Final report for 2019-2021 project funded by Rice Research Board on:

RM-13: QUANTIFYING WATER USE OF COVER CROPS IN ROTATION WITH RICE

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Introduction

California rice fields are highly productive agricultural systems, showing the integration of highly intensive agriculture with valuable ecosystem services. These systems also provide valuable habitat for a wide range of wildlife, including migratory and resident waterfowl. While large scale conversion of lands back into permanent upland habitat is unlikely in the Sacramento Valley in the near future, there is an opportunity to create seasonal, upland nesting habitat on these agricultural lands. Fallowing that occurs in association with organic rotation in rice cropping or in direct relation to water sales that benefit both grower and California state water allocation planning is a good opportunity for breeding waterfowl (Table 1). The creation of seasonal habitat can be done by establishing cover crops in fallow rice fields and maintaining them through the waterfowl breeding season. The cover crops provide a win-win solution for utilizing fallowed lands by providing both soil health benefits and nesting habitat on agricultural lands. Cover crops in Sacramento Valley grown in rice fields rely mostly on rain and water storage in the soil for their growth. We were motivated to measure water use of non-irrigated cover crops grown in rotation with rice and to determine whether winter cover crops can increase soil water storage if they are allowed to grow into mid-July. We are reporting first and second year measurement outcomes.

Table 1. Graphic demonstrating two options for a cover crop planting. The first is that there are no water sales so the crop is terminated and the field is planted to rice. The second option is that there is the potential for water sales so the crop remains in the field until mid-July. The graphic indicates the months the cover crop is in the field as well as when water fowl may be using the fields.

	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**
Option 1		No water sales: cover crop or wheat is terminated at end of March						Rice				
Option 2		Water sales: cover crop or wheat is allowed to grow until mid-July. Cover crops turned in/wheat harvested for grain										
Waterfowl nesting						X	X	X	X	X		

Year 1

Measurements setup

In the first year of the study, which spanned from November 2019 to June 2020, we conducted a measurement campaign over four fields in Yolo County to quantify the differences in evapotranspiration between a fallow field and three fields under different non-irrigated cover crops. We have chosen three fields to do measurements representative of water use of three cover crops that are beneficial for nesting birds and are often grown in rotation with rice in Sacramento Valley: (1) vetch, (2) winter wheat and (3) cover crop mix (oats, pea and vetch). The fourth field was fallow equipped with the same measurements in order to quantify the water evaporation when crops are not grown. Eddy covariance measurements used here are one of the most direct methods to measure evapotranspiration.

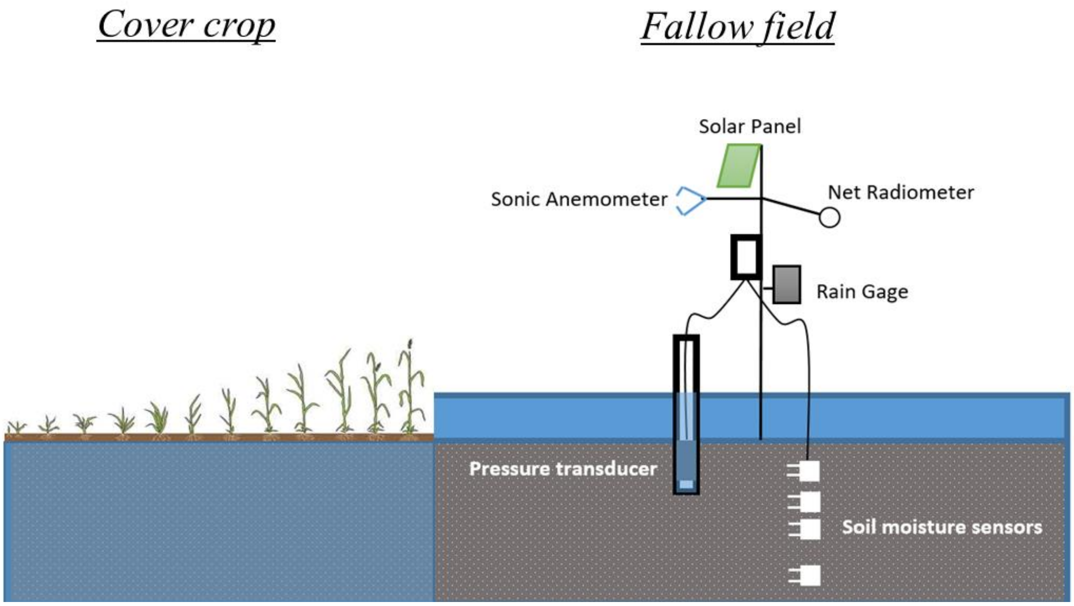


Figure 1. Measurements scheme of water use as evapotranspiration and water monitoring in the soil

Figure 2. Evapotranspiration measurements using eddy covariance stations in winter wheat and fallow fields

Things to consider

After the cover crops' senesce there were still weeds that were green and transpiring (Figure 3). Due to very dry winter, winter wheat was irrigated multiple times in order to secure the grain yield. And fallowing in the field for our baseline measurements was interrupted in mid-April by planting safflower. Since the safflower is deep-rooted crop, our measurements would not be representative of the evaporation of the fallow field and we had to assume no evaporation after mid-April. But these values should be taken with caution. With the new measurement season we hope to have evaporation measurements in fallow field done over the whole period between November and mid-July.

Figure 3. Weed growing after cover crop senesce in our experimental fields

Preliminary results

Daily evapotranspiration values (Figure 4), as expected, were very low in the winter when all four fields were resembling the conditions of the fallow field. The major development of the cover crops started in mid-February, and that is when we observe major differences between the fallow field and the cover crops water use. Winter wheat was developing more biomass than vetch and cover crop mix, and its water use was slightly higher. Although the winter wheat and other cover crops were senescing at a similar pace, there were weeds in the rice fields that were not spotted in the uniformly dry winter wheat crop. Those weeds were driving more evapotranspiration than cover crops alone and that can be observed on the Figure 4 in the period after mid-May when the ET of winter wheat is for the first time significantly lower than the other two crops (Figure 3). Figure 4 also show how we forced the fallow field ET to zero (due to safflower crop development) after mid-April although this was an assumption that needs to be re-evaluated with our new measurement season results.

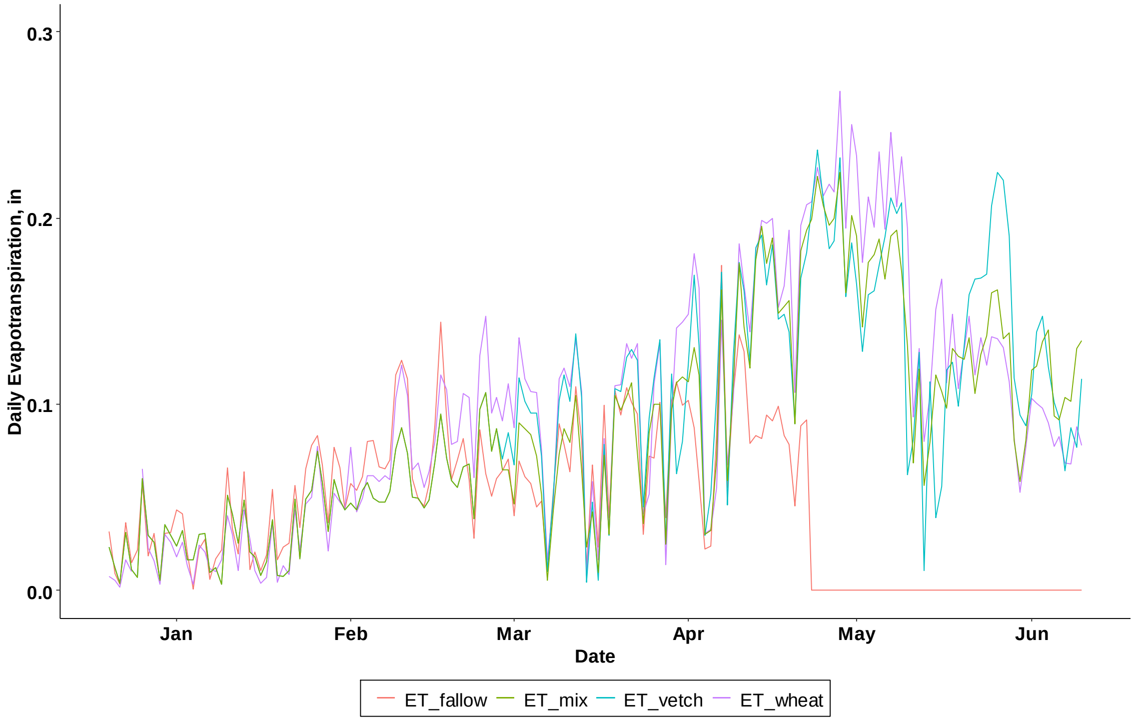


Figure 4. Daily water use through evapotranspiration on different cover crops compared to the fallow field during full measurement season.

When cumulative ET values were computed over the whole measurement season (Figure 5) we can see better the differences in water demand between the different studied fields. Winter wheat used 16.74 inches of water, vetch field used 15.7 inches and the lowest water use (next to the fallow field) was in the mix of cover crops. We can also see that precipitation, as a natural supply of water, was higher than the water use of all four fields until first days of February. That difference in supply and demand amounts of water was probably useful soil storage to be used for subsequent crop development of winter wheat, vetch and cover crop mix. The winter wheat grower decided to start irrigation on March 13th and there were another two irrigation events for the rest of the season.

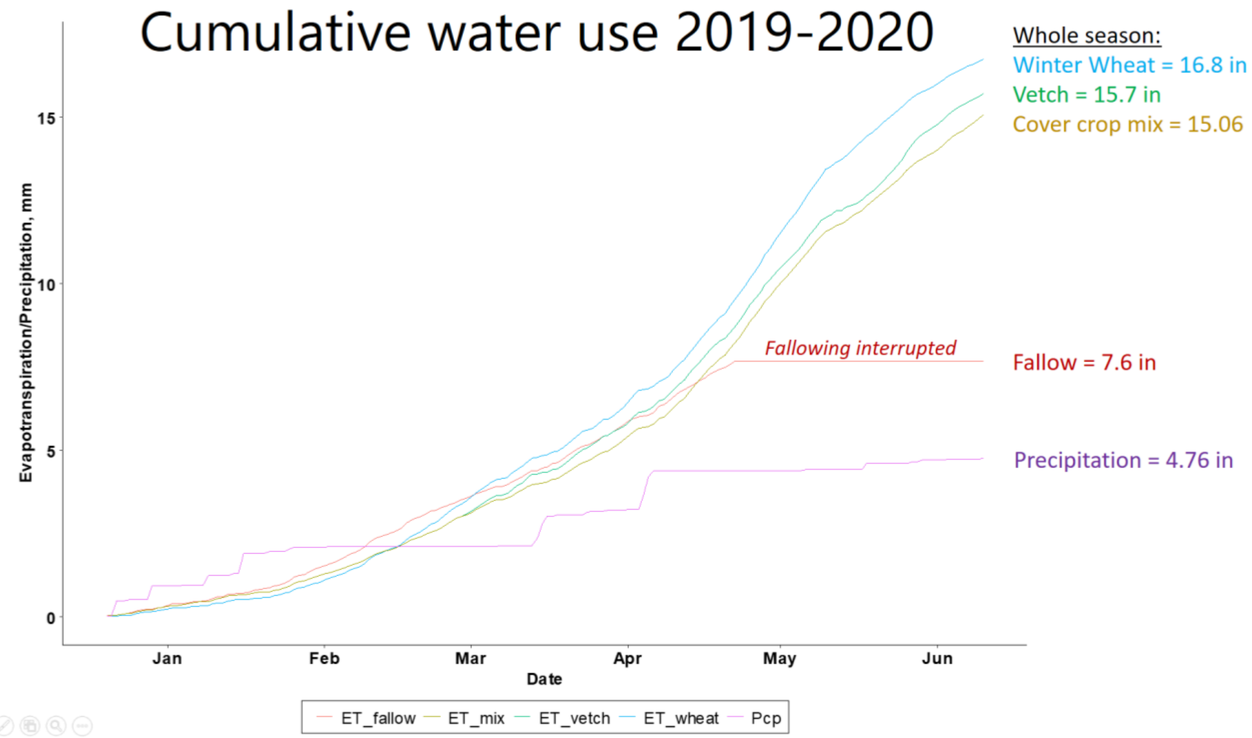
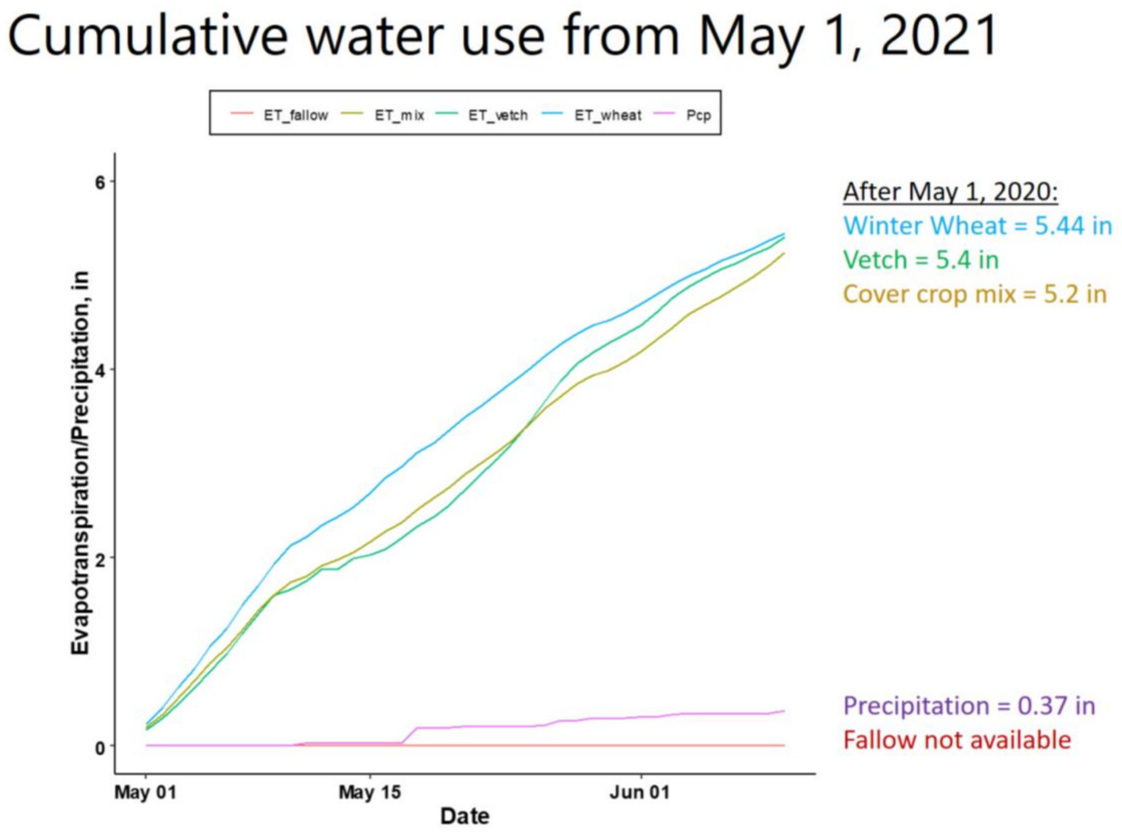


Figure 5. Cumulative seasonal water use (evapotranspiration) of different cover crops compared to the fallow field and precipitation during full measurement season.

Cumulative values of the seasonal water use after May 1st are more useful for water transfer purposes. We have shown on Figure 6 that winter wheat used 5.44 inches of water after May 1st, vetch field used around 5.4 inches and cover crop mix field used around 5.2 inches of water in the same period. We did not have the opportunity to measure ET after June 10th, since we had to remove the equipment for the farm operations that were planned for mid-June. In addition, these values might be different depending on the conditions of different years and if the winter precipitation helps enhance or reduce cover crop growth. Variability in soil conditions at different locations might as well impact variability in these water use values.


Cumulative water use from May 1, 2021

After May 1, 2020:
Winter Wheat = 5.44 in
Vetch = 5.4 in
Cover crop mix = 5.2 in

Precipitation = 0.37 in
Fallow not available

Figure 6. Cumulative seasonal water use (evapotranspiration) of different cover crops compared to the fallow field and precipitation after May 1st

Year 2

Measurements setup:

In the second year of the study, which spanned from November 2020 to July 2021, we equipped a total of three fields (fallow, vetch, and winter wheat) with the same micrometeorological ET measurement system utilized in the first year of the study (Fig. 1). The fallow field was located at the Rice Experiment Station in Biggs, CA while the vetch and wheat fields were located in Pleasant Grove, CA. Field locations in year 2 of the study are shown below in Fig. 7.

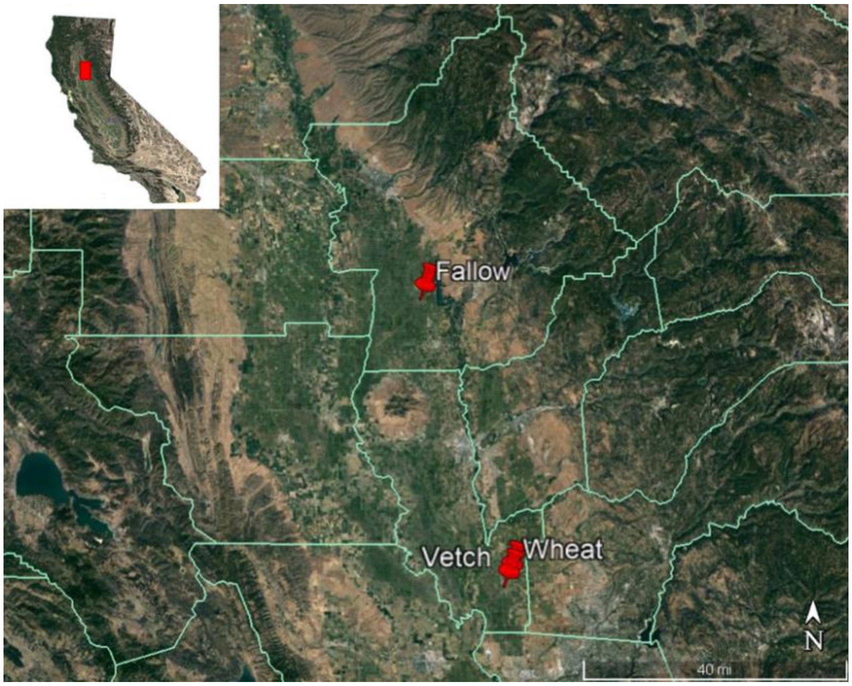


Figure 7. Study sites location map in the second experimental year (2020-2021)

In the second year of the study, we also conducted a soil water balance in which the following equation was used:

$$\Delta S = P + I - ETc - RO - D$$

where ΔS is the change in soil moisture, I is irrigation, P is precipitation, ETc is crop evapotranspiration, RO is runoff, and D is deep percolation. Soil moisture, water table height, ETc, and runoff were monitored in-situ at each site while precipitation and irrigation were obtained from CIMIS database and grower estimates, respectively. Daily changes in soil moisture were measured to a depth of 1m using TDR soil moisture and temperature profile sensors. Instantaneous measurements of soil moisture were also made by manually taking soil core samples at the beginning, middle, and end of the monitoring season. Start and end of season soil cores were taken within a week of planting/harvest with a Geoprobe drilling rig down to a depth of 8ft. Samples were collected at four sampling locations per site, 1 sample per 1 foot of soil depth. Surface runoff was measured at each field's lowest point of elevation at the spot at which each field drains with rectangular wooden weirs. Datasets were then analyzed to compare cumulative changes in water budget components, seasonal distributions of water use and loss and water budget closure. Water budget models were developed at a seasonal time step to understand distributions of water use and loss over the extended cover crop growing season. Seasonal ETc was calculated as the residual of the water budget where RO and D were assumed negligible.

Soil Water Balance Results

There was high spatial variability of seasonal ΔS from soil cores across sampling locations and depths. ΔS in the total vertical soil profile was both positive and negative in the fallow and winter wheat sites, while the vetch site was consistently negative (*Fig 5*). Positive ΔS values signify a net gain in soil water while negative values a net loss.

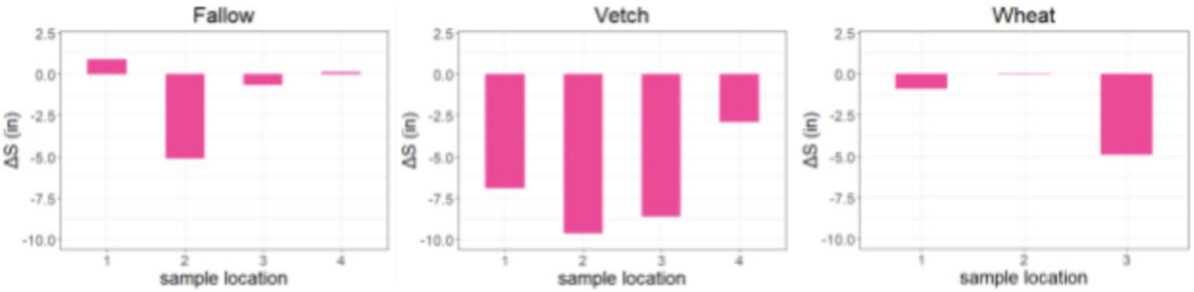


Figure 8. Seasonal change in soil moisture (ΔS) for total vertical soil profile across sampling locations

Average seasonal ΔS by depth (0-8 ft) was analyzed. The fallow site predominantly experienced S loss throughout the soil profile, except for at 8ft (*Fig 8 and 9*). High clay content and biomass residual left over from the previous season reduced evaporation from the soil surface while lower depths may have seen lateral flow from surrounding fields. The vetch site had a loss in S at all depths, with significant loss in the top 3 ft surrounding the root zone. The winter wheat site had average loss of S in the top 5 ft with most significant losses at the soil surface, however there were gains in S at lower depths. The winter wheat crop likely depleted S in the root zone while pulling S from lower depths in the soil profile as needed. The large quantity of applied irrigation combined with a lower clay content that eases flow through the soil, resulted in infiltration and positive ΔS at lower depths over the course of the season in the winter wheat field.

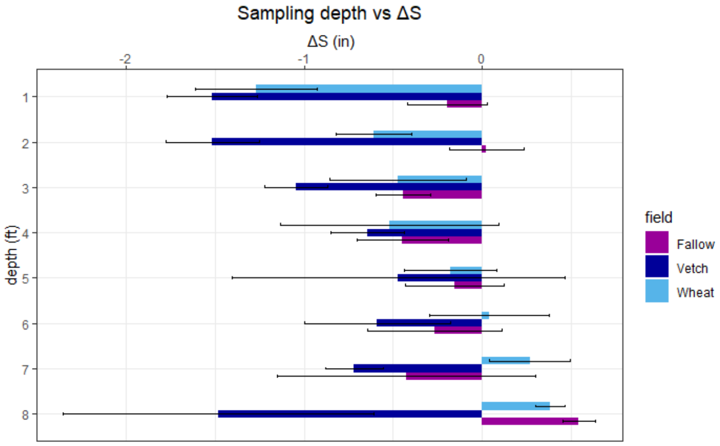


Figure 9. Average ΔS per depth of vertical soil profile with error bars of one standard error.

Soil texture likely influenced the magnitude of ΔS recorded by the TDR sensor in response to precipitation events. Thus, clayey soils required the lab calibration and despite our efforts to do it with soils brought from the field, we do not think the values were as reliable as the soil cores results of soil water storage. In addition, visible macropores in the form of large cracks in the soil surface were present in both the fallow and vetch sites and we think that cause the soil to detach from the sensor. These macropores may have partially/fully exposed TDR sensors to the air resulting in abnormally low readings compared to the soil cores at the end of the season. Although the winter wheat soil showed shrink-swell capacity as well, the irrigation event and sandier soils reduced the presence of soil macropores.

At the end of the season vetch retained only 7% of fractional soil moisture from peak soil moisture from precipitation, significantly less than fallow, 36%, and winter wheat, 30% (*Fig 10*). Because of the large irrigation input, winter wheat held on to approximately the same percent of fractional soil moisture from precipitation as fallow. The irrigation input determined by the grower sufficiently matched the winter wheat's water demand, resulting in the soil water depletion equivalent to the fallow site. High variability observed over the sampled soil cores requires a closer look at these systems to determine the significance of these trends.

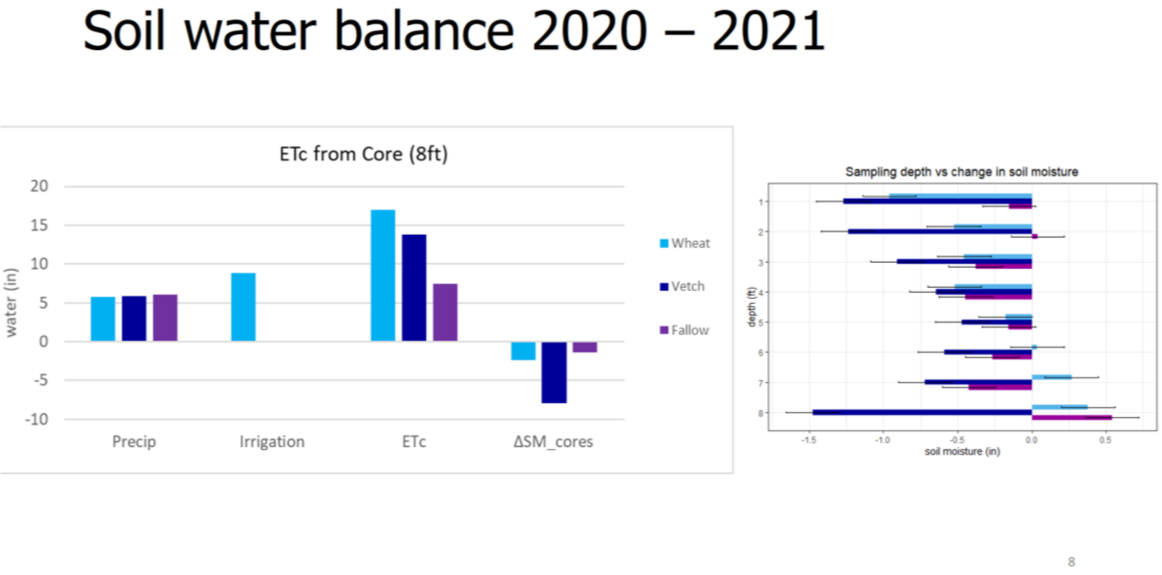


Figure 10. Seasonal water budgets for all sites where ETc is estimated as the residual of water budgets using ΔS measured from soil cores (A) and SoilVUE (B).

Evapotranspiration Measurements Results

Second year data was collected from November 13 until June 13th for fallow field at RES, from November 13th until July 14th for vetch and between November 15th and June 29th for winter wheat (Figure 11). Since the soil cores were scheduled to be done on the day of the tower removal but the Geoprobe machine was not always available, we adjusted the time period of ET values for several days of mismatch using nearby CIMIS ETo values and crop coefficients (derived from our own study for the available days).

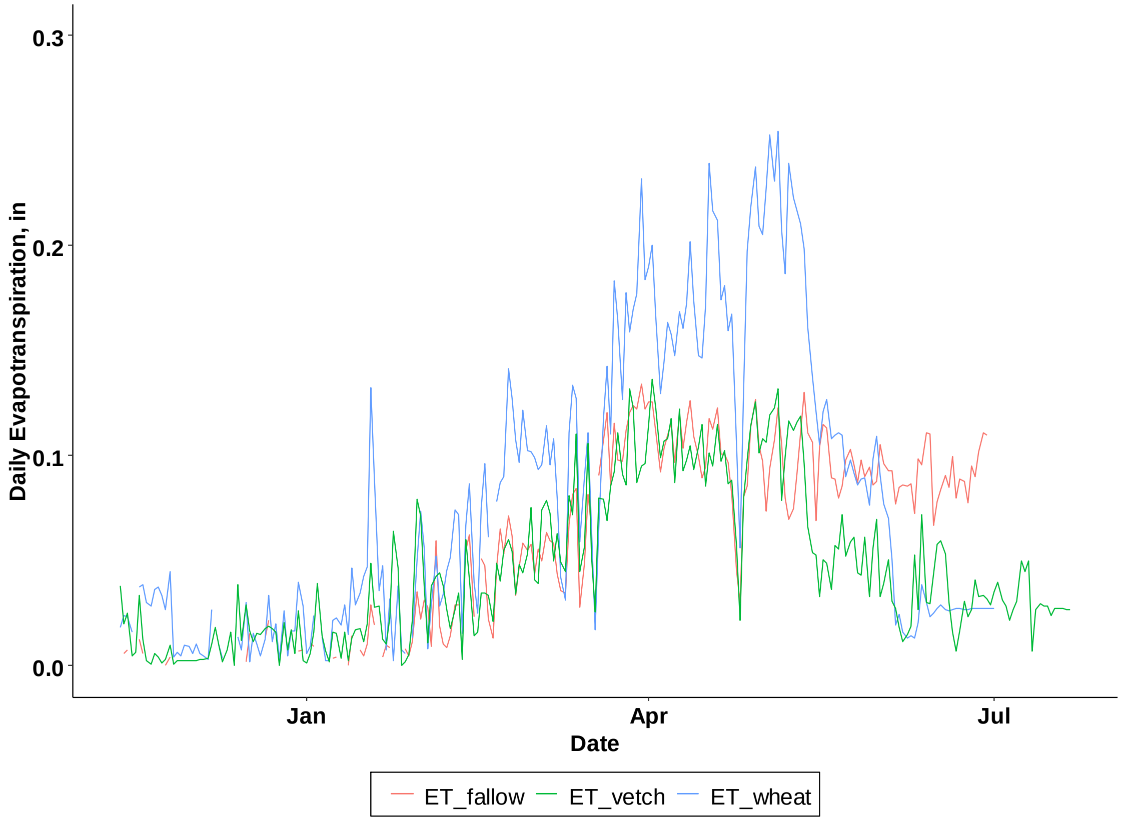


Figure 11. Seasonal Water Use values for vetch, fallow and winter wheat between fall 2020 and summer 2021.

The values for seasonal water use (Figure 12) were very similar when above-ground measurements were compared to soil water budget in case of winter wheat. Our ET measurements for vetch were slightly lower than those derived from the water budget, and slightly higher in case of fallow field (Table 2). This could be attributed to several factors of measurements uncertainty, soil sampling and heterogeneity across the fields, etc.

Table 2. Water use (ET) comparison between different methods used in this study:

	P (in)	I (in)	ΔS Cores (in)	ET Cores (in)	ΔS TDR profile (in)	ET TDR profile (in)	ET Measurement
Fallow	6.04		-1.37	7.37	-7.36	13.36	12.16
Vetch	5.82		-7.98	13.79	-8.52	14.34	11.5
Winter wheat	5.82	8.86	-2.37	17.04	-3.60	18.36	17.9

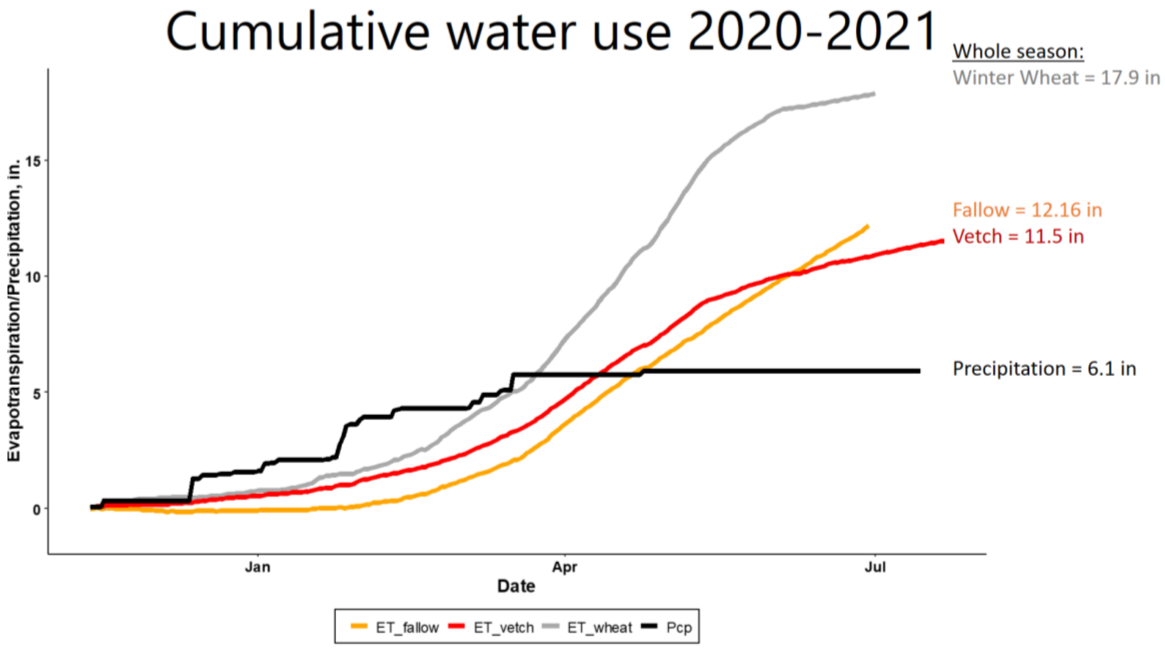


Figure 12. Seasonal Water Use values for vetch, fallow and winter wheat between fall 2020 and summer 2021.

Water use data for period post-May (Figure 13) when water transfers are possible show that there was minor part of water use that occurred as ET in this period, since the cover crops were drying. Fallow field had lower water use during the period of intensive growth in the vetch and winter wheat fields, but later, after cover crops were senescing and drying, the fallow field surpassed the vetch evapotranspiration and was close to the winter wheat ET, at least when we focus on this period.

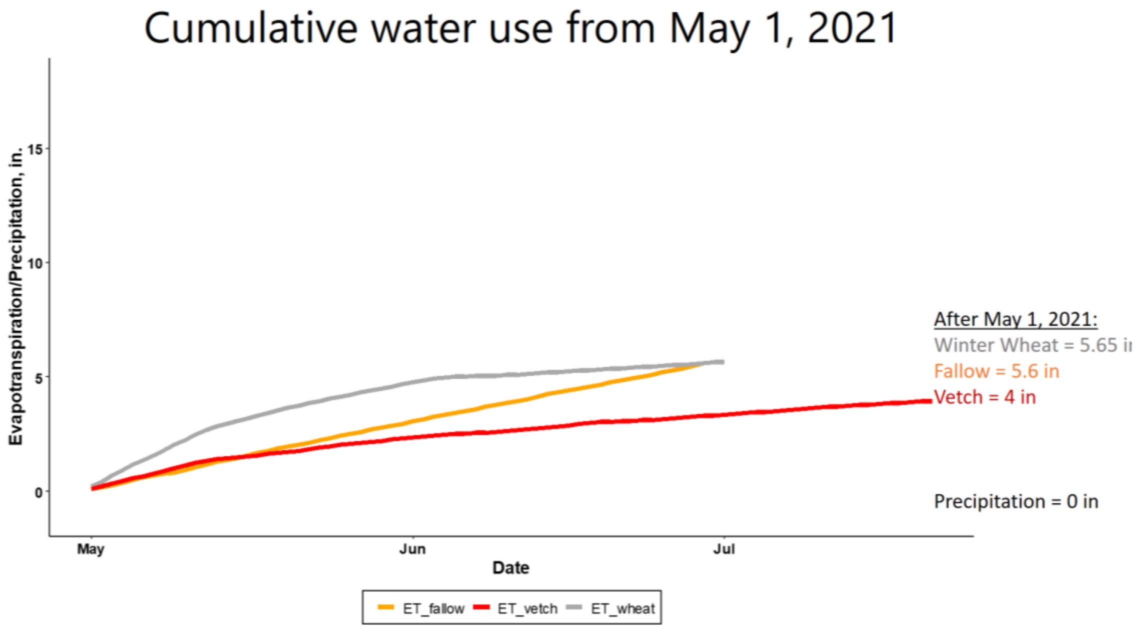


Figure 13. Seasonal Water Use values for vetch, fallow and winter wheat between May 1st and July 2021.

Conclusions and study limitations

After two years of experimental measurements, we show that on a seasonal level fallow field, vetch, mix of cover crops and winter wheat water use. Most of the water use was supplied from precipitation and soil moisture storage. However, since both winters were very dry, winter wheat was irrigated multiple times in both seasons. In the period relevant for water transfers, after May 1st, both years of data confirm that the cover crops are responsible for 4-5.5 inches of water use. Surprisingly, the fallow field had quite high water use, despite not having any crop grown (in the second year of the study, minor weeds were noticed). However, non-irrigated cover crops could deplete the soil profile more than fallowed land during drought periods by drawing water from lower depths of the soil profile. Other studies have shown that during average and wet water years, cover crops have been shown to improve soil health, reduce runoff and erosion, and promote infiltration and water retention; benefits that may be more significant or equal to fallowing during non-drought years. We would like an opportunity to continue this study for another fall-winter-summer season to quantify the hydrological impacts under potentially different precipitation pattern of more natural water supply. This would enable us to quantify fully benefits of cover crops on both soil characteristics and potential water retention.