Cover Cropping in California's Water-Scarce Environments: COVER CROPPING IN ANNUAL SYSTEMS

Background

Over the past 15 years, rain and fog patterns in the Central Valley have shifted toward drier winter conditions that are occasionally interrupted by extreme precipitation events. As growers navigate flashier, drier winters and groundwater pumping regulations, decisions like when to plant cover crops or whether to plant at all are increasingly challenging.

Yet research across the Central Valley offers reassurance on a key water-use question. Rainfed cover crops grown from late fall through early spring generally use no more water than bare fallow fields during the core winter months — a finding that holds across different valley regions and year types.

For wet winters, cloudy and foggy conditions reduce the potential for evapotranspiration (ET). As there is less energy (sunshine hours and warm temperatures) to evaporate water, loss from soils through cover crops is generally minimal.

Key Terms

***Evapotranspiration* (ET)** is the total water loss from the land to the atmosphere through plant transpiration and evaporation from soil and other surfaces.

***Reference evapotranspiration* (ET_o)** is a standardized measure of atmospheric demand ("thirst") calculated as water lost from a well-irrigated, mowed cool-season grass field[1]. It is often calculated using weather station data and the Penman-Monteith equation (*PM* ET_o).

***Actual Evapotranspiration* (ET_a)** is the actual quantity of water lost through evaporation and transpiration, dependent on water and energy availability and status of vegetation. For agricultural crops, ET_a is also called crop water use. ET_a is most accurate if measured directly, though estimates made via remote sensing are increasingly being used and refined with in-field research.

***Precipitation* (PcP)** is liquid or solid water that falls from the atmosphere to the ground. Because it is driven by large-scale atmospheric circulation, it varies across the landscape and is difficult to forecast reliably beyond a 7-14 day window.

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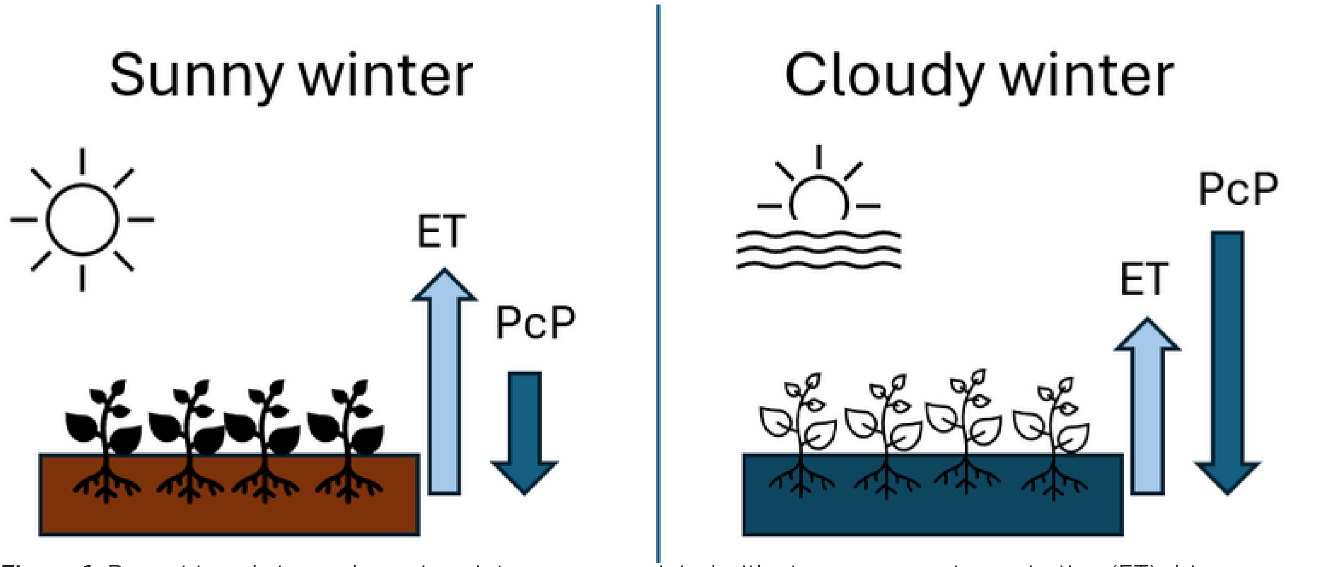

Figure 1. Recent trends toward sunnier winters are associated with stronger evapotranspiration (ET) drivers, reduced precipitation (PcP), and lower soil moisture. In contrast, cloudier and foggier winters are associated with higher precipitation and weaker ET drivers. While winter ET varies less between the season and different regions, recent shifts toward less precipitation and more ET are making soil water less available.

Decades of research observations show that ET is influenced by the atmosphere's 'thirst' and also by crop type, agronomic practices, and crop establishment success. In recent years, field **experiments across the three different Central Valley areas confirm that as long as there is water and energy available, precipitation water is lost as ET from all moist surfaces, including soil and plant tissue, whether fields are bare ground-fallowed or covered in vegetation[2,3,4].**

Cover crops may increase available soil water compared to bare ground, particularly in high precipitation years, by improving soil water infiltration[5,6] and shading the soil surface (reducing evaporative losses). More information is needed, however, on how to balance cover crop water use with potential water benefits given the unpredictability of different hydrological years and field-specific factors.

Comparing regional winter water supply and use

The Central Valley encompasses three major regions: the Sacramento Valley (SV), the Sacramento-San Joaquin Delta (D), and the San Joaquin Valley (SJV), which can be divided into two subregions with distinct precipitation and climate patterns, the Northern SJV (NSJV) and the Southern SJV (SSJV). The regions are interconnected by important hydrological pathways that are shaped by differences in ET_o, precipitation, and soil water retention.

Since ET_o reflects atmospheric water loss based on local weather conditions, it is helpful to compare it to precipitation—the primary water source for wintertime rain-fed cover crops (Figure 2). This comparison helps evaluate the balance between water supply and water demand.

Here, we use this approach to gain insights into: (1) differences among annual cropping regions of the Central Valley, and (2) year-to-year variation within regions.

Over the last 30 years, winter water loss to evapotranspiration (ET_o) has been similar across the SV, NSJV, and the D—ranging from a median of 10-12 inches. Precipitation, however, has differed substantially: it is highest in the SV, lower in the D, and lowest in the SSJV—ranging from a median of 4 (SSJV) to 14 inches (SV). Only in the case of the SV is the median precipitation greater than the median ET_o.

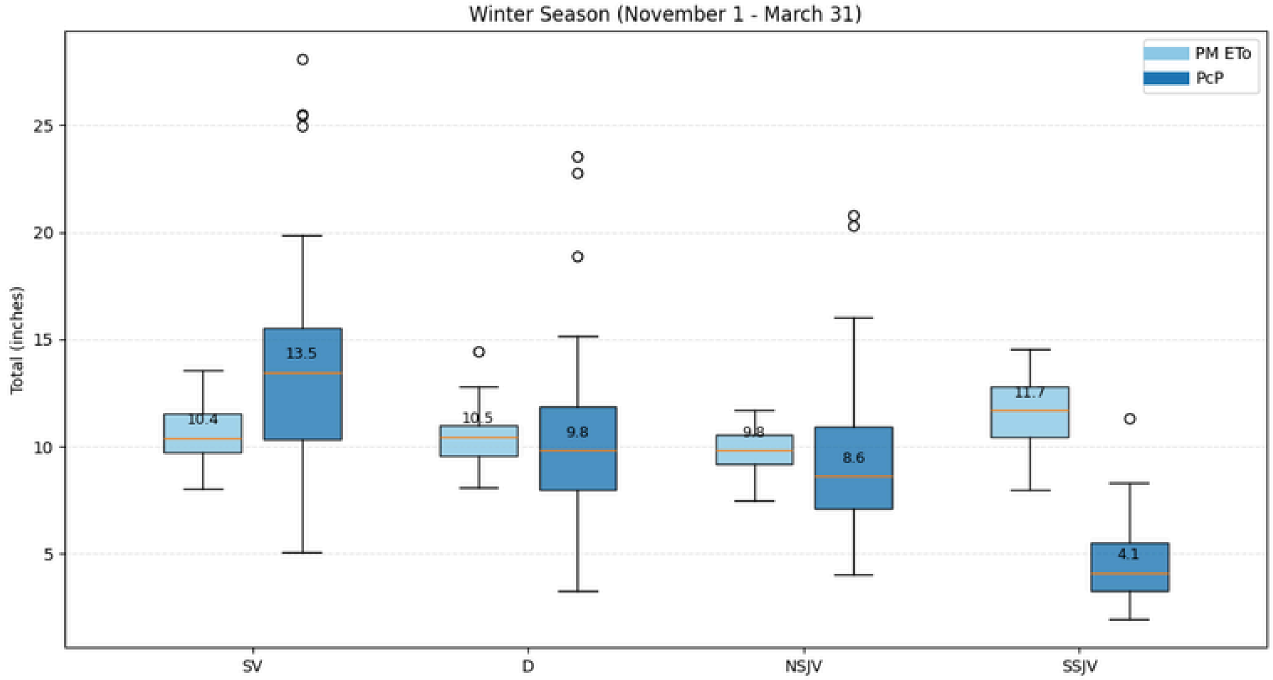

Figure 2. Long-term (30-year) cumulative winter precipitation (PcP) and Penman-Montheith reference evapotranspiration (PM ET_o) for 4 hydrologically different agricultural areas of the Central Valley of California: Sacramento Valley (SV), Delta (D), Northern San Joaquin Valley (NSJV) and Southern San Joaquin Valley (SSJV) span from 1997-2026. CIMIS sites for data retrieval: # 6 (SV), #140 (D), #70 (NSJV), and #105 (SSJV).

Regional soil types and groundwater considerations

In addition to its variable precipitation, the Central Valley also has highly diverse soils and varying groundwater levels. In the SV, annual crops are grown on soils ranging from poorly drained, heavy clay rice soils to lighter, loamy soils commonly used for other annual rotations or woody perennial crops. The soils in the D are primarily organic peatlands and fertile mineral soil types. In contrast, the SJV has deep, well-drained alluvial soils, as well as areas affected by high salinity. These regional differences in precipitation patterns and soil characteristics impact water availability for cropping systems.

Timeline considerations for cover crops in annual systems

In annual systems, cover cropping "windows" refer to periods between cash crops. Both warm-season and cool-season cover crops can be used. Warm-season cover crops, planted immediately after cash crop harvest between July and October can take advantage of residual moisture from irrigation. However, a few inches of irrigation will likely be needed for establishment. Once established, these crops provide soil cover during fall and winter rains.

Winter cover crops are typically grown without irrigation. Early in the season, they have small leaf areas, leaving much of the soil surface exposed as the cover crop establishes. Both too little and too much fall precipitation can be detrimental to cover crop establishment, adding to the complexity of management and planning.

October temperatures are typically warm enough, and with existing soil moisture, cover crops may have beneficial conditions to start and establish before the cool, short days of winter. However, rainfall in October has become less reliable, making the moisture available for cover crop establishment increasingly uncertain. Although deeper soil layers may retain some moisture from the previous crop, seeds planted to shallow depths may fail to germinate without supplemental irrigation or timely rainfall.

ET_o and precipitation can help us understand monthly potential for plant development and water use patterns. Over the past 30 years, average October ET_o has often been double that of November – and sometimes even higher — across all three regions of California's Central Valley, indicating high atmospheric 'thirst' early in the fall. Losses to ET_o are lowest from November through the end of February. This supports cool-season cover cropping to minimize water use. ET_o begins to rise in February and March compared to low January levels, and continues to increase in April – often resulting in cumulative April ET_o values that match or exceed February and March combined.

While most cover crops in annual systems are terminated early to ensure optimal establishment of the following cash crop, some are allowed to grow longer in order to take advantage of increased biomass production during the warmer spring months. By April, a well-established cover crop can rapidly deplete soil moisture as it continues active growth and root development. Rainfall in the months of October and April often fails to offset ET_o losses, especially in the SSJV, and year-to-year variability adds risk statewide.

However, if heavy late-season rainfall occurs, a cover crop may increase infiltration and slow soil dry-down prior to spring planting. Moreover, many of the agronomic benefits of cover crops linked to biomass accumulation or N-fixation by legumes are largely achieved during the warm spring months of March and April. These are also the months when both crop ET_a and ET_o increase rapidly. For some growers, decision-making is guided by greater residue to manage and additional moisture loss, prompting earlier cover crop termination and foregone biomass accumulation.

Monitoring winter cover crops in the spring and timing termination to conserve soil moisture for the next cash crop can help balance these trade-offs. In very wet years, some growers in the SV and D regions use cover crops to drive the surface moisture out of the soil for easier spring soil management. A cost-benefit analysis might be crucial for growers' decision-making.

Species selection should be driven by grower goals

Since the growing window for each cover crop is related to different resource concerns (such as weed suppression, nitrogen addition or scavenging, increasing infiltration in a soil type prone to crusting, soil salinity reduction, carbon sequestration, or breaking pest and disease cycles), species selections should be tailored to grower goals. One of the resources available to help with cover crop selection is the Cover Crop Species Selector. It can be used to select cover crops based on specific goals, the user's location, and the establishment window of the cover crop. The website is also a comprehensive cover crop database with robust information about each species related to agronomic considerations, growth habits, environmental tolerances, and management information such as potential pest risks and termination considerations.

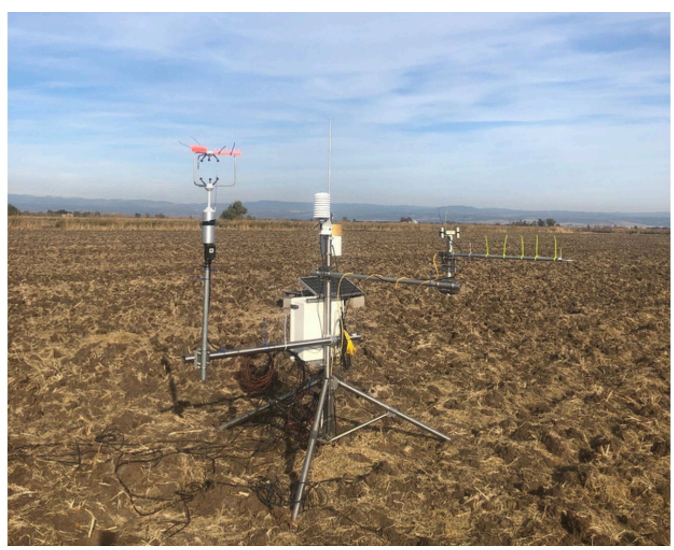

Figure 4. Rice field fallow ET_a measurement

Insights from the Valley

Given the potential for both drought and high-volume winter rain events, winter cover crops can benefit annual cropping systems if they can capture more winter moisture than they lose in ET. Research from the UC Davis Biometeorology Group has examined several cover cropping scenarios in annual systems, including: (1) Cover crops vs bare fallowing in rice systems in the SV, (2) Cover crops vs bare fallowing vs winter bird flooding vs cash crops under drought management in the D, (3) Cash crops used as winter forage cover (e.g. safflower and sugar beet) in SJV dairy farms.

When experimental ET_a measurements across different winter field managements in annual agricultural systems across the Central Valley are combined, they have found that most of the time ET_a is lower than ET_o (Figure 3). This is partly because the calculation of ET_o is based on an established, well-watered reference grass surface, while cover-cropped systems are rainfed, commonly seeded into bare soil, grow through the winter, and may or may not be terminated in the springtime, which altogether yields limited canopy cover. We can think of ET_o as an upper limit of what a rainfed cover crop might transpire over the winter months, assuming that winter weather supports optimal seed germination and cover crop development.

While using ET_o to estimate cover crop water use would be relatively simple, it's important to note that a fully irrigated grass (ET_o) does not reflect initial growth and development stages of cover crops, which generally have much lower water demand. Rather, winter cover crop water use is more comparable to bare soil, particularly during early establishment and before canopy closing.

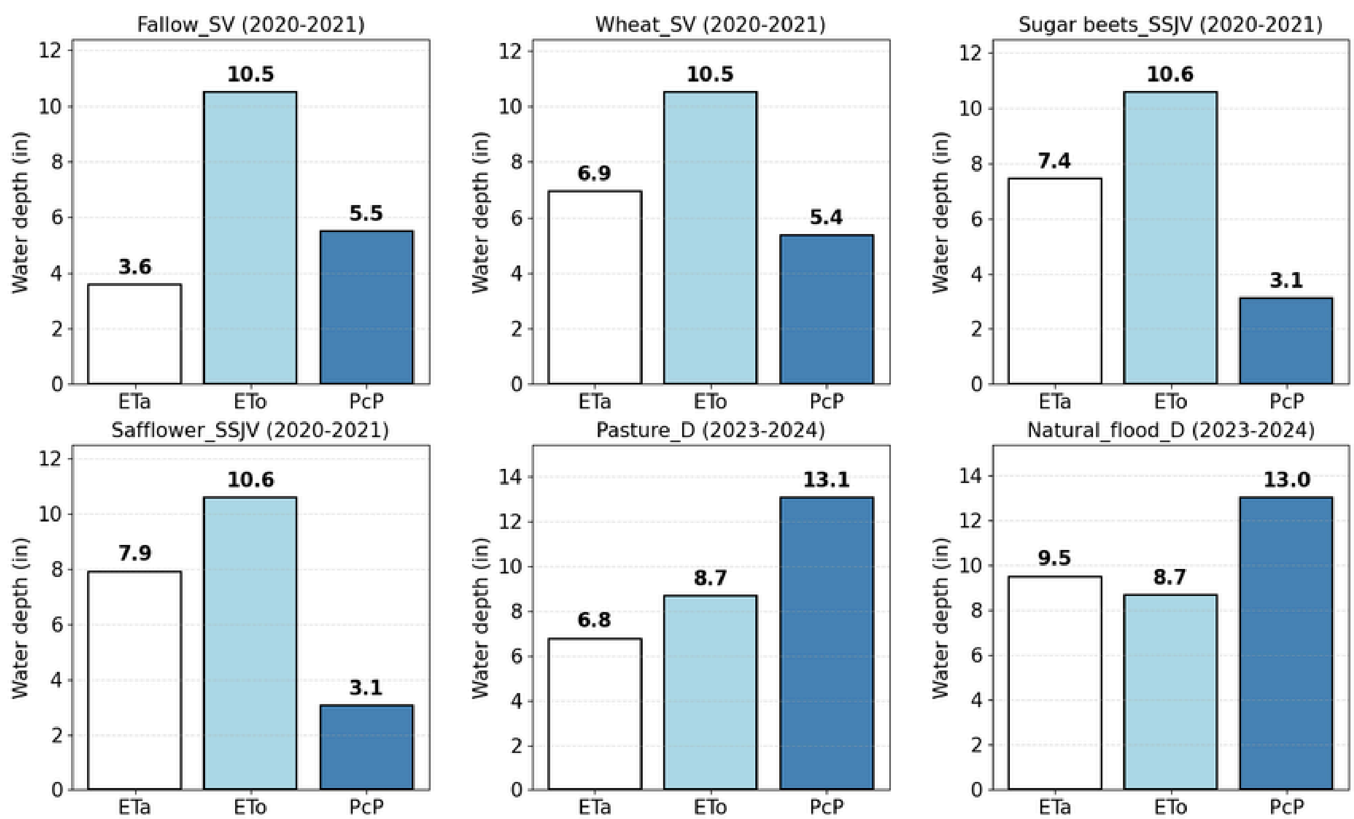

Figure 3. Long-term winter ET_a vs ET_o for all the winter experiments done across the SV, D, and SSJV for winter period (November 19 - March 31). Bars represent: ET_a (actual evapotranspiration: measured water loss from soil and vegetation under real field conditions), ET_o (reference evapotranspiration: theoretical water loss from a fully irrigated, actively growing grass surface, used as an upper benchmark), and PcP (precipitation, in inches of water depth). Values reflect multi-year averages from long-term experiments.

Conclusion

California's hydroclimatic conditions and weather patterns vary from year to year and cannot be predicted far in advance due to the chaotic nature of atmospheric processes (despite modern technologies). However, one consistent trend is the decline in winter fog across the Central Valley in recent decades. Direct measurements of ET_a in annual crop fields that include off-season measurements are scarce in California. In general, local research shows that cover crops use more water when they have more biomass and are actively growing under warmer 'thirstier' months. With a winter cover crop, this would be in the later spring months.

Despite these challenges, winter cover crops improve soil water infiltration and increase soil water storage, enhancing water availability for subsequent cash crops. This benefit might be especially pronounced in the northern part of the Central Valley, where higher winter precipitation increases the likelihood that cover crops will grow successfully with rainfall. Managing or removing winter cover crops early to conserve spring soil moisture, particularly in drought years, can be an effective way to preserve soil moisture for the following cash crop.

This publication is based on a combination of regional expertise and data from local experiments with the aim of providing current knowledge and guidelines on how cover crop management in annual agricultural systems can maximize water benefits. The focus is on the Central Valley of California and specific local barriers and expected agronomic benefits, and does not represent all the diversity of conditions and cover cropping practices that farmers use across the Central Valley.

Holland Tract, Sacramento–San Joaquin River Delta, January 2024, photo credit: Olmo Guerrero Medina

Research Case Studies

Winter water use for cover crops versus bare fallow in rice production[2]	Sacramento Valley

LAND COVER COMPARISON

1. Bare ground fallow with some resident vegetation
2. Planted but otherwise unmanaged cover crops
3. Winter wheat minimally irrigated during dry years only

CONTEXT

In California's Sacramento Valley rice-growing region, winter-season cover can provide a multi-benefit alternative to bare fallowing as growers navigate water shortages and increasing drought pressure. Over three years, measurements of winter ET_a were collected across fields managed with these different winter strategies.

RESULTS — WATER USE

Wet year
ET_a for bare fallow fields and covered fields did not differ. This indicates that winter cover-cropped fields did not lose more water than bare fallow fields under non-irrigated winter conditions.

Dry year
Winter wheat required irrigation, resulting in a relatively uniform, high biomass stand with higher ET_a compared to the patchy, uneven vegetation in the unmanaged cover crop treatment or the bare fallow.

THINGS TO CONSIDER

Winter weather conditions strongly influence cover crop establishment and water use. Very wet winters in high clay soils result in flooding, and after managing for drainage, establishing a uniform cover crop can be challenging. Alternatively, dry winters may not provide enough moisture for cover crops to establish. In both cases, fields may end up with patchy mixed vegetation whether they were cover-cropped or bare fallow, which likely contributed to the similar ET_a values observed.

TAKE HOME

For SV rice fields, wintertime water lost from rainfed cover crops is similar to that of bare fallow fields. Even for minimally irrigated winter wheat, water losses are greater. These findings are similar to the recent report comparing water use of fallowed land to a dry farmed winter cereal (PPIC, 2022).

Drought management and bird habitat[3]	Sacramento-San Joaquin Delta


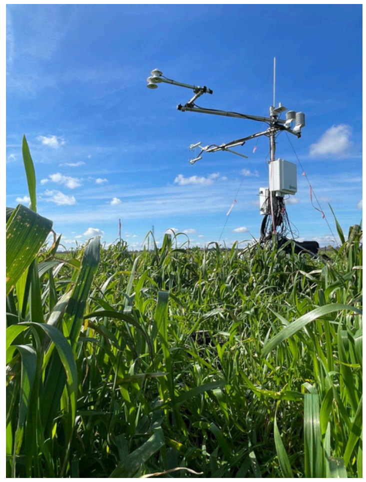


Figure 5. Delta Drought Response Pilot Program Field Experiments in Winter 2024

LAND COVER COMPARISON

1. Bare ground fallow
2. Planted cover crops
3. Winter cash crops
4. Wintertime flooded bird habitat

CONTEXT

In addition to wintertime land uses of bareground fallow, cover crops, or winter cash crops, some Delta fields are intentionally flooded in the winter to provide bird critical habitat along the Pacific Flyway. As part of the Sacramento-San Joaquin Delta and Delta Drought Response Pilot Program, we measured year-round ET_a across fields under different winter management scenarios (Figure 5).

RESULTS — WATER USE

In winter, the treatment with higher winter ET_a values was the bird-habitat flooding. ET_a values were similar between the cover crop, fallow, or winter cash crop treatments. The differences in ET_a mainly occurred in the late spring and summer months, when management and crop choice play a larger role despite the non-irrigated conditions in this study.

THINGS TO CONSIDER

Although some irrigation was allowed to help establish the crop in this drought management program, growers in our study did not have to irrigate their summer cash crops because there was sufficient residual winter moisture in the soil for the low-water-use crops they selected.

TAKE HOME

In the Delta, soil water losses from winter cover crops using rainfall were similar to losses from winter cash crops or bare fallow, while only winter bird-habitat flooding increased ET_a.

Cash crops as winter forage cover[4]

South San Joaquin Valley


Figure 6. Sugar beet (left) and newly seeded safflower (right) grown as a winter cover crop

LAND COVER COMPARISON

1. Sugar beet winter cover
2. Safflower winter cover

CONTEXT

Sugar beet and safflower, which are known for their deep-rooting structures and ability to scavenge nitrate from deeper soil layers, were studied on SSJV dairy farms to explore their benefits as potential winter forage crops. Though the species have not been widely adopted as a winter dairy forage crop, their water use dynamics provide additional insight about winter cover in the context of the SSJV.

RESULTS — WATER USE

For both winter-planted cover types, ET_a measurements started on the same day in November. Our measurements showed that ET_a was low over the winter and early spring months, but as biomass increased, ET_a was similar to ET_o. The sugar beet crop used more total water because of its longer growth cycle and greater biomass production (~13.3 tons/acre dry matter) and summer harvest date. Safflower developed a large biomass (~5 tons/acre dry matter) but with significantly lower water use because it was harvested at the beginning of April.

TAKE HOME

In the SJV, winter cover with deep-rooted crops such as sugar beet and safflower may be attractive forage crops due to the capacity to scavenge residual water and nutrients from deeper soil layers after the main crop. For both species, ET_a was measured to be lower than the ET_o cumulatively for the winter growing period, but greater than the water supplied by precipitation, suggesting that deep-rooted cover uses deep soil moisture and winter rain supplies for their growth.

Winter cover in processing tomatoes[7]

Sacramento and San Joaquin Valleys

LAND COVER COMPARISON

1. Winter cover crop in processing tomatoes
2. Bare ground in processing tomatoes

CONTEXT

A three-year study conducted by UC Davis researchers examined wintertime soil moisture levels across four annually rotated processing tomato farms with clean-cultivated bare ground or cover-cropped management. Two sites – one in Davis and one in Five Points – also included measurements of ET_a to assess cover crop water use compared to bare-ground management.

RESULTS — WATER USE

In annually rotated systems, differences in ET_a between bare ground and cover-cropped fields were small, ranging from 0.1 to 0.7 inches. ET_a was higher at the SSJV site, but at both locations ET_a was below ET_o. Soil moisture was generally not different between cover-cropped and bare-ground-managed fields through the winter months.

TAKE HOME

Overall, the study shows that winter cover—whether cover crops or resident vegetation—has little to no impact on water use during the winter months.

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Resources:

This report and other mentioned resources can be found at: https://linktr.ee/CoverCropGuidance

Additional resources:

- Free, realtime access to meteorological and PM ET_o data for CA: cimis.water.ca.gov
- CropManage models nutrient and water management with ET_o and crop-specific coefficients to calculate water needs in CA: cropmanage.ucanr.edu
- The Western Cover Crop Selection Tool can be used as a resource to select cover crops based on specific management goals, farm location, and establishment windows.

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