ANNUAL REPORT
COMPREHENSIVE RESEARCH ON RICE
January 1, 2023 - December 31, 2023

PROJECT TITLE: Cover Crop Variety Trial in Rice

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OBJECTIVES OF PROPOSED RESEARCH:

1. Evaluate 5-10 winter cover crop varieties for agronomic performance
2. Assess site characteristics and soil properties and relate to agronomic performance of cover crops
3. Extend findings to growers and the industry through meetings and publications

Previous research in California rice systems identified several benefits and challenges from cover cropping (Pettygrove and Williams, 1996). Adding nitrogen to the system is one potential benefit. This may occur either by nitrogen fixation of a leguminous cover crop or by taking up nitrogen that would be lost from the system by leaching or denitrification. Improving subsequent rice yields and long-term soil quality are examples of other benefits. Challenges may include difficulty with residue management that delays rice planting, increased greenhouse gas production in waterlogged soils, and increased management costs. Growers incur costs with cover cropping that may not be recovered with increased rice yield or reduced inputs in the short-term. For these reasons, it is important to identify cover crops that will perform well in rice production systems in order to optimize benefits to the system.

Growers that are interested in cover cropping are interested in the practice for the potential reduction in nitrogen inputs during the growing season, as well as for the potential marketing benefit that would accompany these healthy soils practices (i.e., "Regenerative Agriculture"). Marketers are already funding cover-crop related projects in Sacramento Valley rice fields, and it is critical for the rice industry to have scientifically backed information when making decisions about cover cropping in general, and more specifically on variety selection.

The overall purpose of this proposal is to start assembling information for California rice growers on cover crops that will survive the typically wet winters and water-logged soils found in most rice fields. If cover crops do not grow and produce sufficient biomass, they cannot confer the benefits that are typically associated with cover crops, such as increasing soil carbon and nitrogen, and potentially increasing yields. This proposal would be the first step to developing guidelines for growers on how to incorporate cover crops into rice systems.

OBJECTIVES AND EXPERIMENTS CONDUCTED, BY LOCATION, TO ACCOMPLISH OBJECTIVES:

Objective 1: Evaluate 12 winter cover crop varieties for agronomic performance
Objective 2: Assess site characteristics and soil properties and relate to agronomic performance of cover crops
Objective 3: Extend findings to growers and the industry through meetings and publications

The Rice Cover Crop Variety trail will be conducted over two years from December 2022-December 2024. This trial is located across three sites, two in the Sacramento Valley region: In Butte (Rice Experiment Station) and Colusa County, and one in the Northern San Joaquin Delta region. These sites are representative of the environmental gradients across the Sacramento Valley and Northern San Joaquin regions. Most of the Sacramento Valley Rice is produced on flood basins in high clay soil. Both the Rice Experiment Station (RES) and the Colusa site have dominantly clay soils. The site in the Northern San Joaquin, has a high organic matter soil, differing from the other two sites. Similar to the other sites, the Northern Delta is also on a flood plain.

The trial is a randomized complete block design with four replications at each site. Plots are approximately 10 feet by 20 feet long. The trials were implemented roughly 2-3 weeks apart from each other. The Colusa site was seeded on October 26th, 2022. The RES was seeded on October 31st, 2022. Finally, The San Joaquin site was seeded November 30th, 2022. At each site cover crop seed was broadcasted by hand. However, bed preparation and incorporation were slightly different at each site. At the Colusa site the previous season was fallowed due to water limitations. Here, this field was harrowed after broadcasting the seed. The RES field produced rice in the previous season, resulting in heavy rice straw remaining on the field. The field was mowed and disked four times before seed was broadcasted. There was no seed incorporation after the seed was broadcasted. At the San Joaquin site, the field was transitioning into rice after a corn crop the previous year. After the field was leveled, the seed was broadcasted and raked in. At all three sites soil moisture and soil temperature sensors were deployed, one in each block (4

moisture probes and 4 soil temperature gauges per site). Each sensor was set to record data over the course of the season.

A total of 10 different cover crop species and 2 Cover Crop Mixtures were trialed. The species planted in a monoculture were: 1) Purple Vetch (*Vicia benghalensis* L.), 2) Woolypod Vetch (*Vicia villosa* ssp. *dasycarpa*, 3) Bell Bean (*Vicia faba)*, 4) Balansa Clover (*Trifolium michelianum* Savi), 5) Field Pea (*Pisum sativum* ssp. *arvense*), 6) Yellow Mustard (*Brassica juncea* L.), 7) Purple Top Turnip (*Brassica rapa*), 7) Rye (*Secale cereale*), 8) Oats (*Avena sativa* L.), and 9) Biomaster Pea (*Pisum arvense*). Mixture 1 was a mixture of Purple Vetch, Bell Bean, Field Pea and Rye. Mixture 2 was Purple Vetch, Balansa Clover, Field Pea, Oats, and Radish (Sp.). Seeding rates for cover crops for rice systems have not been evaluated and therefore seeding rates were determined based on two sources including UCANR Cover Crop Species Selection Tool (1) and SARE Cover Crop Handbook (2). Mixture rates were determined using the Pennsylvania State Extension resources (3).

Table 1: Cover crop species and seeding rates for three variety trials. Each site received 1/3rd of the amount recorded under lbs./0.06ac.

Cover Crop Species	Lb/ac	Lb/ 0.06 ac
Purple Vetch	60	3.6
Woolypod Vetch	60	3.6
Bell Bean	160	9.6
Balansa Clover	8	0.5
Field Pea	90	5.4
Yellow Mustard	10	0.6
Turnip	15	0.9
Rye	90	5.4
Oats	100	6
Biomaster Pea	60	3.6

Table 2: Cover crop species in Mix 1 and Mix 2 and pounds required by species for three sites based on % of lbs. per acer.

Mix (1)	Lb/ac	% Mixture	Lb/0.06 acres
Purple Vetch	13.33	10.96	0.80
Bell Bean	33.33	27.40	2.00
Field Pea	30.00	27.00	1.80
Rye	45.00	37.00	2.70
Totals	*121.67*	*102.36*	*7.30*
Mix (2)	**Lb/ac**	**% of mixture**	**Lb/0.06 acres**

Purple Vetch	20.0	21.4	1.2
Balansa Clover	2.7	2.9	0.2
Field Pea	38.3	41.0	2.3
Oats	25.0	26.7	1.5
Radish	7.5	8.0	0.5
Totals	*93.5*	*100.0*	*5.6*

Several evaluations were taken over the winter of 2022-2023, December – January. In order to evaluate cover crop performance, germination counts, and percent cover was measured once a month at each site in December and January, when possible. This data collection will continue through the end of the winter cover crop growing season, estimated to be early spring.

Germination counts were taken using a 20-centimeter squared quadrant. Sampling was taken 5 times in each plot at the beginning of emergence. Cover crop growth was tracked and measured using percent cover, which was taken using a meter-squared quadrant, each plot replicated sampling twice using a visual percent cover. Weeds and rice straw percent cover were also measured as cofactor indicators of performance, where applicable (Weed data will not be discussed here due to the minimal data collected at this time). Before cover crop termination, end of season biomass, total N, total C and PMN will also be collected to assess the potential N and C provisions (but not reported here).

SUMMARY OF 2022-2023 and 2023-2024 RESEARCH (major accomplishments), BY OBJECTIVE:

Objective 1: Evaluate 12 winter cover crop varieties for agronomic performance

Over the season cover crop emergence (germination count), and percent cover were collected to assess overall performance of the 10 cover crops and 2 mixtures. Germination counts can be a good indicator for cover crop establishment. However, each species has a different seeding rate based on seed size. When comparing germination counts across sites, the Colusa trial showed the best establishment compared to the other two, while San Joaquin had the lowest (Figure 1).

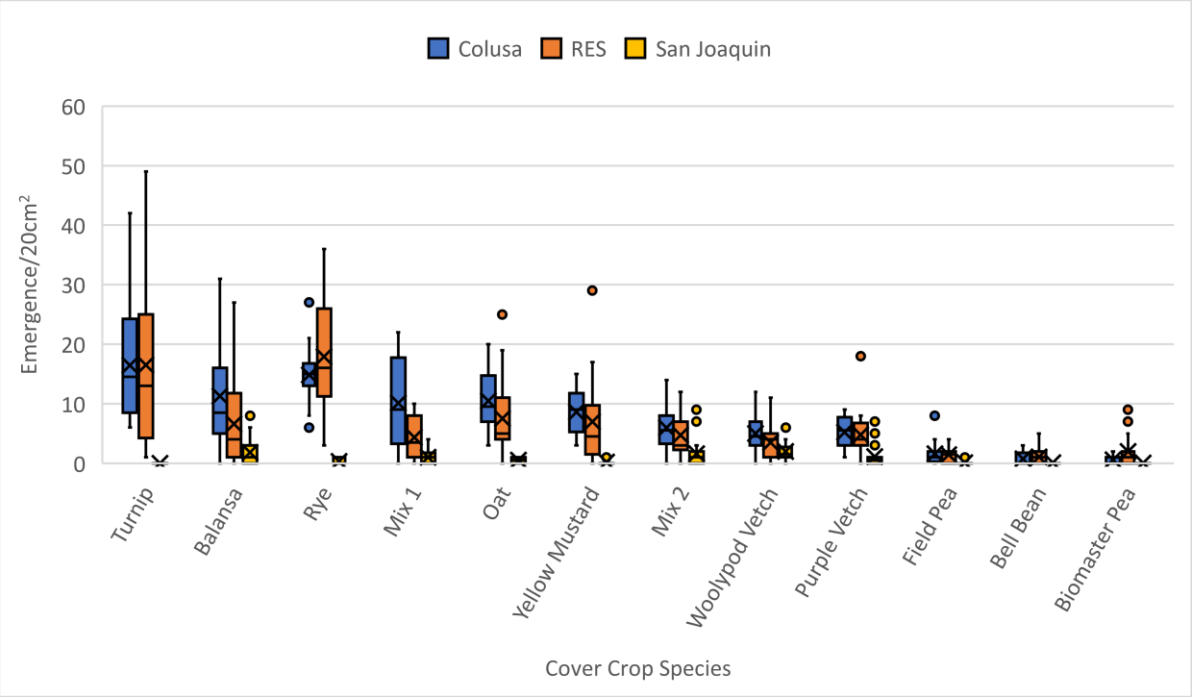


Figure 1: Average germination counts and variance at all three sites represented by box plots. Mix 1 and 2 are calculated as totals of all species.

Percent cover is a way to measure biomass and growth over the season. Biomass is an important indicator because it relates to total carbon and nitrogen content. Both the Colusa and RES sites were planted earlier in the season, 10/26/22 and 10/28/22 respectively. Therefore, a percent cover was taken for each site during the second week of December. For the RES site a percent cover was also taken during the third week of January, however heavy rains and flooding hindered our ability to take measurements for the Colusa site at this time. The San Joaquin site was not seeded until 11/30/22 and due to the later planting and heavy rainfall we were only able to collect data for this site in January.

When comparing cover crop performance by site, Colusa has the highest percent cover on average of all species (Figure 2). However, not shown here is the reduction in growth after flooding events, which will be discussed under objective 2. While overall percent cover in the San Joaquin sat was low, Purple Vetch and Woolypod Vetch presented with the highest percent cover at this site (5 % cover on average) (Figure 2).

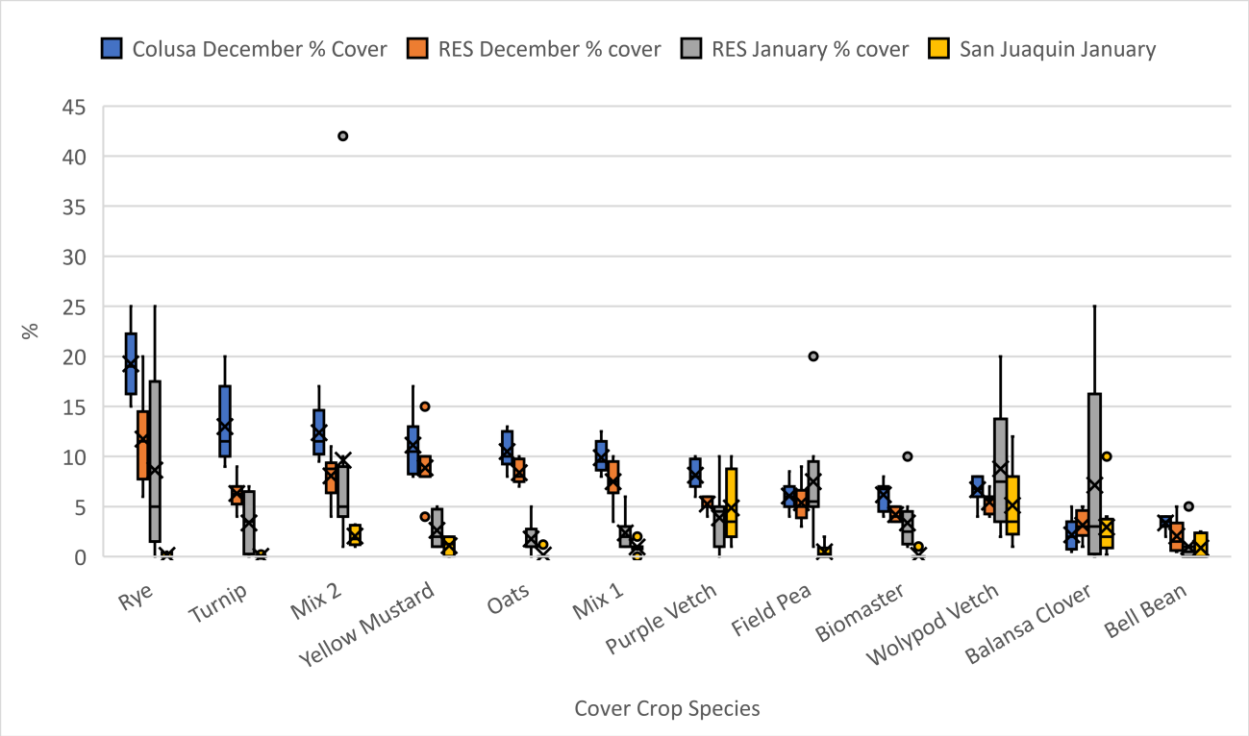
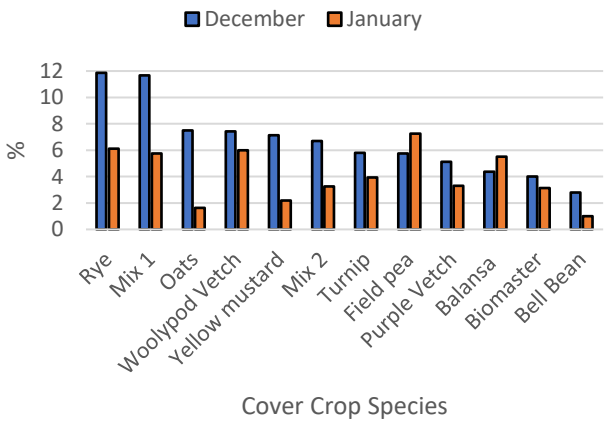


Figure 2: Average percent cover and variance represented by box plots. Rice Experiment Station site has two months of data collected while the other two only have one month. Mix 1 and 2 are calculated as totals of all species.

At the Rice Experiment Station Rye and Mix 1 began performing the best in December, prior to the heavy rainfall (12 % and 11.6 % respectively), with Oats and Woolypod Vetch following at 7.5% cover each (Figure 3 A). The outcomes at the RES site overall were low for every species and there was a reduction in percent cover in January across most species except for Field Pea and Balansa Clover which increased by 2.25% and 1.5% between December and January. In

A



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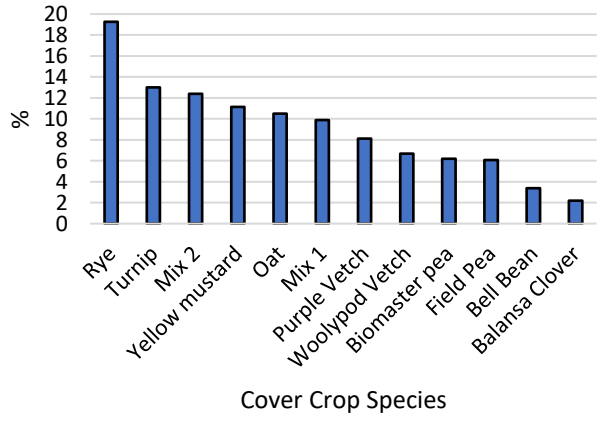

Figure 3: A) Average percent cover taken in December and January at the Rice Experiment Station. Growth reduced in January due to heavy rain fall and flooding events. B) Average percent cover taken at Colusa site. Rye, Turnip and Mix 2 had highest percent cover at time of data collection. Mix 1 and 2 are calculated as totals of all species.

December, Rye, Turnip, and Mix 2 presented with the highest percent cover at The Colusa site, 19.25%, 13.5%, and 12.4 % respectively (Figure 3.B). Not shown in this data is the reduction in all cover crop growth after flooding through January. While the Colusa site showed promise in cover crop development for many species overall, the high precipitation in January has resulted in overall cover crop growth failure, discussed in Objective 2.

Harvest in spring of 2023 was insufficient to get data, except for at the Colusa site. Across the three sites we only had meaningful growth (more then 10g/m^2 dry weight per sample) at the Colusa site and therefore we are only showing these outcomes. Provided are the outcomes of biomass, N and C. Samples were harvested from m^2 quadrat, and dry samples were sent to the Ward Lab for analysis.

Table 3: Summary of C, N and biomass from most successful cover crops for 2022-2023 trial

Row Labels	Average % N	Average % C	Average dried Wt. CC g/m2	Average lbs. N /acre	Average lbs./acre dry Wt.	Average C:N ratio
Balansa clover	4.18	41.45	14.42	5.35	128.66	9.93
Mix 1	3.66	40.84	17.91	6.19	159.77	11.38
Mix 2	2.06	42.92	82.86	14.68	739.22	21.43
Oats	1.60	42.95	86.20	10.29	769.05	28.41
Purple vetch	4.06	40.89	5.31	1.92	47.35	10.11
Rye	1.66	42.24	20.38	3.01	181.78	25.48
Weeds	2.22	42.99	27.10	5.37	241.74	19.75
Wooly pod vetch	4.27	41.49	6.68	2.54	59.55	9.72

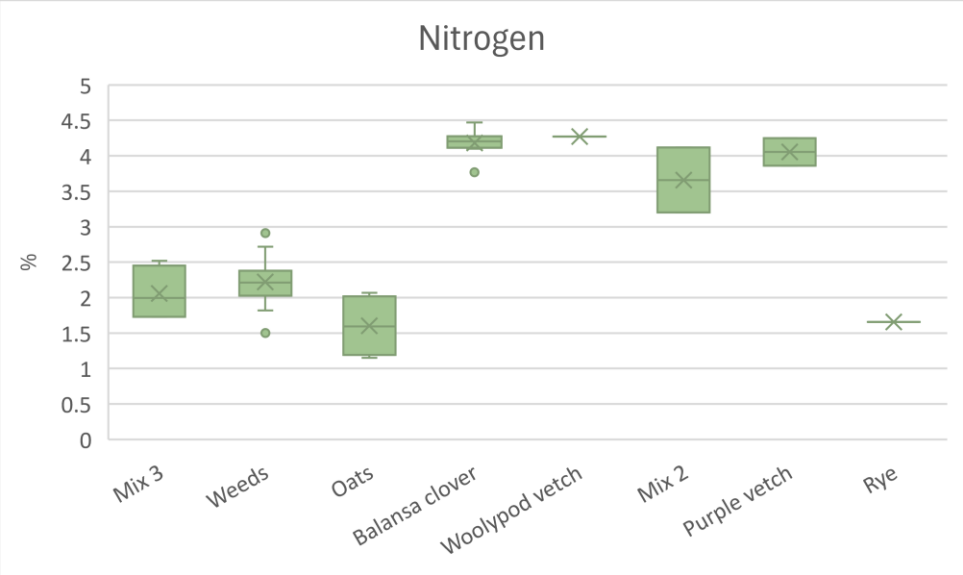

Figure 4: average % Nitrogen of 7 cover crop varieties out of 12 tested and weeds. Balansa clover and Wooly pod vetch has the highest % N (4.20), followed by Purple vetch (4.0), then Mix 1 (3.7), weeds (2.21) , mix 2 (2.06), then oats and Rye (1.6). (Note: Mix 2 = Mix 1, Mix 3 = Mix 2 in figure).

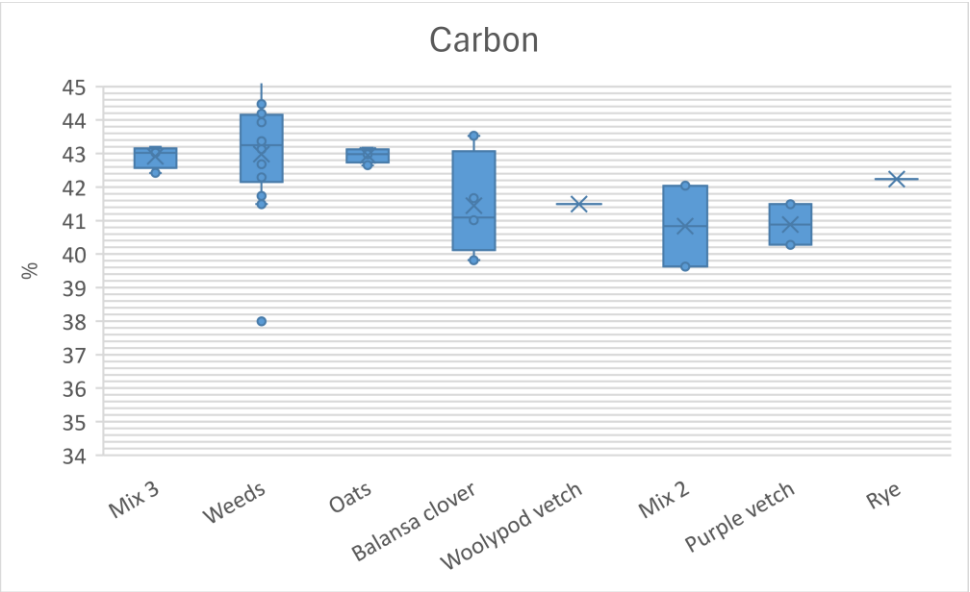

Figure 5: Average % Carbon of 7 cover crop varieties out of 12 tested and weeds. Mix 2, weeds and oats and rye had the highest % carbon, followed by balansa clover, Wooly pod and purple vetch, and Mix 1. (Note: Mix 2 = Mix 1, Mix 3 = Mix 2 in figure).

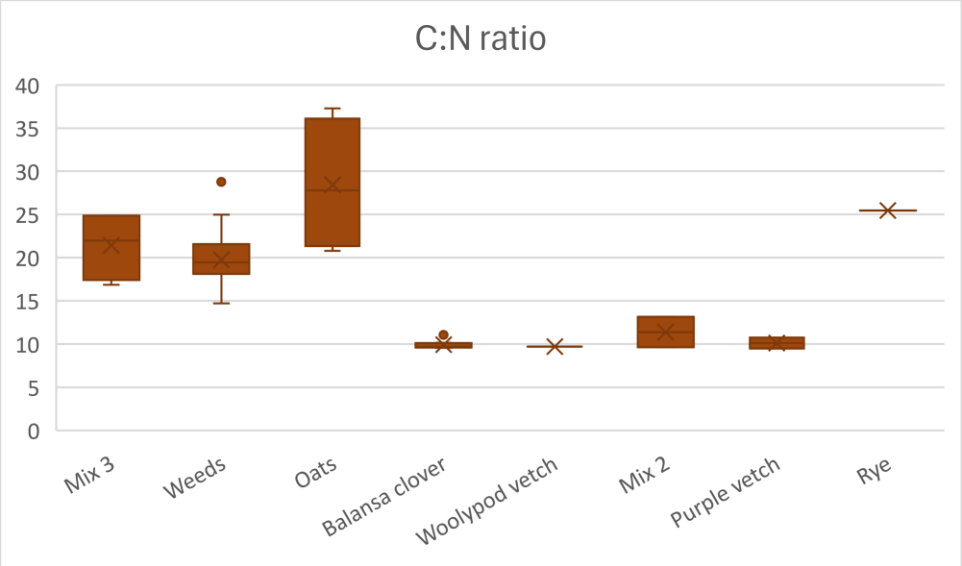

Figure 6: C:N ratios of cover crop varieties and weeds. Oats had the highest, followed by Mix 2 and weeds. Mix 1, balansa clover, and the vetch species had the lowest ratios. (Note: Mix 2 = Mix 1, Mix 3 = Mix 2 in figure).

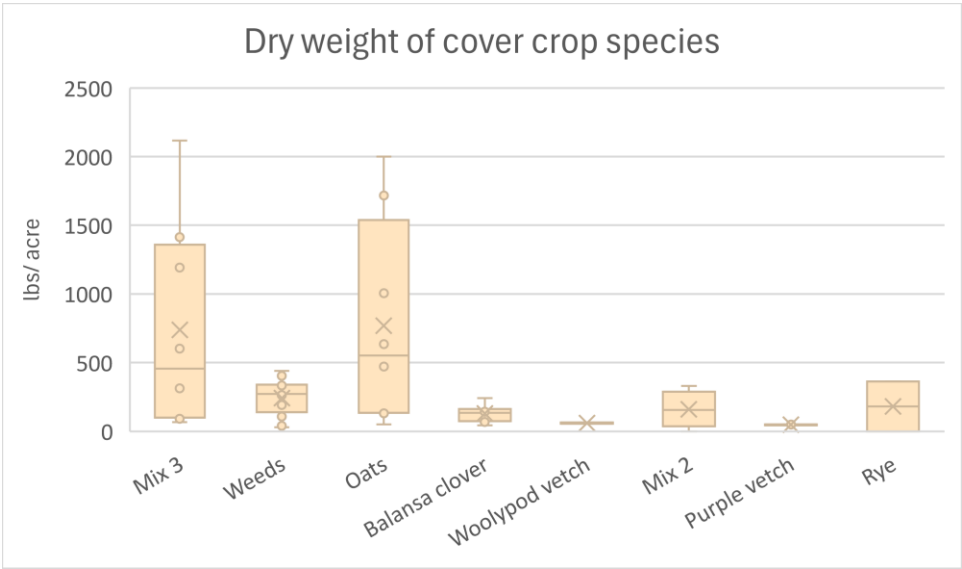

Figure 7: Dry weight adjusted to lbs/acre for 7 out of 12 tested varieties and weeds. (Note: Mix 2 = Mix 1, Mix 3 = Mix 2 in figure).

The high variation represents the uneven growth pattern across the trial for this year due to the flooding events that took place. However, Mix 2 and oats did have the highest growth by the end of the season.

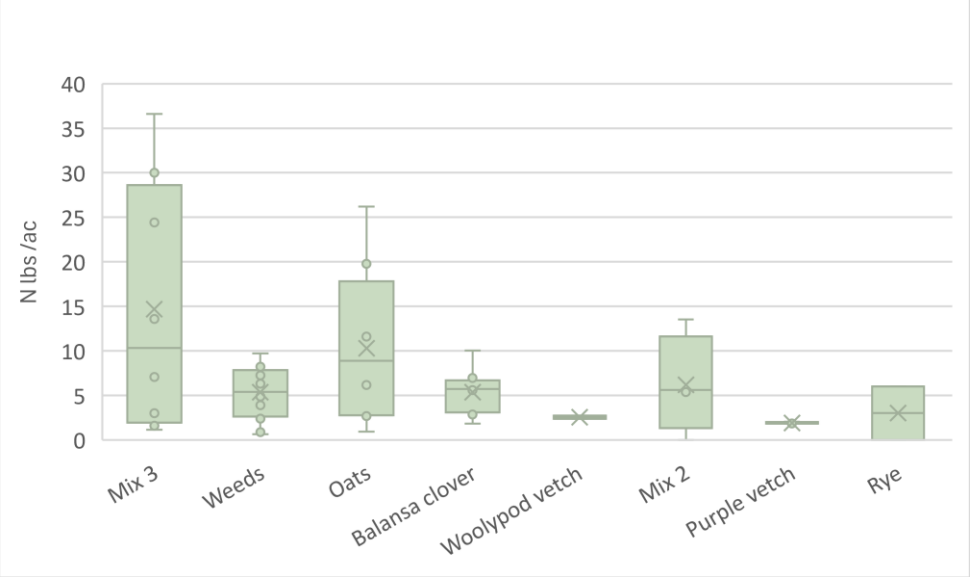

Figure 8: Estimated lbs. of N per acre provided by 7 out of 10 species tested and weeds. (Note: Mix 2 = Mix 1, Mix 3 = Mix 2 in figure).

While Balansa clover and legumes have the highest N content, the low growth rate in 2022-2023 still reduced the total N provided over the year. Mix 3 and oats provide higher amounts of total N, although with the higher C/N content of these species (21-28), mineralization will be slower for them compared to the legumes. Secondly, weeds, oats, and rye are not contributing any N to the system, rather they are acting as a trap crop, preserving N that is already in the soil. The legumes are fixing nitrogen and so we can assume that the total N provided by them is mostly added to the system (between 5-6 lbs). The mixtures may be doing a better job at both acting as a trap crop while still fixing N.

In 2023-2024, we only had data for San Joaquin for December. The data in 2023 looks much better, but at the time of the report, we only have data for San Joaquin (Figures 9 and 10). The turnip and mustard are performing the best at this time, in comparison to all of the other species.

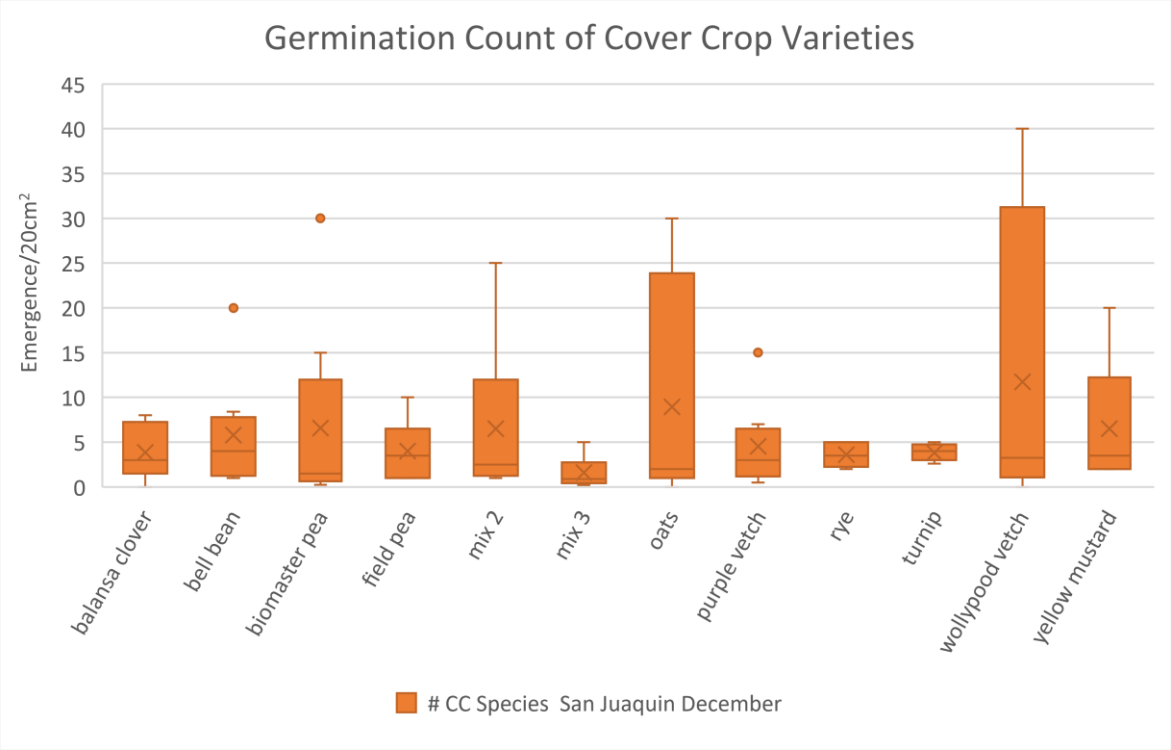

Figure 9: Germination count for the varieties in December 2023, at the San Joaquin site. Germination counts were higher across all varieties in comparison to 2022. (Note: Mix 2 = Mix 1, Mix 3 = Mix 2 in figure).

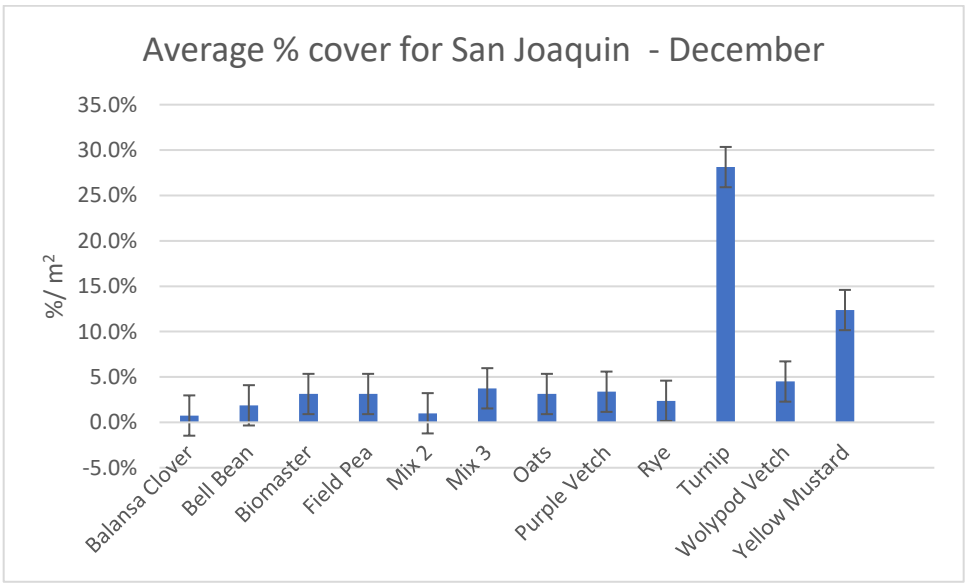

Figure 10: Percent cover of each of the varieties at San Joaquin in December, approximately one month after planting. The turnip and mustard are performing the best in terms of plot coverage. However, the seeds are small and the seeding rate is higher than the other species. (Note: Mix 2 = Mix 1, Mix 3 = Mix 2 in figure).

Objective 2: Assess site characteristics and soil properties and relate to agronomic performance of cover crops

Pre-soil samples were taken to establish soil profiles on texture, and nutrients present. The RES field is 45 % clay with 3.7% Organic Matter (OM). The Colusa site is 66% clay with 5.6% OM. And the San Juaquin site is 30 % clay, considered a clay loam, and 26.5 % OM.

The precipitation for the 2022-2023 winter was significantly more than 2021 and 2020. The San Joaquin site received less rain for 2018-2021. California is known for extreme weather, fluctuating between dry and wet winters, with climate change perpetuating these extremes (4). California rice fields have been developed particularly to hold water, with dominantly clay soils and flat-leveled fields. Wet winters such as these makes cover cropping difficult to establish for these reasons, as we have seen thus far. However other factors play a role in successful establishment, such as planting date, and seedbed development.

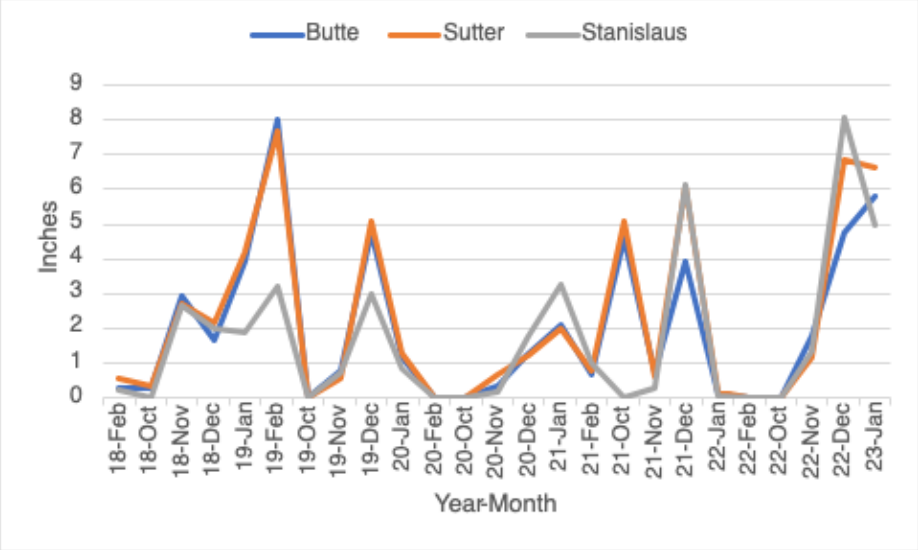

Figure 11: Precipitation during winter months of October - February from 2018 – 2023 in three Variety Trial regions. Precipitation measured in inches (CIMIS, 2023).

Rice straw can be a barrier to proper cover crop establishment. Both the Colusa site and the RES site were planted relatively early in the year at the end of October. However, the RES site produced rice during the 2022 season, while Colusa was fallowed. Rice straw biomass inhibited soil to seed contact for the cover crop seed, and this may be a reason why this site was not as successful as the Colusa site in the beginning (Table 4). For next year's trial, there will be rice straw to manage at all three sites. Taking into consideration techniques for better straw incorporation or management for next year will be a priority. At this site, seed was broadcasted and not incorporated. At the Colusa site however, the site was harrowed after the cover crop seed was broadcasted. This could have also been attributed to the better germination stands at the Colusa site compared to the RES site. Similarly, the San Joaquin site was broadcasted and not incorporated into the soil. The combination of limited seed incorporation, later planting, and high rainfall may have greatly reduced the germination success here.

We do not yet have rainfall data for 2023-2024, but rainfall looks better-suited to cover cropping this year, with a drier October-November.

Table 4: Average percent straw cover for each cover crop (C.C) species at RES and average cover crop percent cover.


Station, Picture taken by Mia Godbey, December 2022

Cover Crop	% Straw December	C.C. % Cover December
Balansa Clover	52.5	4.4
Bell Bean	78.8	2.8
Biomaster Pea	46.3	4
Control	68.8	0
Field pea	53.8	5.8
Mix 1	85	6.7
Mix 2	55	11.7
Oats	63.8	7.5
Purple vetch	70.3	5.1
Rye	44.4	11.9
Turnip	48.4	5.8
Woolypod vetch	66.3	7.4
Yellow mustard	50	7.1

Soil moisture, and soil temperature data will be assessed at the end of the cover crop season, data is not reported at this time.

Objective 3: Extend findings to growers and the industry through meetings and publications

In 2023, we held a grower field day out at the Colusa site to present on the current outcomes of the cover crop trial. It was well-attended (by about 25 people). We also presented results at the Winter Grower Meetings in 2023, so results were heard by about 250 people. A poster was presented at the Rice Field Day in 2023, where about 400 people attended. We will hold a field day in San Joaquin in 2024.

CONCISE GENERAL SUMMARY OF CURRENT YEAR'S RESULTS

This year three cover crop variety trials were implemented across Sacramento Valley and Northern San Juaquin. 10 different cover crop species and two cover crop mixtures were tested in a replicated block design. Each cover crop was replicated 4 times at each site in 10 by 20 ft^2 plots. Germination counts of each species, and percent cover was measures in December and January. Final harvest was taken in February-March in 2023. In 2023, harvest was only sufficient to get carbon and nitrogen data at the Colusa site. At the Rice Experiment Station site, rice straw may have hindered the development of a good seed bed, while at the San Joaquin site, late planting and minimal seed incorporation may have reduced germination success. In 2022-2023 high rainfall and flooding at each site greatly reduced cover crop success by January overall, even at the Colusa site. Overall, Oats alone and Mix 2 (Purple Vetch, Balansa Clover, Field Pea, Oats and Radish) performed best in 2022-2023, in terms of survival over the winter.

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