGATION ISSUES ON GROWER REVENUE

For a hypothetical grower with 1,000 acres of drip-irrigated almonds:

27 issues	x 9.9 acres	x 0.0484	x $8,000	= $103,499
Average issues detected per season	Average issue size	Estimated impact on yield per average issue	Average revenue per acre	Estimated revenue losses per season

9. Goldhamer, D. A., & Fereres, E. (2016). *Establishing an almond water production function for California using long-term yield response to variable irrigation.* Irrigation Science, 35(3), 169–179. https://doi.org/10.1007/s00271-016-0528-2

SUSTAINABILITY IMPLICATIONS

Our data show that drip irrigation issues such as clogs, leaks, and pressure issues are widespread in California speciality agriculture. We believe that these issues contribute to water waste and lost yield, both directly (e.g. water lost from a leaking line) and indirectly (e.g. crop health issues caused by persistent underwatering). However, a review of the existing literature finds a surprising lack of research and analysis available to conclusively quantify the water waste or yield loss associated specifically with drip irrigation issues at a statewide level.

Further research in this area is important because a quantitative understanding of sustainability impacts may further substantiate the argument for investment in techniques and technologies that help growers more quickly detect and correct common drip irrigation issues. Just as in California specialty agriculture's initial transition from flood irrigation to drip irrigation, incentives, support, and knowledge-sharing around the ROI of optimizing drip systems will help to facilitate the next phase of improvements in agricultural water use efficiency—improvements all the more urgent in the face of a changing climate.

Recommendations for stakeholders

FOR POLICYMAKERS

1. Familiarize yourself with the latest advances in and capabilities of irrigation technology.
2. Consider timely irrigation issue detection as an efficient and farmer-friendly route to reducing water use—with potential for other additional related environmental benefits, including reduced nitrate leaching and reduced energy, pesticide, and fertilizer use.
3. Consider options for incentivizing irrigation system evaluation and monitoring, such as remote sensing technologies and distribution and transpiration uniformity testing.

FOR GROWERS

1. Check for drip irrigation issues more frequently and more thoroughly: a DU test every few years is likely not enough. Aerial imagery provides a cost-effective means to more frequent checks for irrigation issues.
2. Ensure that field staff are trained, empowered, and incentivized to identify and act on irrigation issues throughout the season.
3. Track irrigation issues identified and resolved in order to measure improvement over time.

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