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.

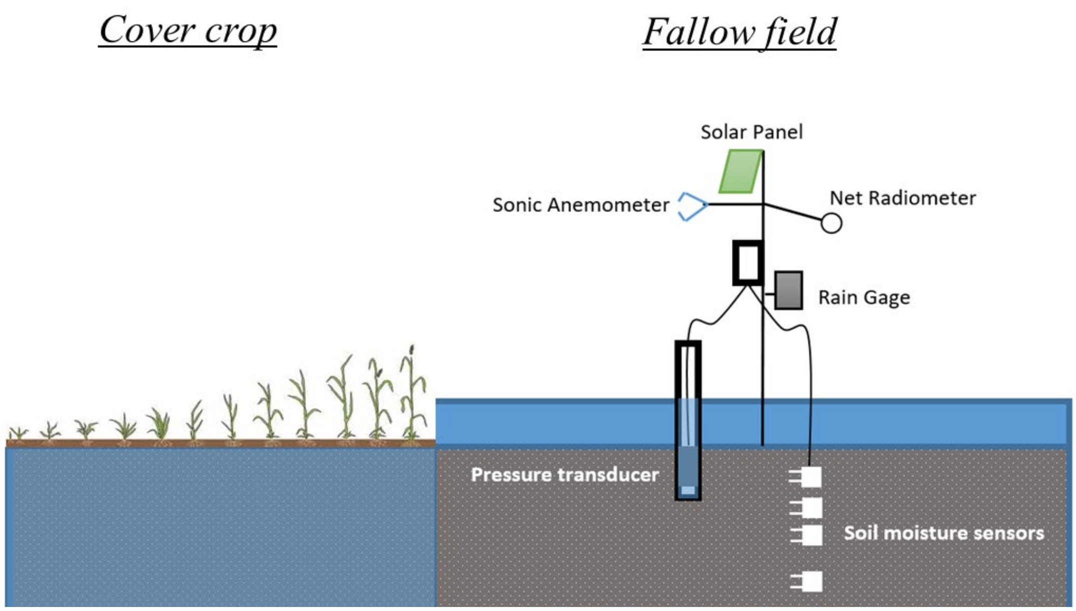

Figure 1. Measurements scheme of water use as evapotranspiration and water monitoring in the soil

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.

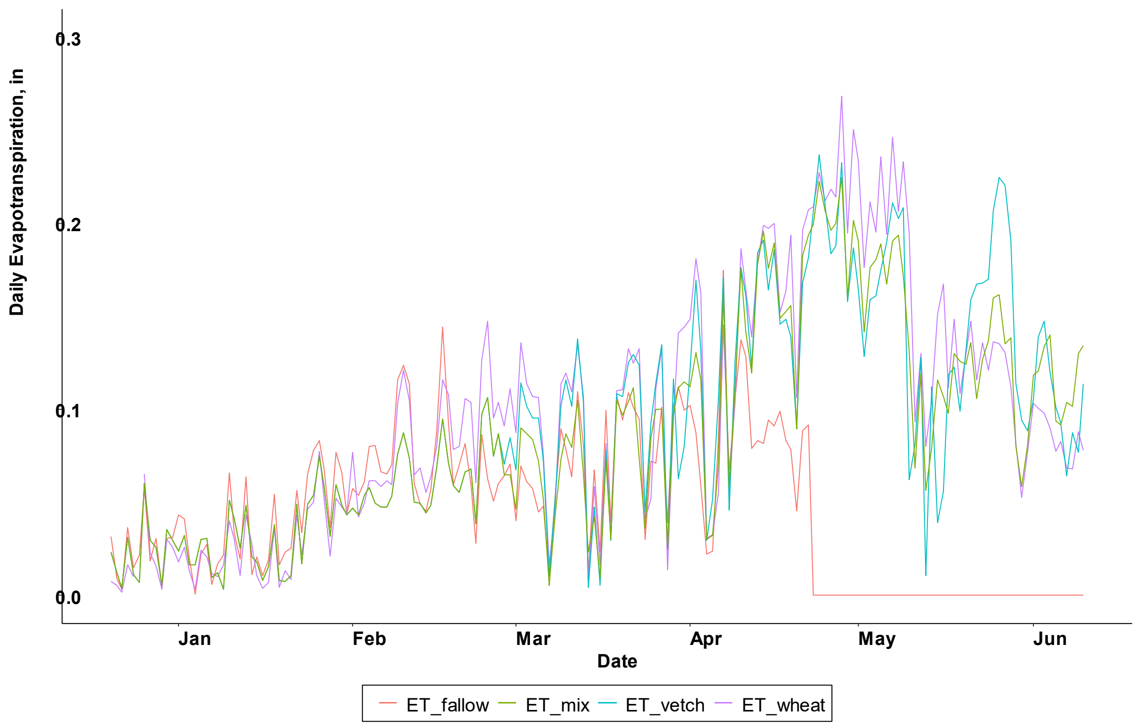

Figure 4. Daily water use through evapotranspiration on different cover crops compared to the fallow field during full measurement season.

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.

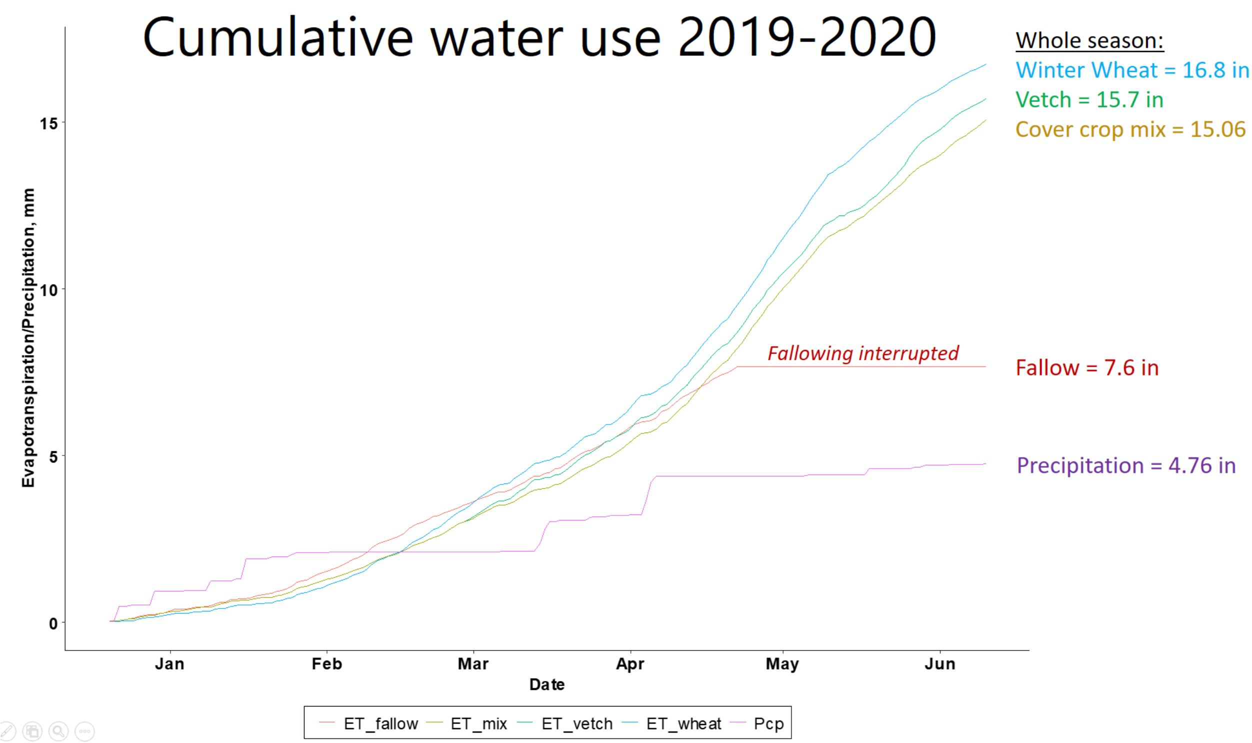

Figure 5. Cumulative seasonal water use (evapotranspiration) of different cover crops compared to the fallow field and precipitation during full measurement season.

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.

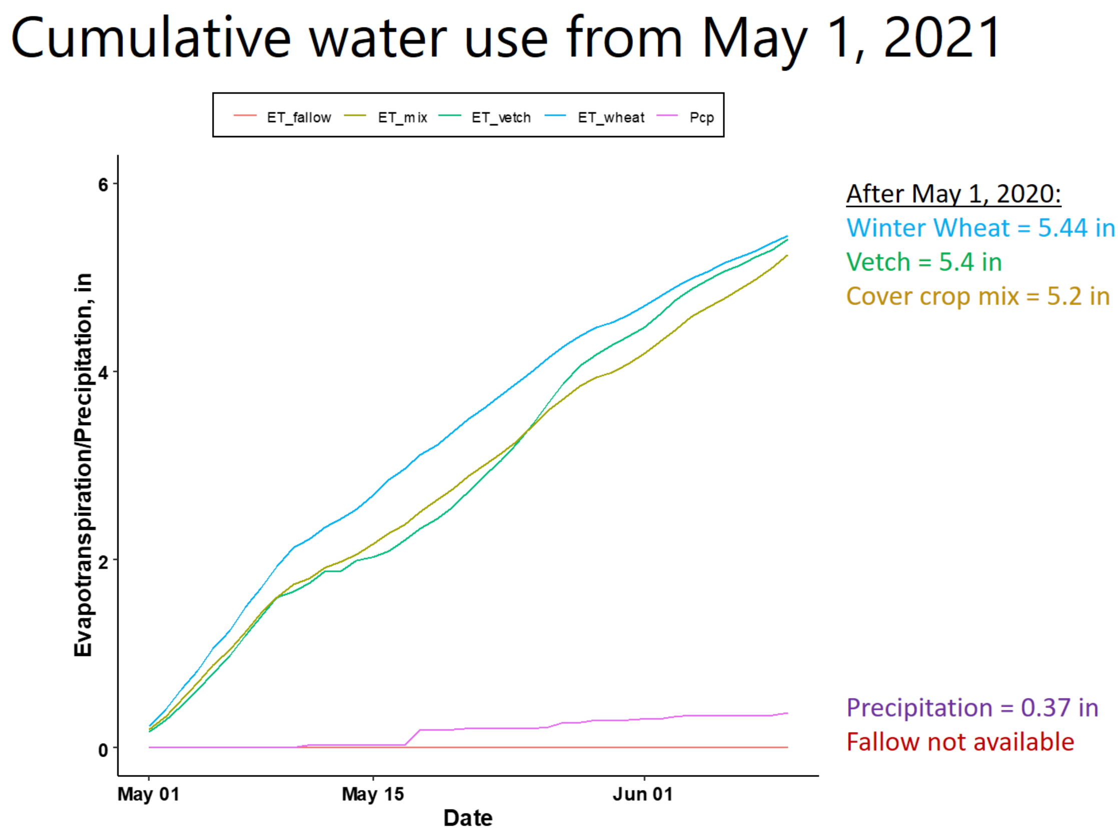

Figure 6. Cumulative seasonal water use (evapotranspiration) of different cover crops compared to the fallow field and precipitation after May 1st

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.

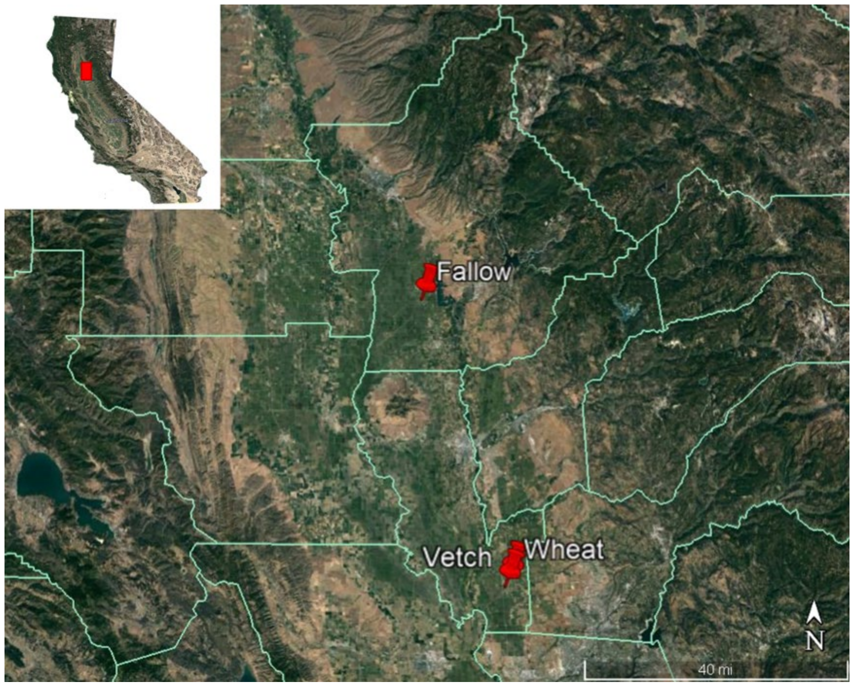

Figure 7. Study sites location map in the second experimental year (2020-2021)

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.

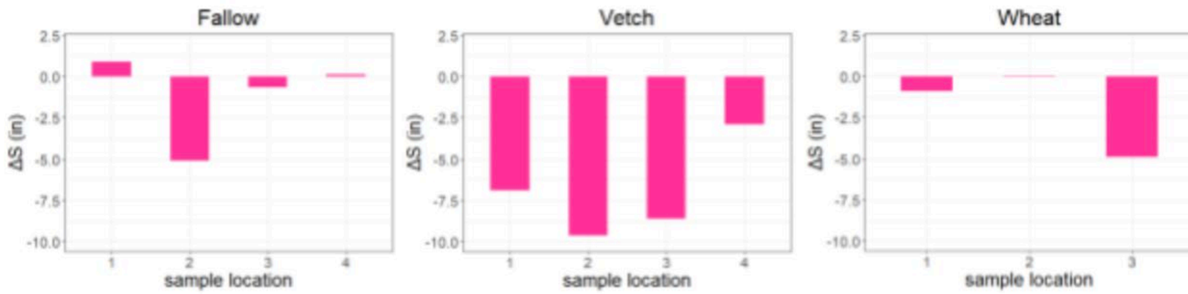

Figure 8. Seasonal change in soil moisture (ΔS) for total vertical soil profile across sampling locations

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.

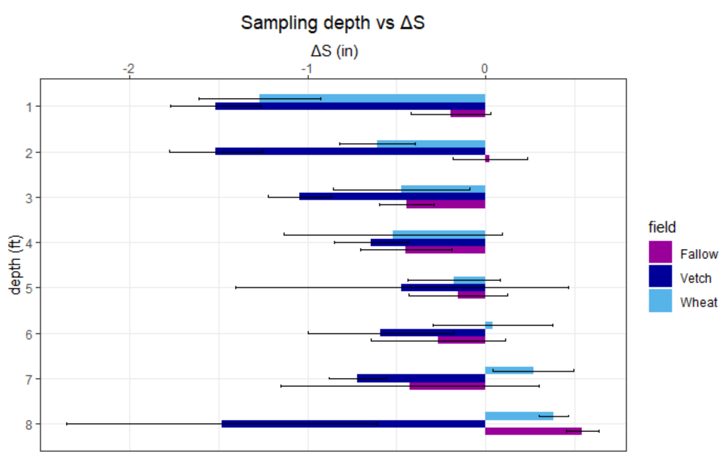

Figure 9. Average ΔS per depth of vertical soil profile with error bars of one standard error.

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.

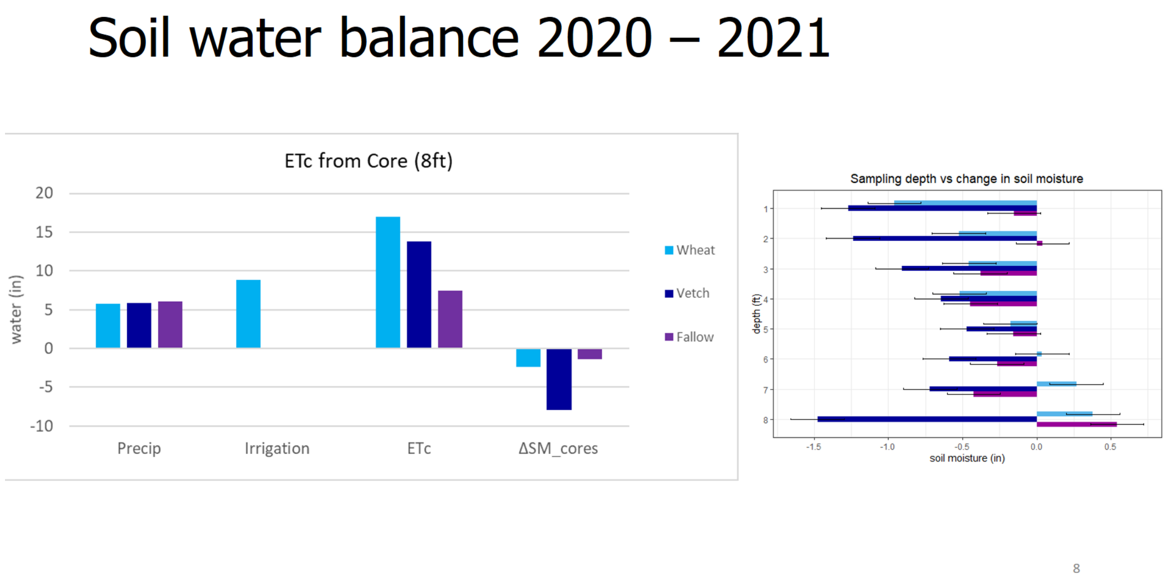

Figure 10. Seasonal water budgets for all sites where ETc is estimated as the residual of water budgets using ΔS measured from soil cores (A) and SoilVUE (B).

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).

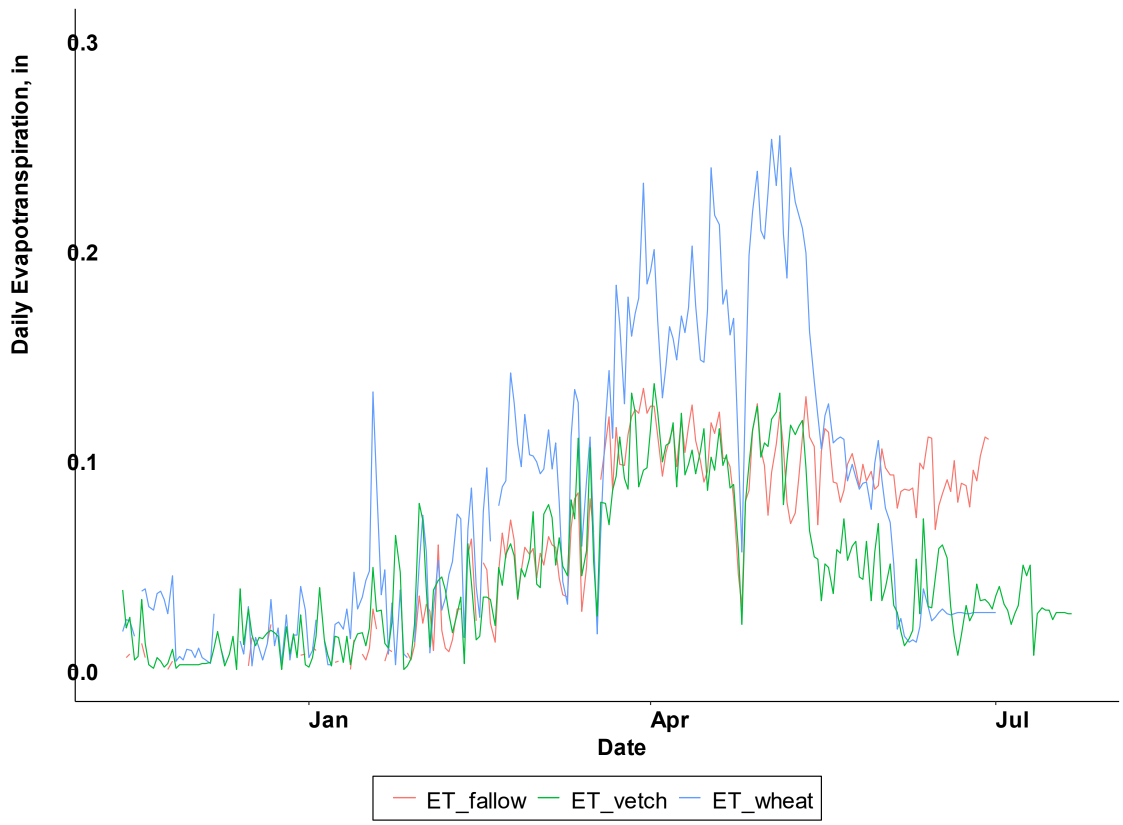

Figure 11. Seasonal Water Use values for vetch, fallow and winter wheat between fall 2020 and summer 2021.

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

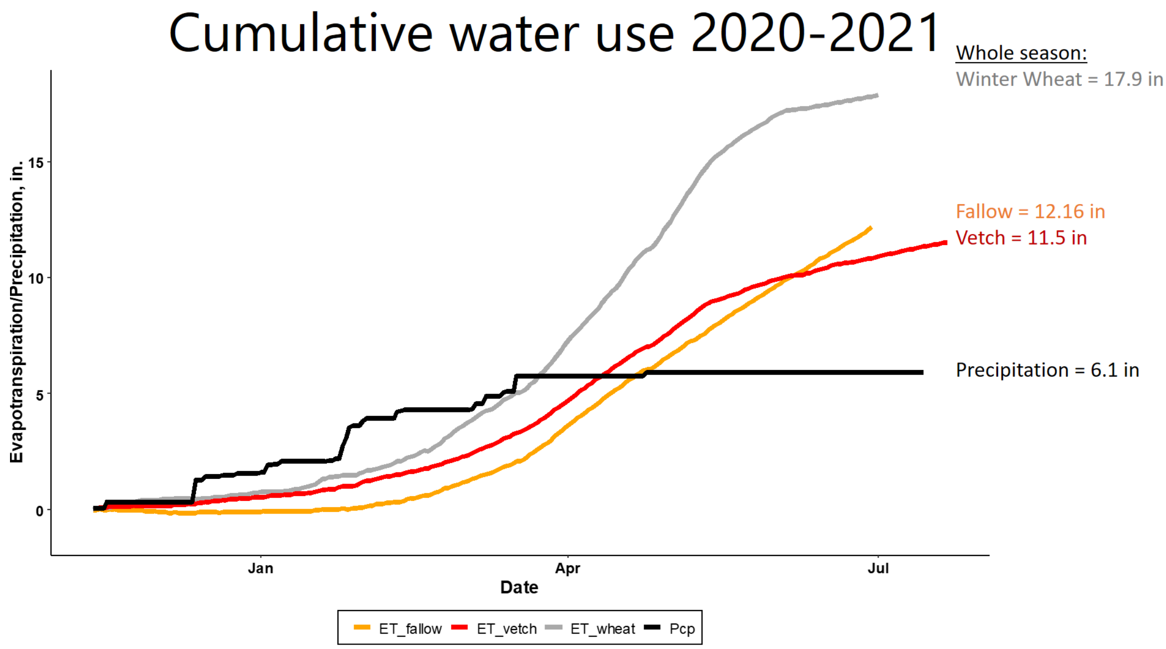

Figure 12. Seasonal Water Use values for vetch, fallow and winter wheat between fall 2020 and summer 2021.

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.

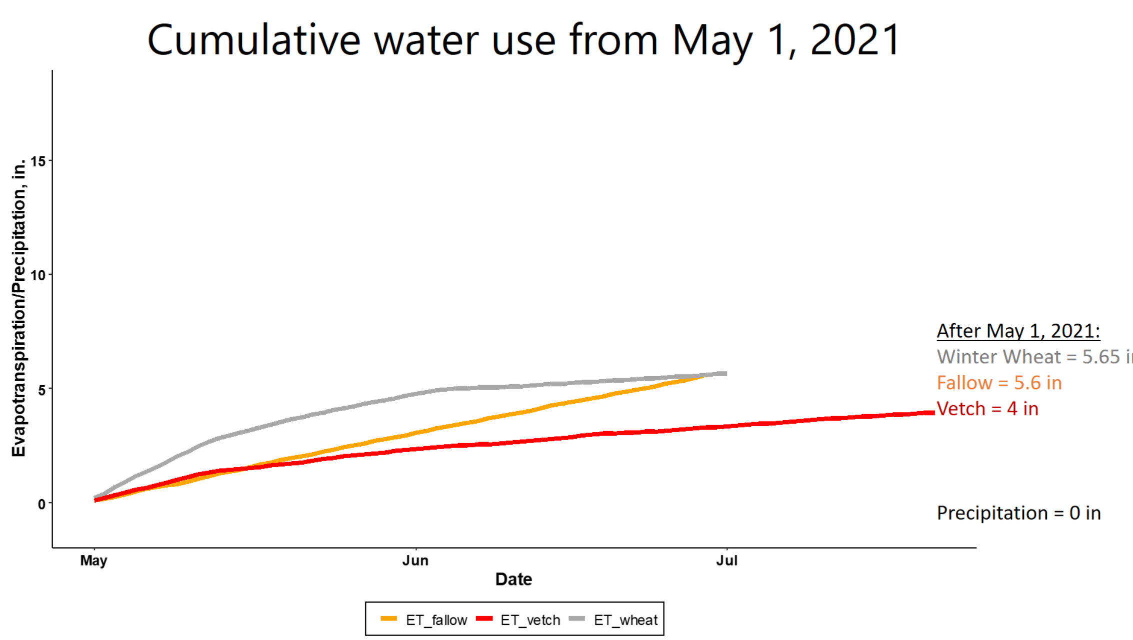

Figure 13. Seasonal Water Use values for vetch, fallow and winter wheat between May 1st and July 2021.

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.

Year 3:

Season 2022-2023

Experimental design and site description:

The experimental site was located in the Butte County, northwest of Richvale, CA (39°31'23.2"N 121°46'22.9"W). The mean elevation at the plot is 112 ft a.s.l. and the site is part of the agricultural system fed by the Feather River and Oroville Dam, the main use of the land in the area is rice growing (USCB, 2020). The experiment consisted of two plots, that are actually two large checks of the same field, of about 14 acres, distant ~500 ft from each other, as showed in Fig.3.1. Closer to the road (yellow) a plot that was fallowed and further from the road (red) a plot where a mixed cover crop was established. For both plots, a system of micrometeorological measurements for evapotranspiration calculation following the first two experimental years was installed (Fig.1). Measurement were performed from the last week of November 2022 to the third week of June 2023, but in this report, for comparative reason, data from December 1st, 2022 to June 20th, 2023 was analyzed because of the best quality of collected dataset.

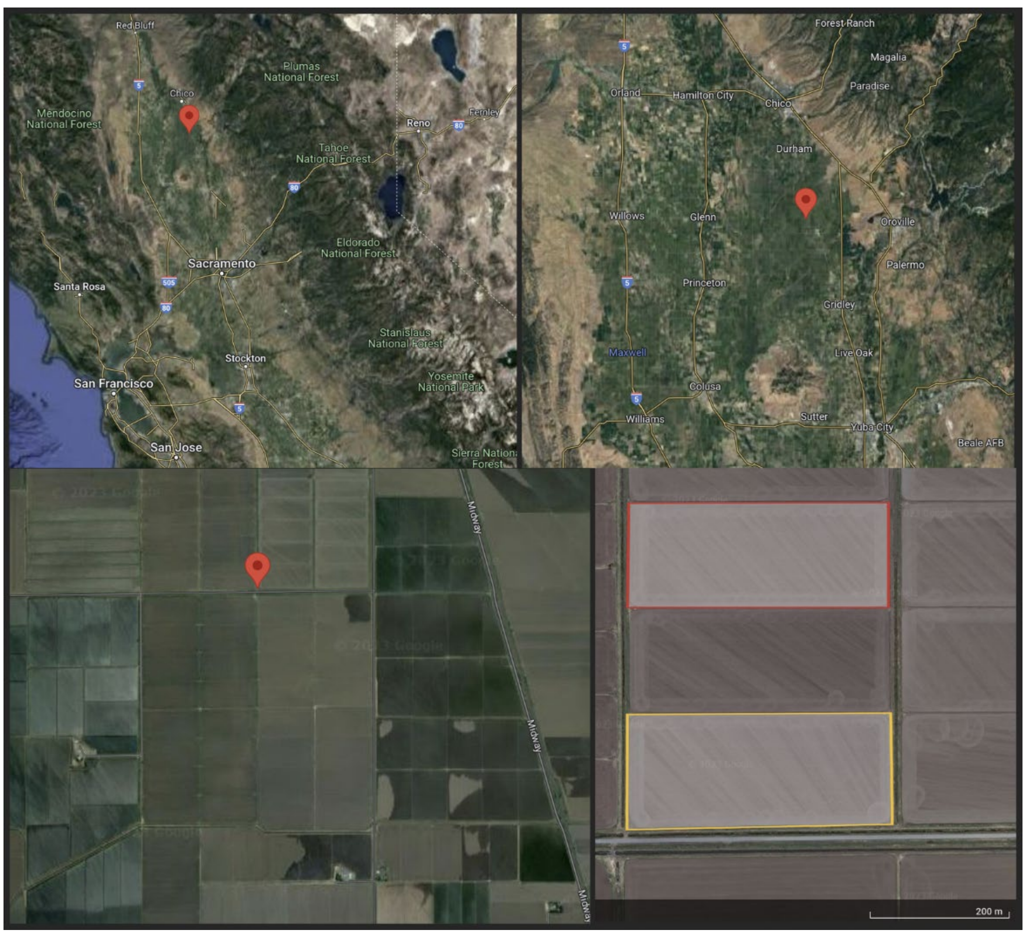

Figure 3.1: Experimental site location (northwest of Richvale, CA) and satellite view of the experimental plots (39°31'23.2"N 121°46'22.9"W).

Similar to the previous experiment, a soil water balance analysis was performed. As irrigation was not applied to monitor non-irrigated cover crops in this season, water budget was calculated according to:

$$\Delta S = P - ET - RO - D$$

where ΔS is the change in soil moisture, P is precipitation, ET is evapotranspiration, RO is water runoff, and D is deep percolation. All measurements were continuous, except instantaneous gravimetric water analysis was performed at the beginning and the end of the season across the whole field, 7 points per field down to 8 feet depth (Figure 3.2) for quantifying the change in soil water storage. Deep percolation was assumed to be the residual of all other components of the water budget that were measured.

Figure 3.2: Soil sampling for soil water storage: (a) Geoprobe soil sampling, (b) map of the soil sampling locations within both fields/checks; top field check is under cover crop and the bottom field check is fallowed.

Although the cover crops seed was broadcasted in the cover crop field on time by the grower in the fall of 2022, due to a very wet winter, the cover crops have started late in the spring of 2023 and both fields had vegetation growing (Fig 3.3 and Fig 3.4).

Figure 3.3: Fallow plot and plant coverage on Dec 21st, Apr 14th, May 17th respectively.

Figure 3.4: Cover crop plot and plant coverage on Dec 21st, Apr 14th, June 21st respectively.

Evapotranspiration measurements results:

As mentioned above, daily evapotranspiration (ET) between Dec 21st 2022 to Jun 21st 2023 was measured (Fig.3.5). Due to the technical limitations of the methods employed, mainly being unable to measure when rain droplets wet the sensor parts, mismatching values of ET and precipitation were corrected using data obtained from CIMIS. Fig 3.5 shows that both field had similar evapotranspiration rates due to the wet winter providing a lot of moisture in the soil and vegetation being present at both fields.

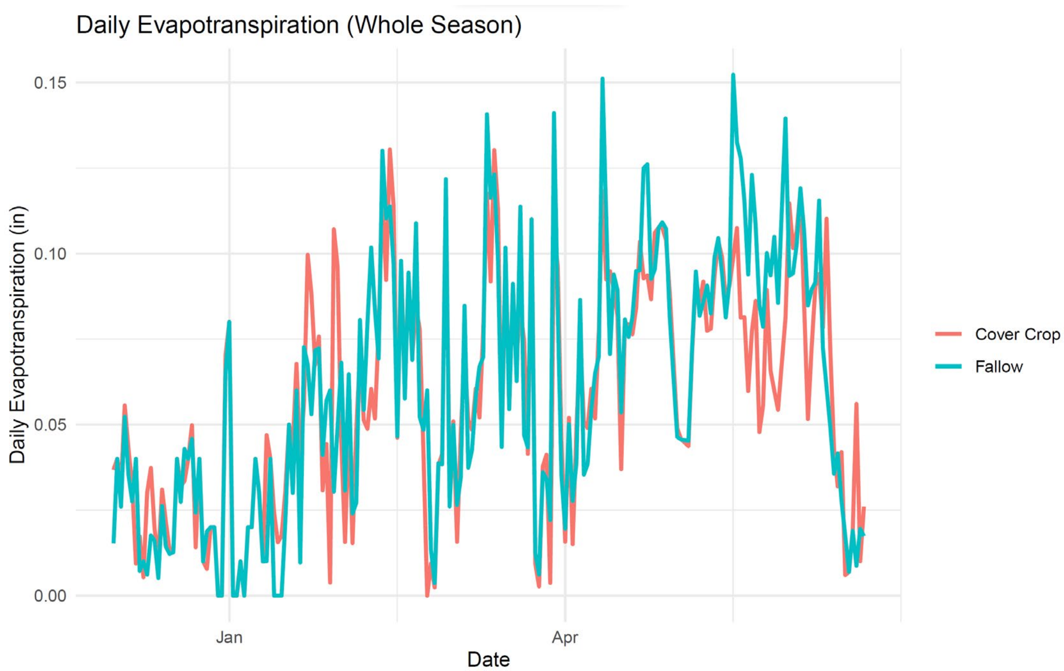

Figure 3.5: Daily evapotranspiration (in) measured in the whole season for the cover crop and fallow plots.

As shown in Fig.3.4 maximum ETa for Fallow was 0.15 in and 0.13 in for cover crop. ET values, other than the late May and June, were similar for fallow as cover crop. As both plots were located close to each other, similar ET was expected; nonetheless, some of the differences on the warmer months might be driven by the differential treatment or the differences in the soil moisture availability for each of the plots. As establishment of the cover crop might reduce soil bulk density, improve soil structure and hydraulic properties to facilitate increased water infiltration and storage (Koudahe et al., 2022), main impact on ET should be associated with the establishment of a cover crop. However, there was little difference found in our observation in the cumulative ET for the whole season (Fig.3.6) and the values are higher at the fallow field due to the vegetation that was growing.

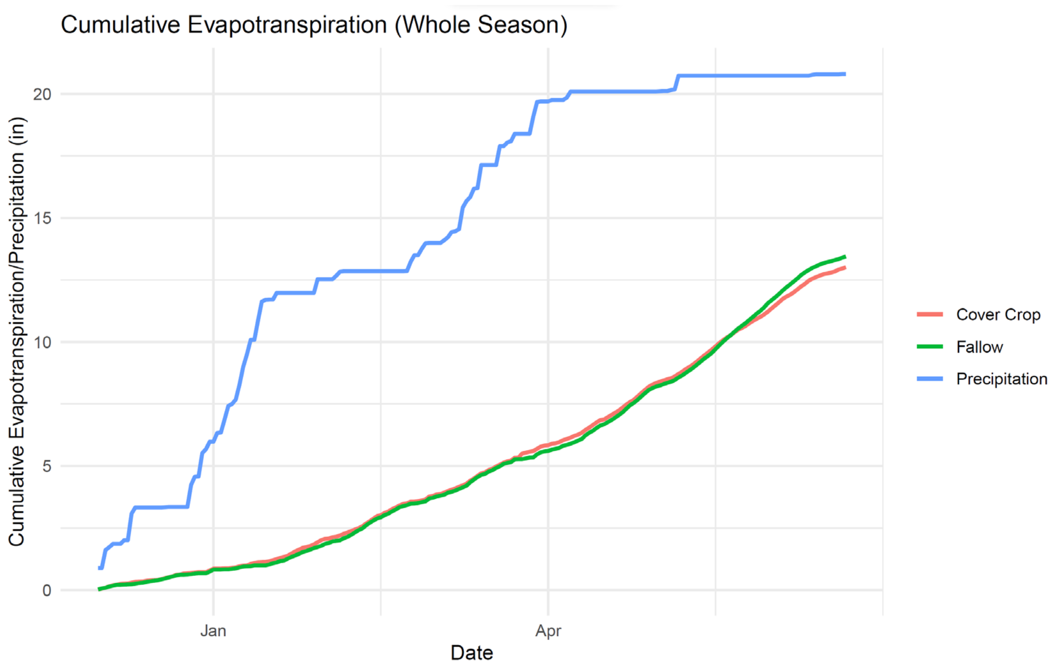

Figure 3.6: Cumulative evapotranspiration and precipitation (in) for the whole season, measured at the cover crop and fallow plots.

As can be seen in Fig.3.5 the cumulative ET for fallow was 13.45 in, while for cover crop the cumulative ET was 13.1 in. The cumulative precipitation for the whole season was 20.8 in. The cumulative ET for cover crop at the end of the season was slightly lower than fallow. As before mentioned, those differences might be associated to the establishment of cover crop. This difference between the two fields falls into the uncertainty range of the method used for measurements. Therefore, because the atmospheric conditions and plant establishment was similar at both plots, and the water availability through large volume of precipitation was supplied, we may not say that there was a significant difference between the two treatments. Further difference can be better appreciated when visualizing the ET measured at both plots from May 1st (Fig.3.7 and Fig. 3.8).

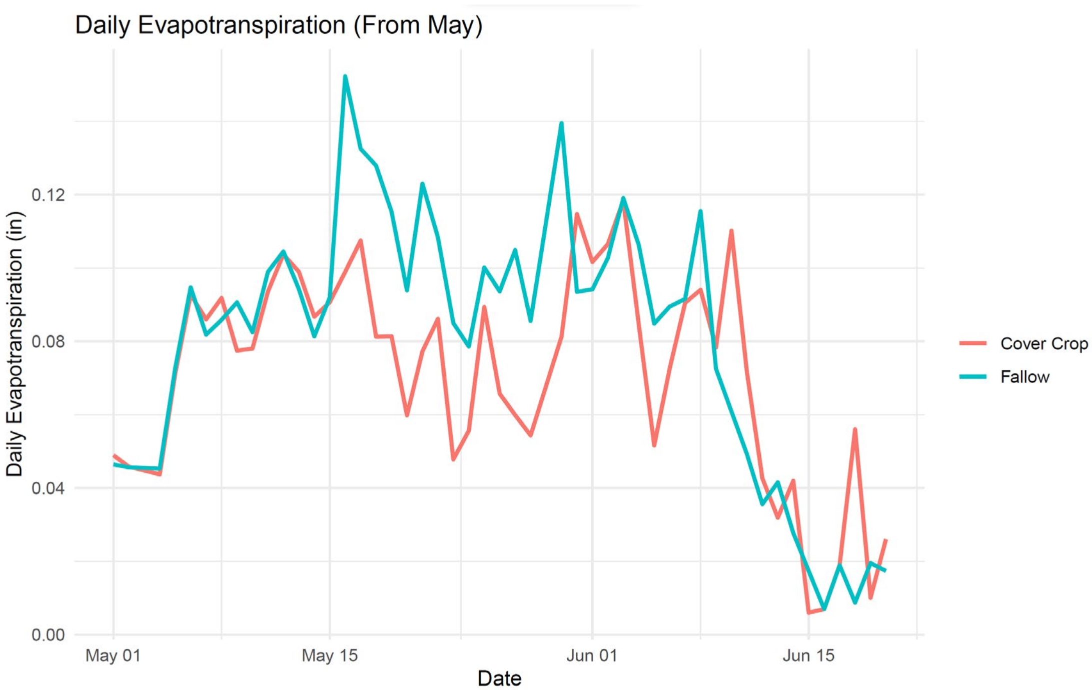

Figure 3.7: Daily evapotranspiration (in) measured from May 1st for fallow and cover crop.

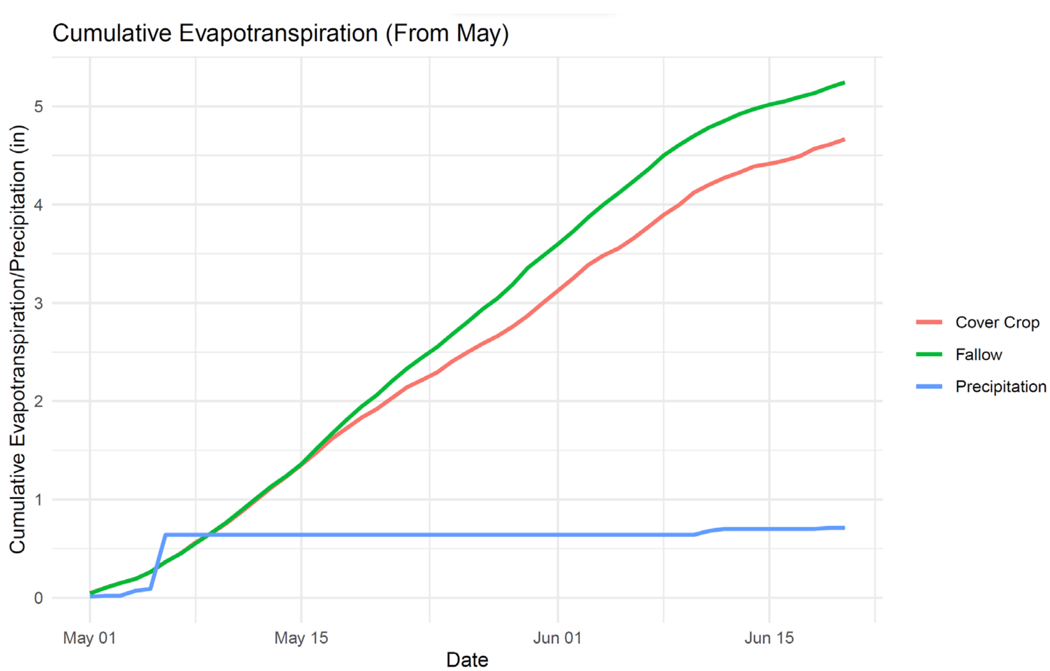

Figure 3.8: Cumulative evapotranspiration and precipitation (in) from May 1st.

In Fig.3.6 is shown that maximum ET for fallow was 0.15 in, while in cover crop it was 0.12 in. When observing the cumulative ET for the period (Fig.3.8), it can be observed that cumulative ET for the period for fallow was 5.24 in and for cover crop the ET measured from May was 4.67 in. This difference between the two fields is also very close to the measurement uncertainty and therefore cannot be attributed to the difference in the field management.

Soil water balance:

Gravimetric soil water content analysis:

As also shown in previous seasons, a high spatial variability in volumetric water content was determined by gravimetric analysis of the soil profiles. We have increased the number of saoil samples to 7 per each field for better capture the soil moisture variability across the fields. Fig.3.9 shows that for different location along each plots showed high variability in change of water content for their whole profile. It can be observed that in similar way for fallow and cover crop, positive values might be associated with net water storage in the soil while negative values might indicate water loss in the soil profile either to ET or to deep percolation.

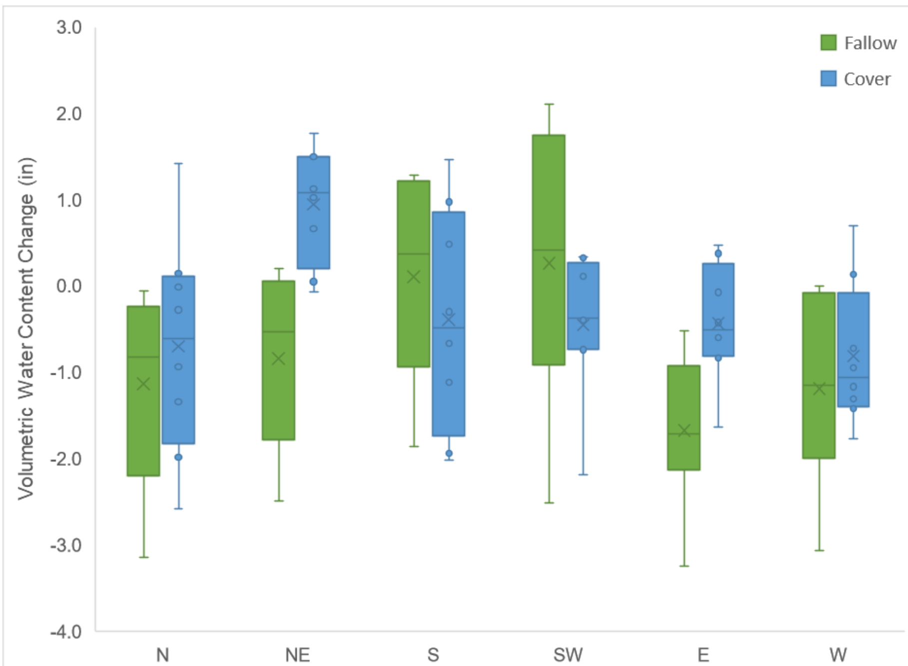

Figure 3.9: Volumetric water content change (in) across the different sampling locations for the whole profile of soil (8 ft) for fallow and cover crop plots.

As high variability in the whole profile for cover crop and fallow can be observed, further differences can be observed when analyzing the volumetric water content change in the profile by foot (Fig.3.10).

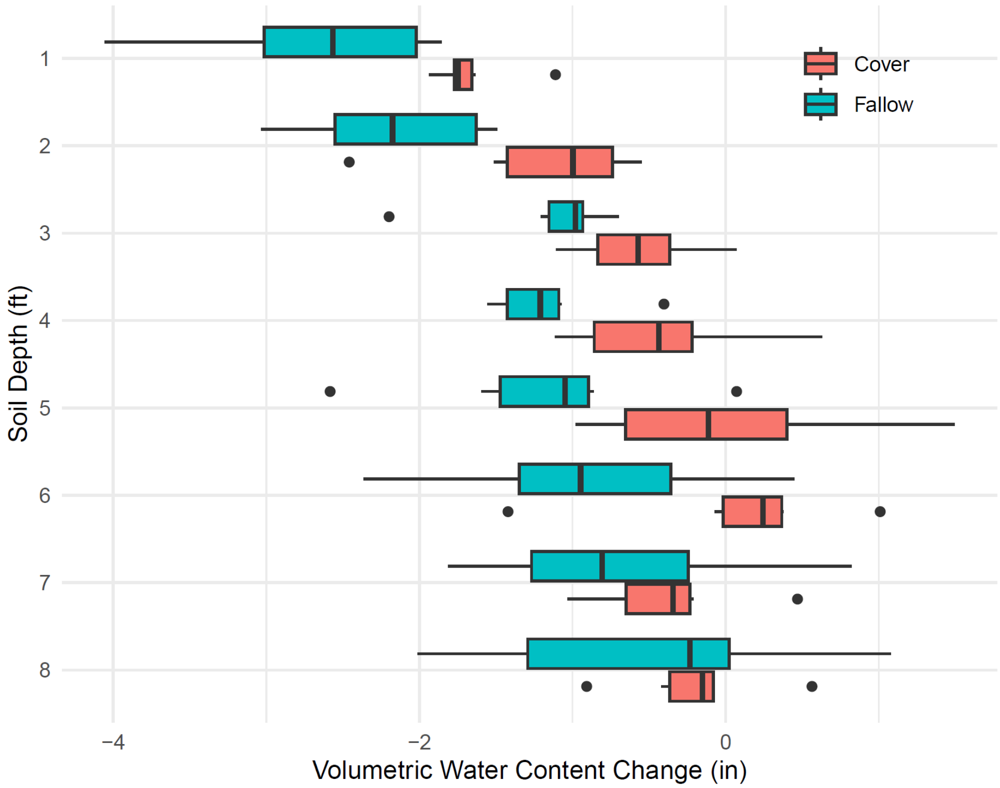

Figure 3.10: Change in volumetric water content (in) by soil depth (ft) measured by gravimetric analysis for fallow and cover crop plots.

As shown in the change of volumetric water content by soil depth (Fig 3.10), when analyzing the change in water content for cover crop, compared to fallow, it can be seen that for whole sampled profile of soil, the losses were higher for the fallow field. There were even some gains in soil water storage at the deeper levels. Indicating that in areas when the root exploration for crops is more relevant, the establishment of a cover crop might be associated with a soil water storage despite the losses of soil water season ET after a very wet winter. Literature has shown that earlier colonization of soil by plant compared to bare or less covered soil might affect water infiltration in the soil, affecting the seasonal dynamics of water storage in the soil, especially because of the root penetration. Even though the plant coverage at the end of the season was similar, the root development of the plants grown in the cover crop plot might have facilitated the water penetration, hence storing the water more efficiently across the season.

For further exploration of the water dynamic in the soil across the season, using a TDR and temperature soil sensor, volumetric water content in the soil was monitored of the first 3 foot of soil profile (Fig.3.11). As high clay soils physicochemical properties are impacting the accuracy of TDR measurements, corrections for each depth based on sampled bulk density, and granulometry analysis was applied. Due to technical limitations of the method, when water saturated, the volumetric water content was matched with field capacity (0.523 and 0.526 in^3 in^{-3} for fallow and cover crop respectively). As soil clay content was high for both plots, in the lower precipitation season, macropores and soil cracking might have interrupted the contact with the soil and upper sensors, hence, when lower volumetric water content occurs, erratic values tent to be recorded.

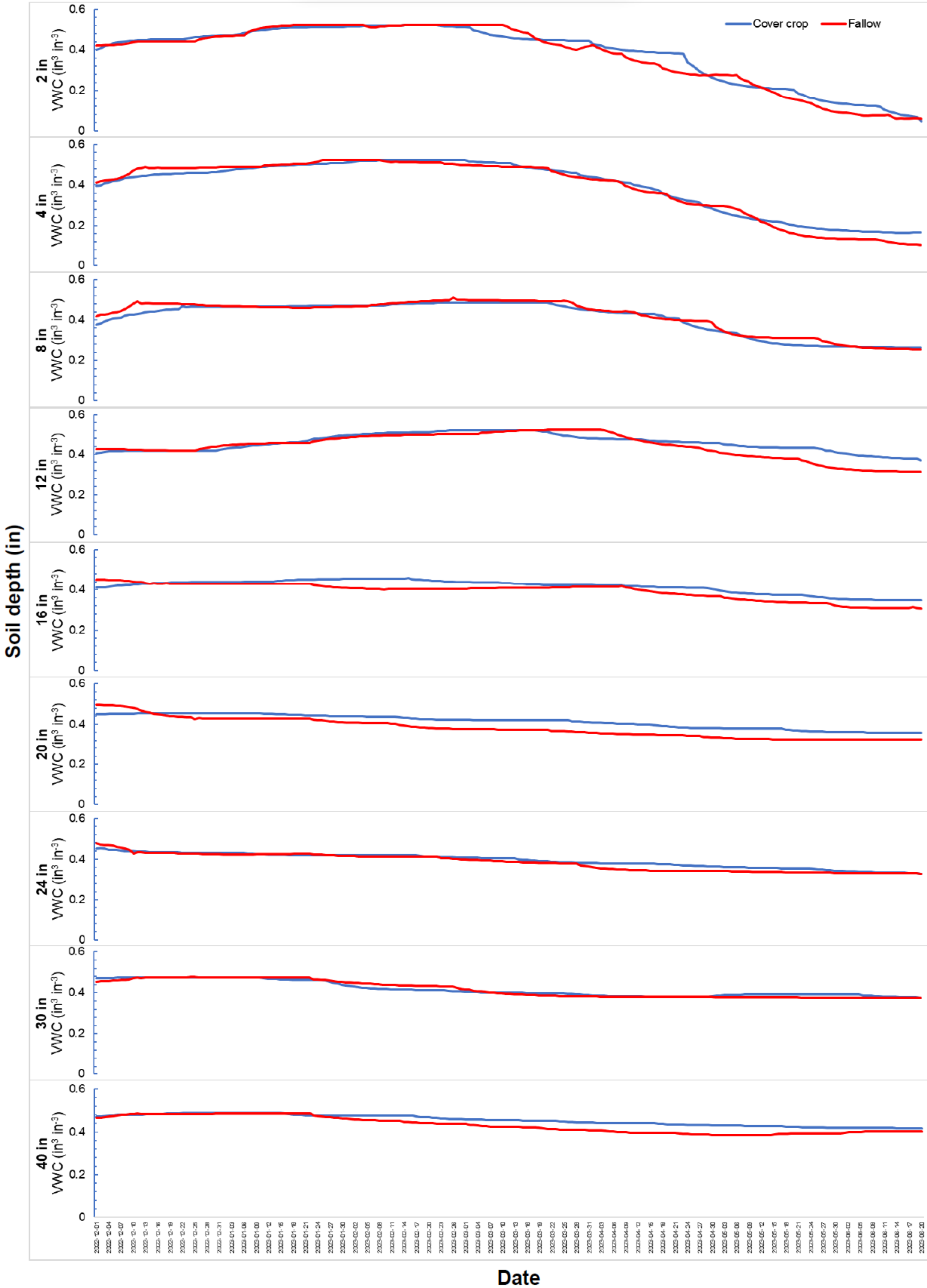

Figure 3.11: Soil volumetric water content (cubic inches of water by cubic inches of soil) measured through the season for fallow and cover crop by soil depth (2, 4, 8, 12, 16, 20, 24, 30, 40 inch).

As Fig.3.11 shows, the upper profiles of soils show a high variability in of soil water content thorough the season. Going from high water content, during the wet season, to values of 0.06 in^3 in^{-3}. As can be seen, for the 12-, 16- and 20-inch profile depths, the volumetric water content for cover crop at the end of the season was 11, 8 and 6% higher than fallow respectively. For the 4-inch profile, despite of observing similar values for the rainy season, over the warmer moths showed to be slightly higher for cover crop. The lower profiles, despite of showing a lower variation for cover crop and fallow and showing similar water contents by the end of the season, might show that water penetration on the soil might be different when a cover crop is established.

Runoff water:

As previously described, the rate of runoff water at the lower point where each plot drainage was occurring, was quantified using the weirs together with the water level sensors. Using the recorded height of the water table and correcting based on the precipitation data and the method described by Zhang et al. (2009), water runoff for both plots was calculated (Fig.3.12). Runoff water was monitored through the season, but it was recorded on occasional occurrences from December 15th, 2022, to March 15th, 2023.

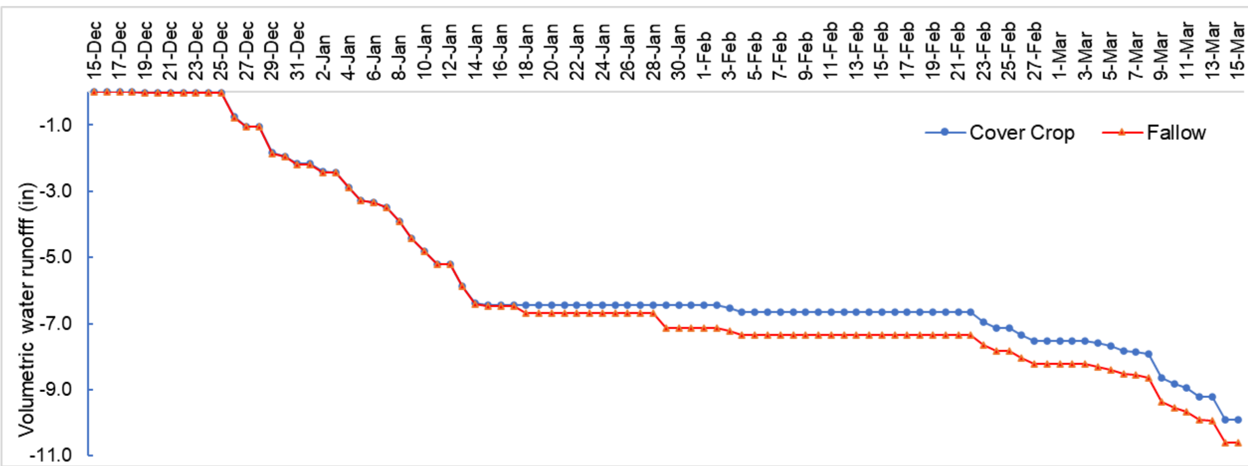

Figure 3.12: Volumetric runoff water (in) measured at the fallow and cover crop plots from December 15th, 2022, to March 15th, 2023.

As can be seen in Fig.3.12, the volumetric water runoff for the fallow plot was -10.6 in while for cover crop was -9.9 in. As expected, runoff water values for both plots were similar. Despite of the cumulative runoff for cover crop was slightly lower, both plots were close to each other, and similar drainage was expected. Land management and soil preparation for the cover crop, might have influenced the runoff for the cover crop.

Water budget:

The cumulative water budget components that we measured are summarized in Tab.3. Using the formula described previously and considering deep percolation as non-significant, the ET estimated based on the volumetric water change for fallow was 12.92 an 11.27 in for cover crop. The values estimated by soil water analysis, are comparable to micrometeorological measurements, 12.4 in and 11.7 in measured by eddy covariance for fallow and cover crops respectively.

Table 3: Precipitation (P), Change in volumetric water content (ΔS), Evapotranspiration (ET) and runoff water (RO) measured for cover crop and fallow plot.

Treatment	P (in)	ΔS (in)	ET (in)	RO (in)
Fallow	20.8	-1.58	13.45	10.60
Cover crop	20.8	-1.17	13.1	9.90

Nevertheless, when incorporating the ET measured by micrometeorological techniques to the calculation of the water budget, the residual water for fallow was -1.67 in, while for cover crop was -0.94 in. The residual water, despite of being low, can be associated to the deep percolation or lateral water movement from or to the adjacent fields. It also might be considered that experimental error might be the cause of small-scale variations.

Vegetation coverage analysis:

Across the season, development of vegetation over cover crop and fallow was recorded. As shown in Fig.3.3 and Fig.3.4, vegetation coverage was similar for both treatments. Vegetation height at the end of the season varied from 4 to 16 inches. Coverage during the cold months remained low until mid-March/early April, when vegetation coverage started to increase. Plant composition for both fields was similar (mostly *Poa spp.* and *Viccia spp*.), until mid-April and the end of the season when the persistent weed *Chenopodium album* was the dominant species in both plots (as well as access roads and boarders).

To estimate the portion of the plot covered by vegetation, the leaf area index (LAI) was measured across the season. When vegetation was not covered by water, LAI was measured using a Accupar LP-80 ceptometer (Meter, Pullman, WA), this method discriminates between plants that were physiologically active against non-active plants. Nonetheless, due to technical limitations when the plots were flooded LAI was estimated by image analysis using the software ImageJ2 (Rueden et al. 2017: BMC Bioinformatics) and the method described by Qu et al. (2021: CEA).

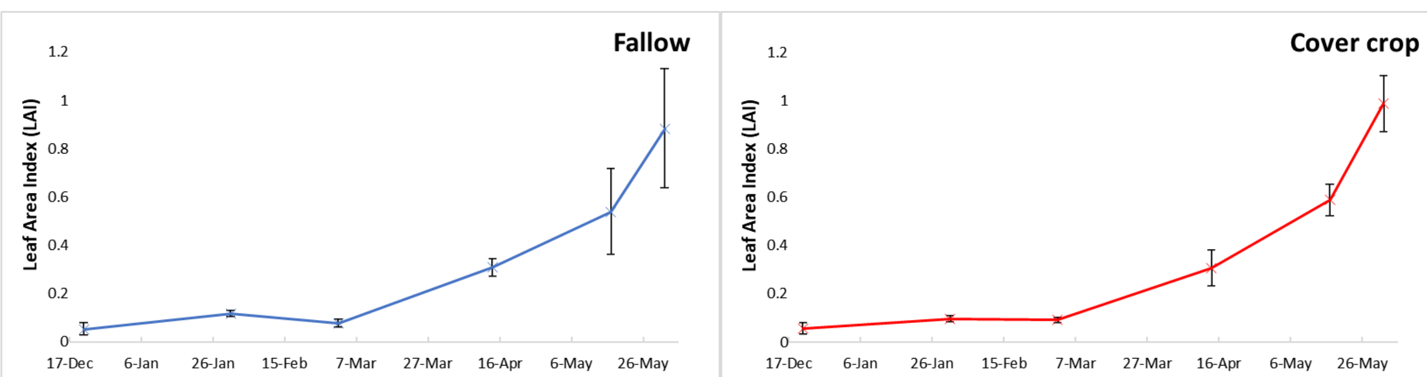

Figure 3.13: Leaf area index (LAI) measured for the Fallow and Cover crop over the season 2022-2023. Left pane show LAI for the fallow plot and the right pane shows LAI for the cover crop plot. Measurements were made on December 21st, 2022, January 31st, March 2nd, April 14th and June 1st, 2023.

As shown in Fig.3.13 leaf area index for cover crop and fallow was significantly similar. Even if we consider that the mean LAI for cover crop in the last measurement was 7% higher than fallow, the high variation for both treatments does not indicate if there was a treatment with denser coverage, but it shows that the fallow field had significant vegetation cover. Nonetheless, it might be possible that due to soil preparation, plant development and water use of those plant behaves in a differential way between plants grown in the cover crop plot vs. fallow.

Vegetation characterization:

To analyze if the treatments had a differential effect over the water use of the vegetation growing in the plots, leaf water potential and water use efficiency for two major groups of plants growing on the plot was analyzed: Grass (*Poa* spp.) and Broad leaf (*Viccia* spp.). Leaf water potential was determined using a 600D pressure chamber (PMS instruments, Albany, OR). LWP was measured on April 14th, May 17th and June 1st. Leaf water conductance and net assimilation rate was measured on May 17th from 10:30am to noon using a LI6800 leaf clamp photosynthesis analyzer (LI-COR Instruments, Lincoln, NE). Intrinsic water use efficiency, an index that indicates how much water is being used per unit of carbon synthesized by the plant, was calculated dividing the net assimilation rate (A_n, an estimate of the photosynthesis rate of the plant) by the leaf stomatal conductance rate (g_s) that measures how much water the plant is transpiring.

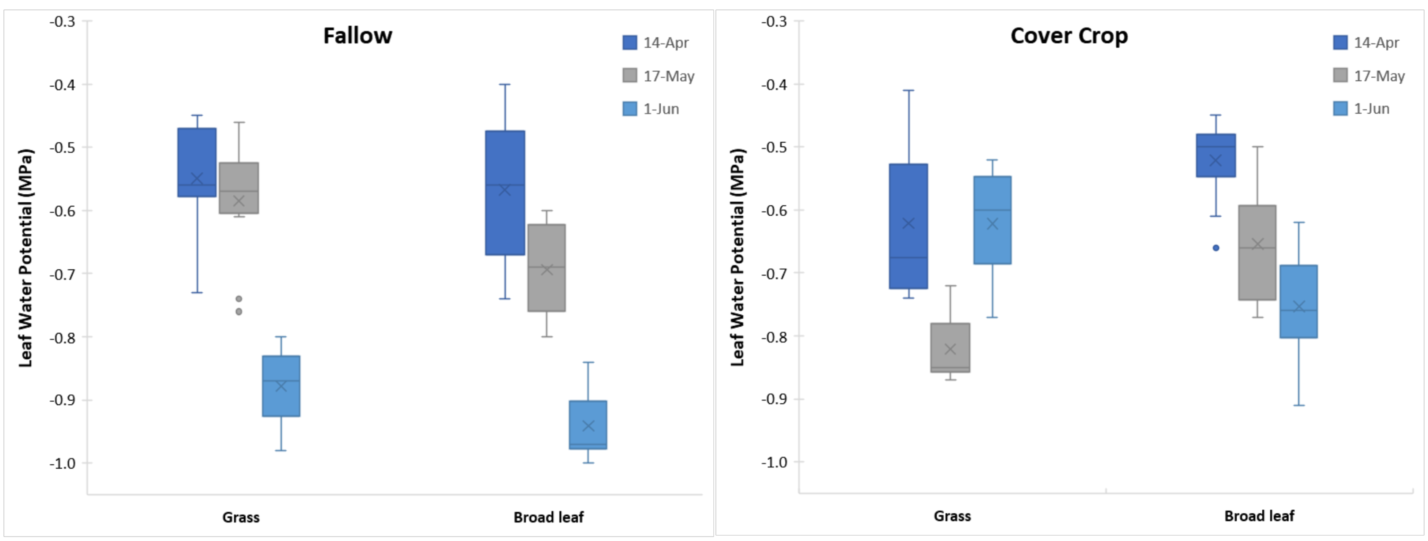

Figure 3.14: Leaf water potential measured for grass and broad leaf plats growing over the Fallow and Cover crop mixture plots. The left pane shows measurements for fallow and the right pane shows LWP in plants growing on the cover crop plot.

As can be seen in Fig.3.14, mean leaf water potential for both treatments are highly variable. As in crops variability of leaf water potential is expected to be lower, for both groups (grass and broad leaf), closely related to major crops, the leaf water potential was significantly lower in the fallow plot in the last measurement. Considering that temperatures were higher and water availability lower than those in previous months, it would be expected to have reduced leaf water potential. Nonetheless, as for cover crop in said conditions leaf water potential remained close to physiological optimal, it is possible that the establishment of a cover crop might have helped to improve water retention in the soil or might be an increased development of the root portion of the plant, due to land management and soil preparation previous to the cover crop establishment.

To analyze further differential physiological responses to the treatment, as pointed in Fig.3.15, even if the instant assimilation rate and the conductance to water, that represents the photosynthesis and water transpiration respectively, for both treatments was similar, when analyzing the intrinsic Water Use Efficiency index, the mean value for cover crops shows to be slightly higher for cover crop than fallow. Especially for grasses.

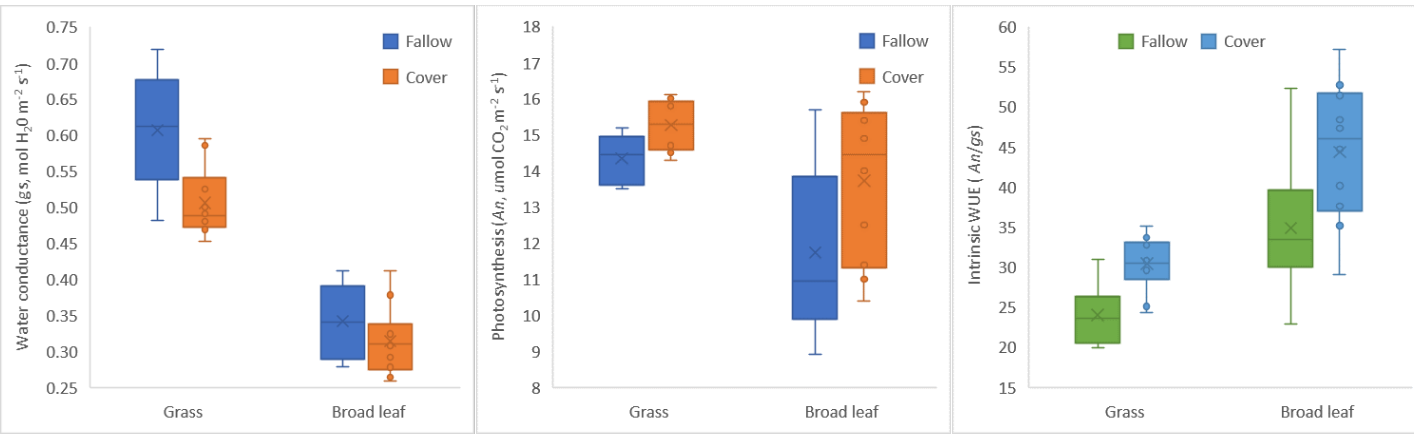

Figure 3.15: Water responsive physiological characterization of plants growing on the fallow and cover crop plots. Measurements were made on May 17th, 2023. Left pane shows Leaf stomatal conductance to water and it shows how much water is being driven through the leaf to the environment. The middle pane shows the CO_2 assimilation rate, an estimation of photosynthetic state of the plant. The right pane shows the intrinsic water use efficiency rate, that is the assimilation rate divided by the stomatal conductance rate and it shows an index of how much water is being used to fix a unit of carbon via photosynthesis.

Considering that coverage for both treatments was similar, and even considering that the variation for cover crop on LAI was smaller than the variation for fallow, these results might be an indication that plants growing in the cover crop plot might be using water more efficiently compared to fallow. Nonetheless, the development of the plants was truncated by the lack of water, hence, further measurement on the same group of species were not possible. It might be necessary to analyze longer cycles of plant development to achieve further clarification.

Conclusions and study limitations

After the eddy covariance measurements over the growing season, that cover almost fully the period relevant for wildlife habitat, and analyzing the water budget of the soil, we have shown water dynamics and estimated water usage for the fallow and cover crop plots. As shown, the precipitation for both experimental plots were the same, due to their close location; nevertheless, slight differences between water use and storage in the soil could be observed for cover crop. Previous studies have shown that runoff is reduced when cover crops are used, as well as water infiltration to the soil is improved. Some of our results might indicate that the use of cover crops might decrease the seasonal water loss at soil depths closer to the surface. But it is important to consider that the crop development and soil coverage (as shown by LAI) were similar for both treatments. Due to the wet year and vegetation growing within both experimental plots, we did not have the opportunity to measure impacts of water for field fallowing. The results for ET measurement show similar values between the two plots seasonally 13.45 and 13.1 in, and after May 1,2023: 5.24 and 4.67 in for fields that were fallowed and cover cropped, respectively. These values fall into the same range observed during the past two experimental seasons.

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