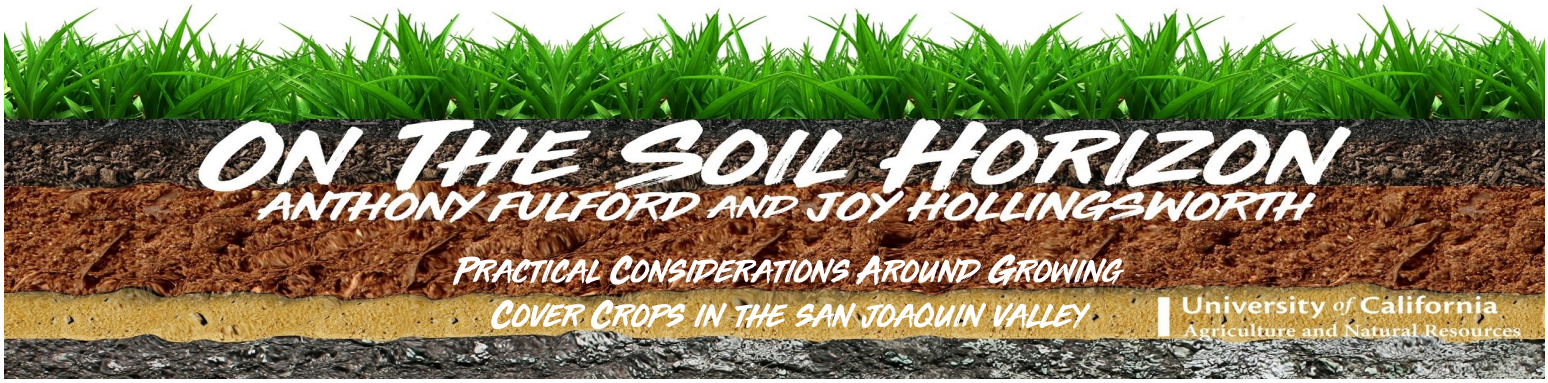


Introduction

It has been well documented that cover crops can provide many agroecosystem benefits to growers, such as improving water infiltration, contributing to soil fertility, preventing nutrient loss, and providing resources for pollinators and beneficial insects (Mitchell et al., 2017; Shackelford et al., 2019; Unger, 1998). However, growers in California's southern San Joaquin Valley worry that the lack of consistent winter rainfall and high cost of water make cover cropping impractical (Mitchell et al., 2015). Because of this, we wanted to assess how different winter cover crop mixes grew with and without supplemental irrigation in our region. Last year, we carried out a research trial at two locations – Shafter (Kern County) and Parlier (Fresno County) - and found that while there were slight differences in biomass between irrigated and non-irrigated plots, the differences were not significant. Cover crops that did not receive any supplemental irrigation were still able to contribute a decent amount of biomass, and simply by having roots in the ground, the rain fed cover crops were feeding the soil and preventing erosion.

This year, we wanted to replicate our trial and include cover crop mixes with species that performed well with low water in our previous trial, as well as a native cover crop mix. Beyond evaluating performance under different irrigation levels, we wanted to assess more practical questions around the implementation of cover crops, such as methods of planting and termination. We also used our cover crop demonstration site to host a field day, where we invited farmers to look at the different mixes and share their own thoughts and experiences. This article will outline what we found in our trial, farmer feedback from our field day, and reflections on what may be needed to make cover cropping a more widespread practice in the San Joaquin Valley.

Experimental Design

This trial took place at the Kearney Agricultural Research and Extension Center (KARE) in Parlier, California. The soil type is a Hanford Sandy Loam and the site received 5.7" of rainfall during the period of time that the cover crops were in the ground.

Three cover crop mixes were planted in a randomized block design on December 1, 2021 using two different planting methods: half of the plots were drill seeded using a Schmeiser seed drill and the other half were broadcast seeded using a fertilizer spreader. Table 1 outlines the mixes planted and the seeding rates used. The east side of the field was irrigated 4 times throughout the season, receiving 1.06" of supplemental irrigation via solid set sprinklers, while the west side of the field received an initial 0.25" of irrigation to help with germination but was then dependent on rainfall.

Cover crops were terminated on April 7, using various termination methods. 1/3 of the plots were mowed and the crop residue was left on the soil surface, 1/3 of the plots were mowed and the residue was disked into the soil, and the final 1/3 were left standing to assess when the different species might re-seed and die off on their own without mechanical termination.

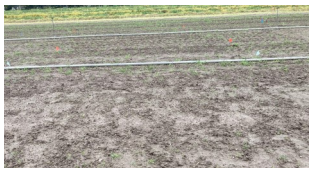
The height of different cover crop species is important to consider because it can affect management practices around terminating cover crops. Different sized equipment might need to be used to terminate the cover crops of differing heights. Additionally, taller species, or "high-growing cover crops", may be better suited for annual cropland during fallow periods and shorter growing species, or "low-growing cover crops", might be preferred in between tree crops.

Height measurements were taken at peak flowering time, during the first week of April. In the native flower seed mix, the fiddleneck was significantly taller than the other three native flower species. Under both irrigation and seeding regimens, rye grew to be significantly taller than the vetch in the rye and vetch mix. In the soil builder mix, the triticale and brassicas grew significantly taller than the two pea varieties, regardless of seeding and irrigation methods. Between grass species, the rye was significantly taller than the triticale.

Total cover crop biomass was not significantly different between the soil builder and rye/vetch mix across seeding methods and irrigation levels. Similarly, the presence of weeds was not significantly different across seeding and irrigation methods, except for the rye/vetch mix that was planted with the drill seeder and received low water; those particular plots had significantly more weed biomass than the other rye and vetch plots that were broadcast seeded (with and without irrigation) and drill seeded with irrigation.

TABLE 1

Cover Crop Mixes Planted	**Soil builder mix**: *30 % Triticale, 35% Bell Beans, 28% Peas, 1% Canola, 1% Common Yellow Mustard, 5% Daikon Radish* • *Seeding rate: 75 lbs/acre* • *Price: $0.55/lb*	
	Rye + vetch mix: *20% Merced rye, 80% hairy vetch* • *Seeding rate: 75 lbs/acre* • *Price: $1.74/lb.*	
	Native mix: 25% *layia platyglossa (tidy tips), 25% lasthenia glabrata (yellowray goldfields), 25% calandrinia menziesii (red maids), 25% amsinkia menziesii (fiddleneck)* • *Seeding rate: 35 lbs/acre* • *Price: $100/lb.*	
	Resident vegetation: *plots with nothing planted to compare what emerged without seeding a cover crop*	
Establishment	Field was disked to prepare the soil and cover crops were planted on December 1, 2021 – half of the plots were planted with a Schmeiser seed drill and the other half with a broadcast seeder.	 Planting with the seed drill

	0.25” of irrigation was applied for germination	 Broadcast seeding
Irrigation	Half of the field was irrigated 4 times from December to April The irrigated plots received 6.76” of total water (1.06” from irrigation + 5.7” from precipitation). The non-irrigated plots received 5.95” of total water (0.25” from irrigation + 5.7” from precipitation)**	 Irrigation sprinkler pipes in between plots
Termination	Cover crops were terminated on April 7th • 1/3 of the plots were mowed and the crop residue was left on the soil surface • 1/3 of the plots were mowed and the crop residue was disked into the soil • 1/3 of the plots were left standing to assess when the different species might reseed and die off on their own	 Cover crops being mowed

**We also discovered that an irrigation pipe was leaking near our field, so an amount of supplemental water that cannot be quantified ended up in the “non-irrigated” half of our trial. Thus, the “non-irrigated” half received more water than intended in our experimental design.

Height and Biomass

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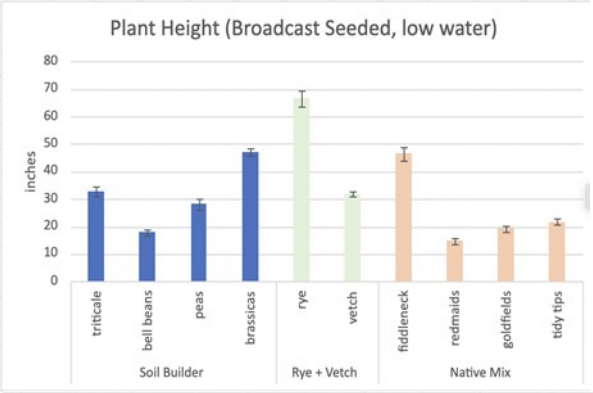
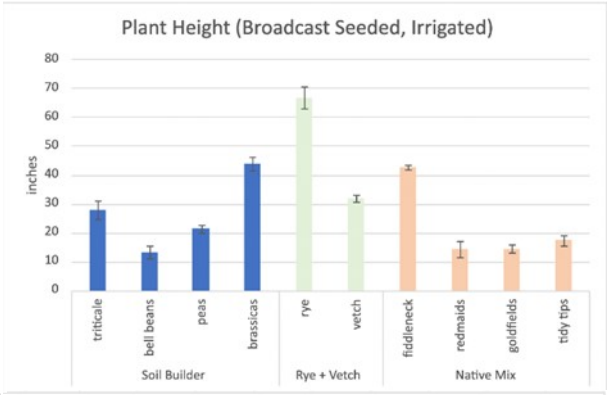
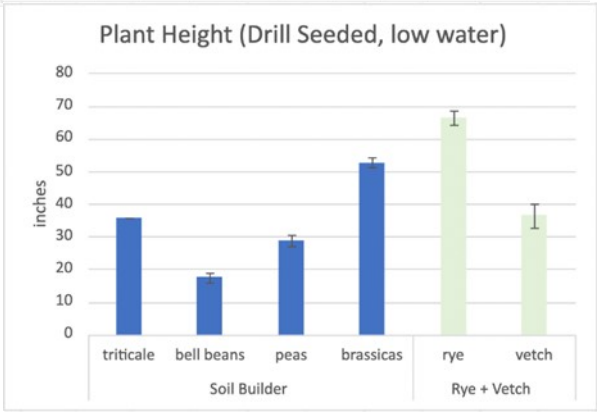
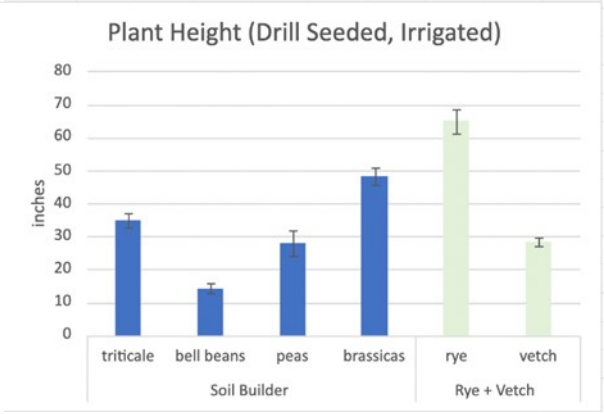
Measuring cover crop plant height

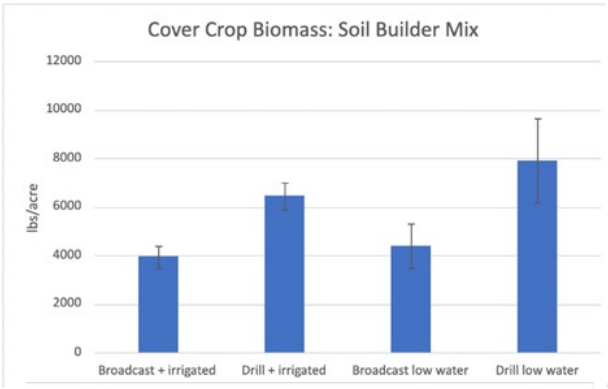


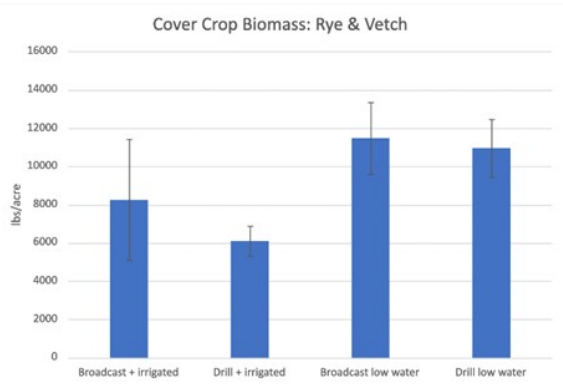


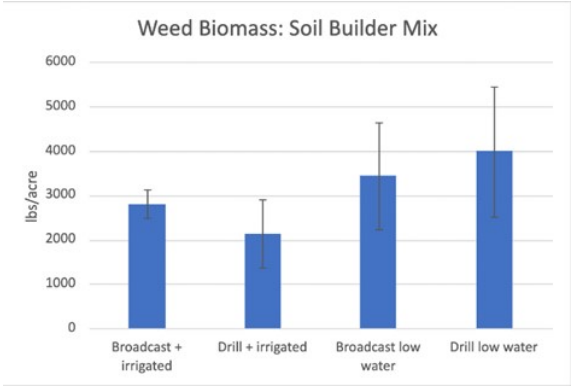


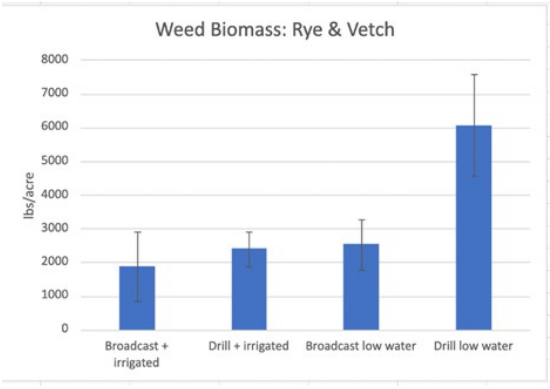


	
Separated species for soil builder mix biomass samples	Separated species for rye and vetch mix biomass samples









Seeding Methods

Key Question: Which seeding method will yield the most cover crop growth?

The soil builder mix had significantly more biomass when drill seeded than when it was broadcast seeded. For the rye and vetch mix, there was no significant difference in biomass whether the seed mixes were broadcast or drill seeded. We suspect this outcome might have to do with the many sizes of seeds present in the soil builder mix. Due to the variety of seed sizes, drill seeding the soil builder mix directly into the soil might have resulted in higher germination success rate than if the seeds were broadcast onto the soil. The rye and vetch mix only has two types of seed that are relatively small in size; this could explain why germination rates and, consequently, biomass did not significantly differ across seeding methods.

Note - The seeding rate was kept the same while seeding with the broadcast and drill seeder. This difference in the concentration of seeds might also explain why, for the soil builder mix, there was significantly more biomass when drill seeded than when broadcast seeded. Although it is common for farmers to increase the seeding rate when broadcast seeding, having a lower seeding rate when broadcast seeding still yielded a considerable amount of biomass for both mixes (about 4,000 lbs/acre of biomass for the soil builder mix and between 8,000-11,500 lbs/acre of biomass for the rye and vetch mix) and could be used to reduce overall expenses when purchasing cover crop seed.

Irrigation Methods

Key Question: Do I need to irrigate my cover crop, or can I rely on rainfall? Will cover crops improve the soil's ability to retain water?

If planting is properly timed with the start of winter rainfall when establishing the cover crop seed, the need for irrigation at germination may be eliminated as long as too much time does not pass between initial rainfall and subsequent rain events. In this case, 0.25" of irrigation was applied for germination, followed by subsequent rain events.

In terms of water entering the soil profile, last year we saw higher infiltration rates when cover crop roots were in the ground compared to the bare soil before the cover crops were planted. This year, we compared infiltration between the different termination methods and found plots that were mowed with residue retained on the surface had a higher average infiltration rate (12.46 in./hr.) than the plots that were mowed and disked (9.49 in/hr.). This is likely due to the fact that disking causes greater disturbance to soil structure, including the destruction of channels created by plant roots.

Bloom Time

Key Question: How can cover crops attract more pollinators to my farm?

Another benefit of cover cropping is that it provides pollinator resources. In our trial, the seed mix of native flowers seemed to flower in succession, providing resources for pollinators over a long period of time. The fiddleneck started blooming at the end of January, followed by the red maids in mid-February. Then the yellowray goldfields bloomed in mid-March, and finally the tidy tips blossomed towards the end of March. In the soil builder mix, brassicas started flowering in early March, followed by the peas. In the rye and vetch mix, the hairy vetch did not start flowering until the end of March.

In thinking about choosing a cover crop mix that attracts belowground biodiversity as well as aboveground biodiversity, choosing a variety of flowering species that bloom at different times would be something to consider to provide a consistent source of nutrients for pollinators over a period of time.

Termination Strategies

Although disking is a widely used practice on small-scale and large-scale farms throughout the San Joaquin Valley, it often results in increased levels of erosion and soil compaction, which can negatively impact air quality and soil aggregate stability (Baker et al., 2005; Hernanz et al., 2002). In this trial, we tested two alternative termination strategies in addition to disking to see if there was an impact on soil quality.

When it came time to terminate cover crops during the first week of April, we divided the cover crop plots into three sections. The first section was terminated by mowing and the cover crop residue was left on the surface (left image); the next section was mowed and disked to incorporate residue (center image). The third section remained untouched to see when cover crop species would die back and/or re-seed themselves (right image). The most immediate observation between the mowed and disked plots was that the soil of the mowed section was less susceptible to erosion due to the layer of cover crop residue resting on the surface of the soil. The soil of the disked section, on the other hand, was fully exposed to the sun and easily susceptible to erosion (caused by wind and other external physical disturbances).

Retaining residue on the soil surface also helps lower soil temperature and reduce evaporation of water from the soil. About a month after termination, an infrared thermometer was used to assess soil temperature in the parts of the field where the cover crop residue has been disked and where the cover crop residue had left on the soil's surface. The average temperature where the residue was disked in and the soil surface left bare was 126.03° F, while the average temperature where residue was retained on the soil surface was 101.73°F, over 20 degrees cooler than the bare soil.

This is important to pay attention to, especially in the context of the Central Valley's high-heat summers, because the optimal soil temperature for planting and growing most vegetables is 65° to 75°F. When soil temperatures rise above optimal ranges, plant water and nutrient uptake can be impeded. Extreme air and soil temperature can alter the water transport rate from the soil into the root and plant system, which can reduce plant transpiration rate where plant transpiration cannot keep pace with high atmospheric evaporative demand (Irmak, 2016). Whereas, dry, sandy soils can heat up very fast, keeping the soil covered can greatly reduce soil temperature and protect soil and plant health.

Moreover, crop surface residue is important to consider as concerns about cover crops and consumptive water use will likely continue to increase when groundwater sustainability plans under the Sustainable Groundwater Management Act (SGMA) come into effect. Recent studies have found that there is not a significant difference in soil moisture between cover cropped fields and bare soil throughout the winter, and evapotranspirative losses due to winter cover crops are negligible relative to bare soil (DeVincentis, 2022). If it can be shown that cover crop residue left on the soil surface after termination can reduce evapotranspirative losses into spring and summer, this may encourage more growers to consider cover cropping as a water conserving practice.

Peas and brassicas (left) and yellowray goldfields and tidy tips (right) blooming in March

Mowed, disked, and untouched cover crop plots

Soil temperatures on a disked cover crop section (left) and a mowed section (right)

Cover Crop Trial Field Day

In April, we hosted a Cover Crop Trial Field Day for farmers and technical assistance providers, and we were very pleased with how many farmers came out to the event. After walking through the research plots and viewing different cover crops, we all convened and had a group discussion. Farmers shared insights and asked questions pertaining to cover crop varieties and the ways they can incorporate them into their current farm management practices.

Listed here are the main questions challenges that farmers discussed, along with recommendations on how to address those concerns:

- How can I access the proper equipment to plant and/or terminate cover crops?
    - Equipment, such as drill seeders or mowers, can be expensive and - with today's supply chain disruptions - are often only available in limited quantities. This presents a barrier for many farmers wanting to apply cover crops. We first recommend reaching out to fellow farmers or local extension agencies to see if there is an equipment-lending program available that will allow you to lend or rent machinery, and/or advocating for such programs to be a budget priority for the state. If equipment-lending programs are not available in your area, contact your local extension agency or nonprofit organizations to see if any grant opportunities exist for purchasing on-farm equipment. Different seeding and terminating methods can also be used in lieu of equipment-intensive planting/terminating methods, as presented above in this paper.
- How can I build soil health and soil structure on my farm?
    - Planting different seed mixes can yield different outcomes for the soil. For instance, in the soil builder mix, the legumes (peas and fava beans) fix nitrogen and, thus, contribute to the fertility of the soil; the brassicas help loosen up the soil and reduce compac-

tion with their fibrous root system; and the triticale helps to improve water infiltration and prevents erosion with its dense root system. Depending on the needs and goals of a specific farm and its soil, cover crop species can be mixed and matched, along with the ratio of the seeds in any mix, to best support soil health in a particular farming context.

- Certain cover crop seed mixes can be expensive. How can I make cover crops more affordable?
    - Some incentive programs will subsidize the cost of cover crop seeds for farmers trying cover crops for the first time. Choosing a balance of expensive and less expensive seed combinations for your cover crop is another option to decrease cover crop seed costs. For instance, the native wildflower seed mix used in this trial was significantly more costly than the soil builder and rye and vetch mixes; however, native species tend to perform well under low water and provide resources for native pollinators and beneficial insects. These cost-benefits can balance out the initial high price of native seeds.

After the cover crop field day, we sent out a farmer feedback survey to attendees that included take-aways on the different planting/termination methods, planting/termination times, and using resident vegetation to keep soil covered. Future research ideas from farmers included focusing on cover crop mixes that do not harbor pests for subsequent crops and evaluating how cover crops can impact soil organisms, such as nematodes. Questions remained about the impact of cover cropping practices and water conservation, like the advantage of using mulch and how changes in soil organic matter may impact water use. Others asked for practical information around cover cropping, such as methods to prepare the ground and apply irrigation.

Group discussion with local farmers at the Cover Crop Trial Field Day

Conclusion

The ecological benefits of cover crops are well-established (Mitchell et al., 2017; Shackelford et al., 2019; Unger, 1998). Beyond the ecological benefits of cover crops, this trial examined how cover crops can be incorporated practically on farms. We compared different seeding and termination techniques, and recognized – through farmers' feedback in group discussions and a survey – the financial challenges farmers face in acquiring the necessary equipment to purchase, plant, and terminate cover crops. In general, many farmers are interested in the practice of cover cropping, but they do not always have the resources to do so.

What we discovered was that both drill and broadcast seeding strategies fared well in producing a considerable amount of cover crop biomass, with the drill seed having significantly more biomass for the soil builder seed mix. In regards to termination methods, mowing is recommended for building soil health and structure because it resulted in cooler soil temperatures, less observed erosion, and a higher infiltration rate.

Purchasing the seed and equipment for growing cover crops was a main concern for growers interested in this practice. The paper outlined some strategies farmers could use to reduce costs such as mixing and matching different priced seeds, reaching out to local agencies and organizations to apply for cover crop incentive programs, and vocalizing that it remains difficult to access equipment even with grants. Programs local to the Central Valley and California, at large, that farmers can apply to include:

- Xerces Society (Nonprofit) - https://www.xerces.org/
- Seeds for Bees program - https://www.projectapism.org/seeds-for-bees.html
- CDFA's Healthy Soils Program - https://www.cdfa.ca.gov/oefi/healthysoils/incentivesprogram.html
- USDA NRCS EQIP Program - https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/contact/local/

In the future, we are interested in testing out more cover crop seed mixes, especially those that will not only provide biodiversity above and beneath the soil, but also seed mixes that are economically practical for farmers. We are also interested in trialing perennial cover crops (which also have the potential to reduce overhead costs) and summer cover crops. Finally, we plan to continue to engage with farmers to assess what is working and not working on their farms, with a focus on water conservation and pest management, two areas of interest brought up by farmers in our group discussion and survey responses.

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