CALIFORNIA LEAFY GREENS RESEARCH PROGRAM
Emergency Funding August 2021 to March 31, 2022

Title: Simple Methods for Evaluating Cover Crop Nitrogen, C:N Ratios, and Biomass
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ABSTRACT

Ag Order 4.0 approved by the Central Coast Regional Water Quality Control Board in April 2021 provides a credit for nitrogen (N) scavenging by winter-grown cover crops in the A-R metric. This credit is a major incentive to cover cropping on 540,000 acres of irrigated land in the central coast region, an area with high nitrate leaching and low cover crop adoption (i.e., 5% of the land). The credit was approved for 97% of cover crop shoot N uptake, but to qualify the cover crop must 1) be a non-legume that produces at least 4500 lbs/acre of oven-dry shoot biomass, 2) be grown for 90 or more days from October to April, and 3) have a carbon to nitrogen (C:N) ratio ≥ 20:1. To help growers meet these requirements, this research evaluated simple methods to determine the cover crop shoot biomass production and its associated percent nitrogen, N uptake, and C:N ratio. This research augments decades of cover cropping research in the region that was used to justify the approved credit. During the winter of 2021 to 2022, data were collected from a total of 16 on-farm sites and 5 research station trials with Merced rye and Pacheco Triticale. These data were also compared with measurements with these two cover crops taken in the summer of 2021 from 17 additional on-farm cover crop fields. We determined that for both these cereal cover crops, the height of the main stem (i.e., stem length) is a simple, reliable and robust method for growers to estimate cover crop shoot biomass production, and also that the Feekes growth stage is a good predictor of a cover crop's C:N ratio. The research station trials provided practical information on the rate that the cover crops accumulate biomass and scavenge nitrogen based on five different planting dates. This information can help growers predict how soon a cover crop will reach the biomass and C:N ratio requirements based on the number of accumulated growing degree days. This data was used to a develop set of reference tables and an online tool for growers to calculate the cover crop nitrogen scavenging credit in Ag. Order 4.0 using only a cover crop's height and its Feekes growth stage.

OBJECTIVE

To help growers to receive the cover crop nitrogen scavenging credit to meet the Applied (A) minus Removed (R) limits and targets in Ag Order 4.0 approved by the Central Coast Regional Water Quality Control Board in April 2021. This research evaluated various methods to easily determine the percent nitrogen (N) in the cover crop tissue, N uptake of the cover crop and the associated C:N ratio of cover crops.

PROCEDURES

Evaluations were with the two most common cereal cover crops grown in the region (Merced rye and Pacheco triticale) in multiple locations and soil types in the Salinas and Pajaro Valleys in collaboration with cooperating growers and in an organic field at the Spence USDA-ARS research station. Cover crops were planted in typical fall/early winter planting slots and were evaluated for the following: 1) Planting date and density; 2) Cover crop development using the Feekes scale; 3) Shoot, oven-dry biomass production monthly at the USDA site and near season end at the farm sites; 4) Plant height when biomass and Feekes were measured. This was done to determine the correlation of plant height (from the soil surface to tip of the inflorescence or apex of the tallest leaf) with shoot biomass. Shoot biomass samples were oven-dried until stable at 150F and were analyzed for total carbon and nitrogen at the UC Davis Analytical Laboratory.

At the USDA station trials, Merced rye and Pacheco triticale were planted on five dates including October 1 and 15, November 1, 15 and 30 using a grain drill with 6 inch spacing between seedlines. Seeding rates were 80 lbs/acre for Merced rye and 120 lbs/acre for Pacheco triticale. Plantings were replicated 4 times. At the USDA sited, 250 lbs of 8-5-1 organic fertilizer was added to the soil prior to planting to assure adequate N for good growth of the cover crops. The cover crops were sprinkle irrigated as needed during the dry winter conditions to assure good growth. Cover crop biomass, height, and Feekes evaluations were conducted monthly for at least 150 days after planting. Cover crop biomass was evaluated by sampling 3 adjacent 1 meter long seedlines per plot. Samples were weighed fresh then dried at 150°F until the weights were stable. Samples were run through a hammer mill as needed and were sent to the UC Davis Analytical Lab for total N and C analysis. At each evaluation date a subsample of 5 random plants were uprooted and evaluated for the Feekes growth stage and total height. Height was measured on the main stem of each plant from the crown root (soil surface) to the tip of the most distal leaf or head. Regression analysis was used to determine the correlation between of oven-dry crop biomass and height, and between Feekes growth stage and the C:N ratio. Degree days for each of the USDA planting date trials were calculated based on the UC IPM web site calculator using the weather data from the Salinas airport FAA.

Although we had initially planned to use leaf color to estimate cover crop N content, we did not proceed with this because our initial attempts with this did not indicate that it would provide useful information.

RESULTS

Cover Crop Biomass Production

Rye and triticale both grew well in the trial at the USDA-ARS and by 150 days after planting had produced at least twice as much biomass as the 4500 lbs per acre required in Ag Order 4.0 (Figure 1). Over all 5 planting dates, triticale produced consistently more final shoot biomass than rye, although during the first 30 days after planting rye was more productive than triticale. Weed biomass was not measured, but we observed considerably more weed biomass in rye than in triticale, which was likely due to the faster canopy closure and growth with rye than triticale. Planting date had a strong effect on the rate of biomass production by the cover crops which was clear at the second harvest date (≈ 60 days after planting). For example, with both rye and triticale, at approximately 60 days after planting, biomass production was in order of Oct. 1 > Oct. 15 > Nov. 1> Nov. 15 > Nov 30. By the third harvest date (≈ 90 days after planting) rye biomass had exceeded the 4500 lbs/acre threshold for all plantings except for the November 30 planting, and a similar trend also occurred with triticale, although both the November 15 and 30 plantings took more than 90 days to reach this threshold.

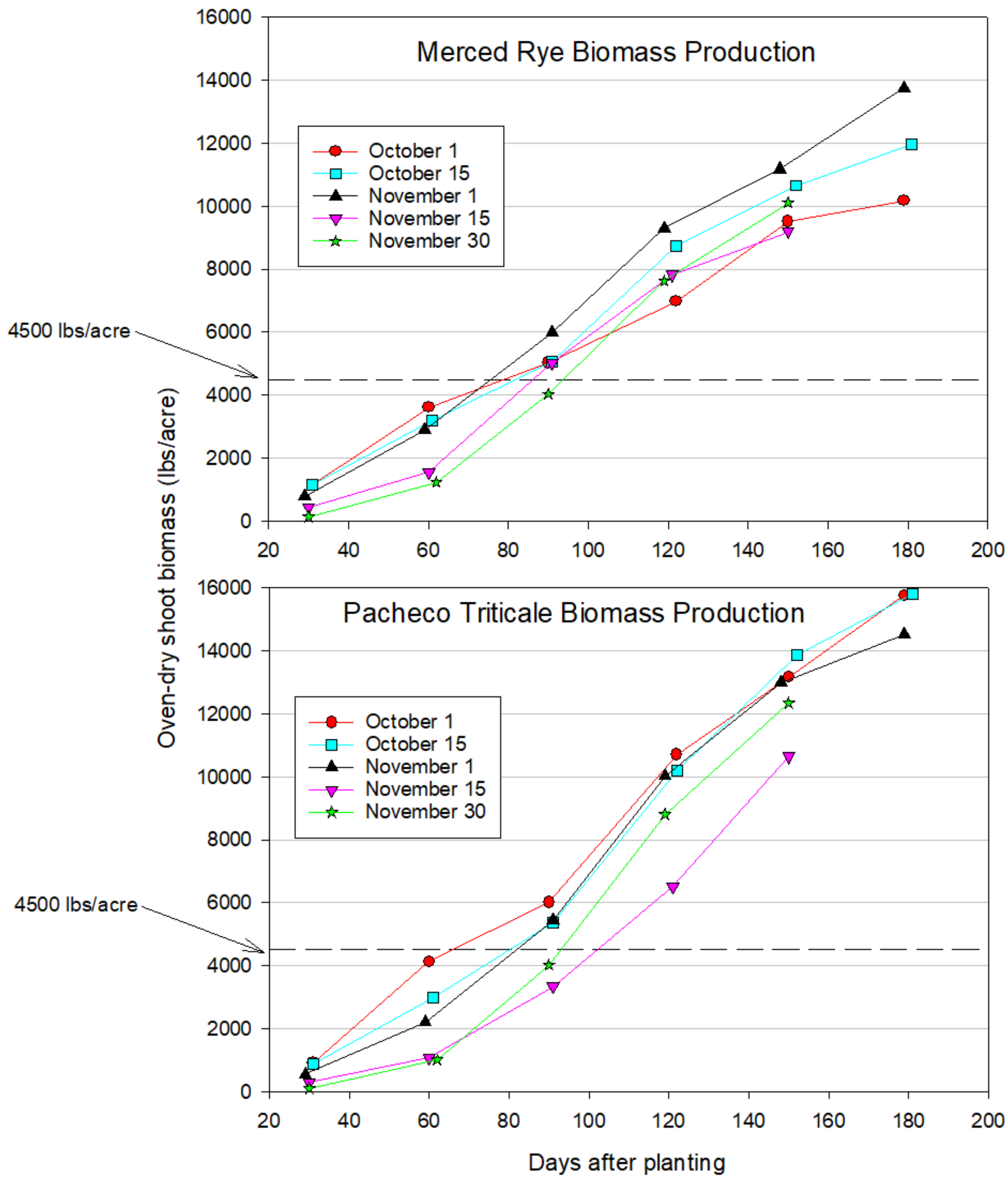


Figure 1. Biomass production of Merced rye and Pacheco triticale planted at 5 planting dates at the USDA-ARS organic research farm. Each symbol is the average across 4 replicates, except for the October 15 of rye that had only 3 replicates. The dashed horizontal line indicates the 4500 lbs/acre threshold required by Ag. Order 4.0. All 5 planting dates were harvested monthly up to 150 days after planting, however three plantings (October 1, 15, and November 1) were harvested up to 179 days after planting.

Cover Crop Nitrogen Uptake

Total shoot nitrogen uptake by rye and triticale were generally in the range of 100 to 150 lbs/acre with more total and incremental nitrogen uptake occurring on cover crops that were planted earlier in the season (Figure 2). For example, by 30 days after planting, Merced rye planted on October 1 had taken up about 10 times more nitrogen (69 lbs/acre) than was taken up by the

November 30 planting (5 lbs/acre); a similar pattern occurred with Pacheco triticale. Despite variability in total uptake, overall the data indicates that the majority of the nitrogen uptake occurred during the first 60 to 90 days after planting.

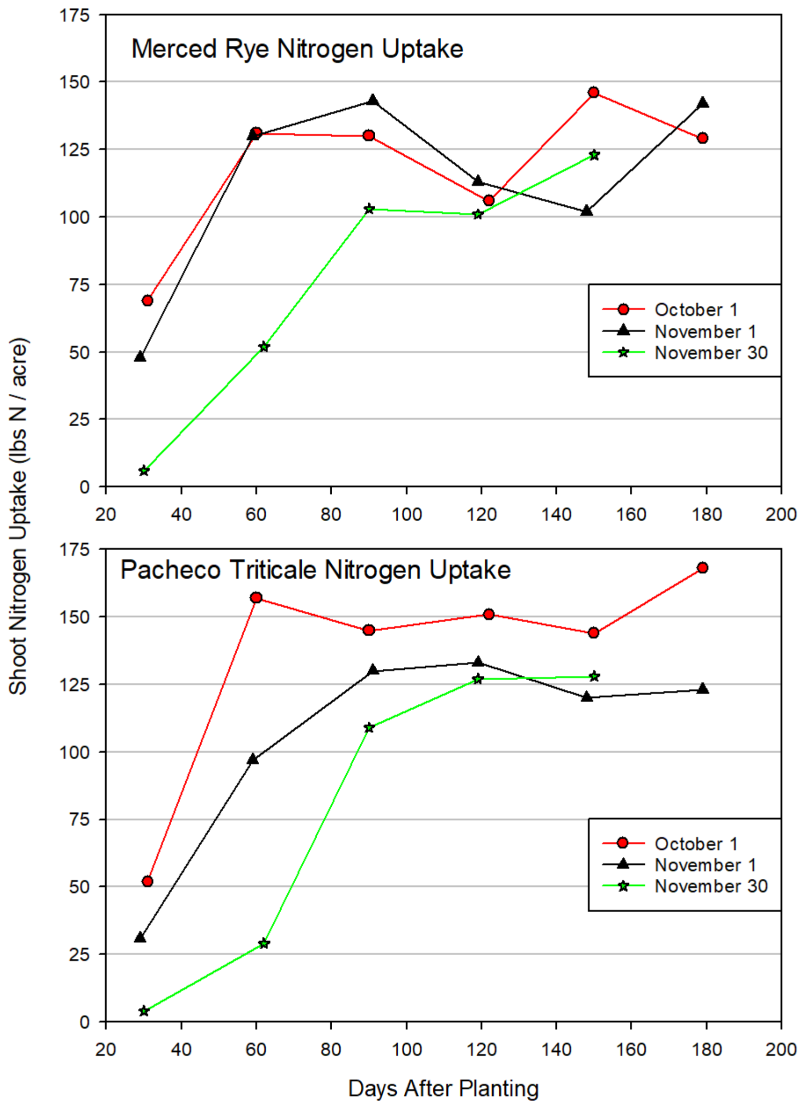


Figure 2. Nitrogen uptake of Merced rye and Pacheco triticale planted at 3 planting dates at the USDA-ARS organic research farm. Each symbol is the average across 4 replicates. All 3 planting dates were harvested monthly up to 150 days after planting, however two plantings (October , and November 1) were harvested up to 179 days after planting.

Correlation of Height and Oven-dry Shoot Biomass

The approximate maximum height of the cover crops was 165 cm (65 inches) for Merced rye and 128 cm (50 inches) for Pacheco triticale (Figure 3). Cover crop shoot height was highly correlated with oven-dry shoot biomass (R^2=0.87), however the majority of the variability occurred when the shoot biomass was greater than the Ag Order 4.0 regulation biomass requirement of 4500 lbs /acre. Regression analysis indicated that cover crops will meet the 4500 lbs/acre biomass threshold of Ag. Order 4.0 when their main stem height is 30.5 inches for Merced rye and 27 inches for Pacheco triticale. Preliminary analysis suggests that to meet the biomass and C:N ratio requirements of Ag Order 4.0 to receive the cover crop nitrogen scavenging credit, both rye and triticale will need to receive approximately 700 degree days (in °C with a 4 °C lower threshold, single sine method); growers can use the UC IPM degree day calculator (see link in the references) to determine degree day accumulation based on weather data from nearby weather stations.

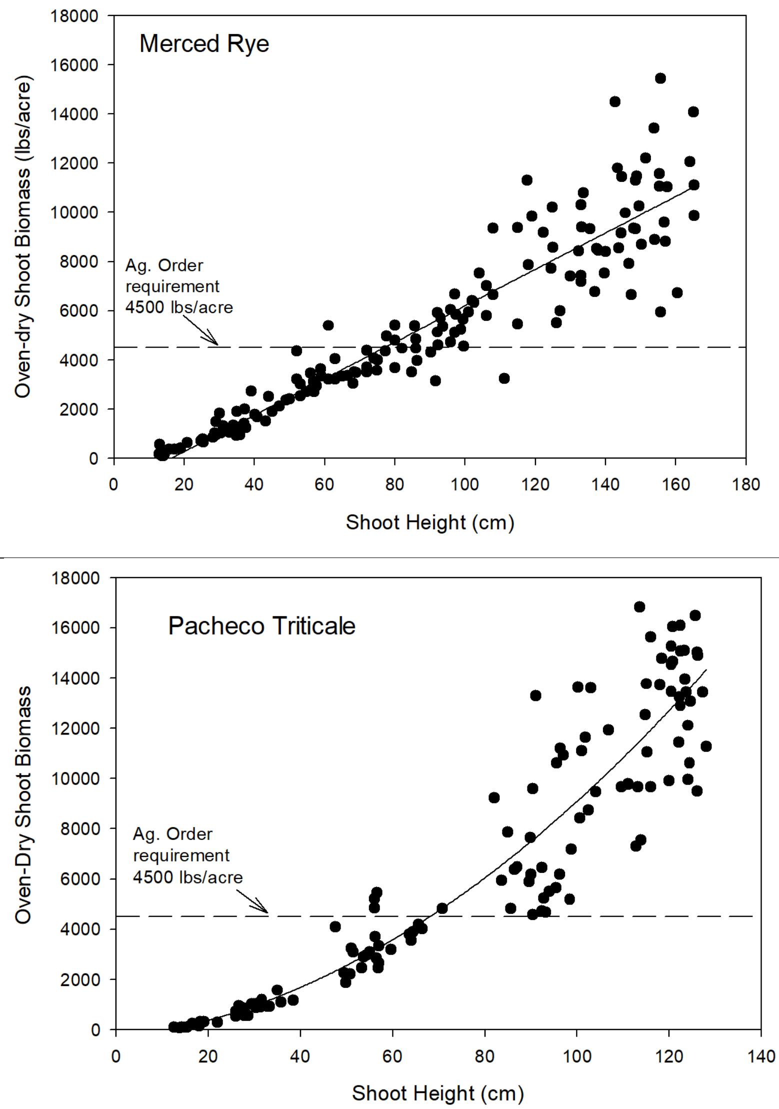


Figure 3. Relationship between cover crop shoot height and oven-dry shoot biomass for Merced rye and Pacheco triticale. The raw data were from the five winter cover crop trials at the USDA-ARS (planted Oct. 1, Oct. 15, Nov. 1, Nov. 15, Nov. 30) and also from late summer cover crop plantings and over-winter plantings on growers fieldsin Salinas Valley during 2021 to 2022. The R^2 values were 0.87 for both cover crops indicating that 87% of the variability in cover crop shoot biomass was explained by cover crop height.

Correlation of Cover Crop Development and C:N Ratio

Cover crop development based on Feekes growth stage measurements and C:N ratios of the harvested biomass increased through the season and were well correlated (R^2=0.81) for both Merced rye and Pacheco triticale (Figure 4). In general, for both cereals the C:N ratios of the shoots were less than 20:1 for the first 90 days after planting and the Feekes growth stages were less than 8 (flag leaf just visible but still rolled up). Regression analysis indicated that a Feekes growth stage of 9 (ligule of flag leaf just visible) was the stage when the C:N ratio of the rye and triticale met the Ag. Order threshold of ≥ 20:1. Figures 5 and 6 illustrate these regression figures along with drawings of the various Feekes growth stages.

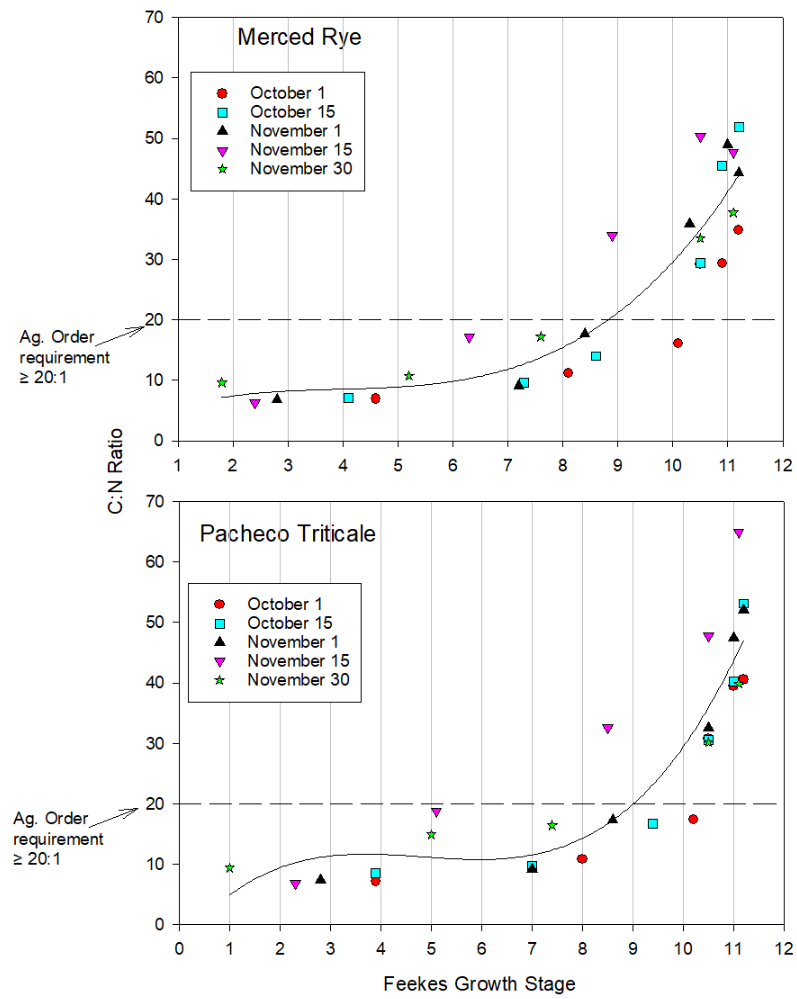
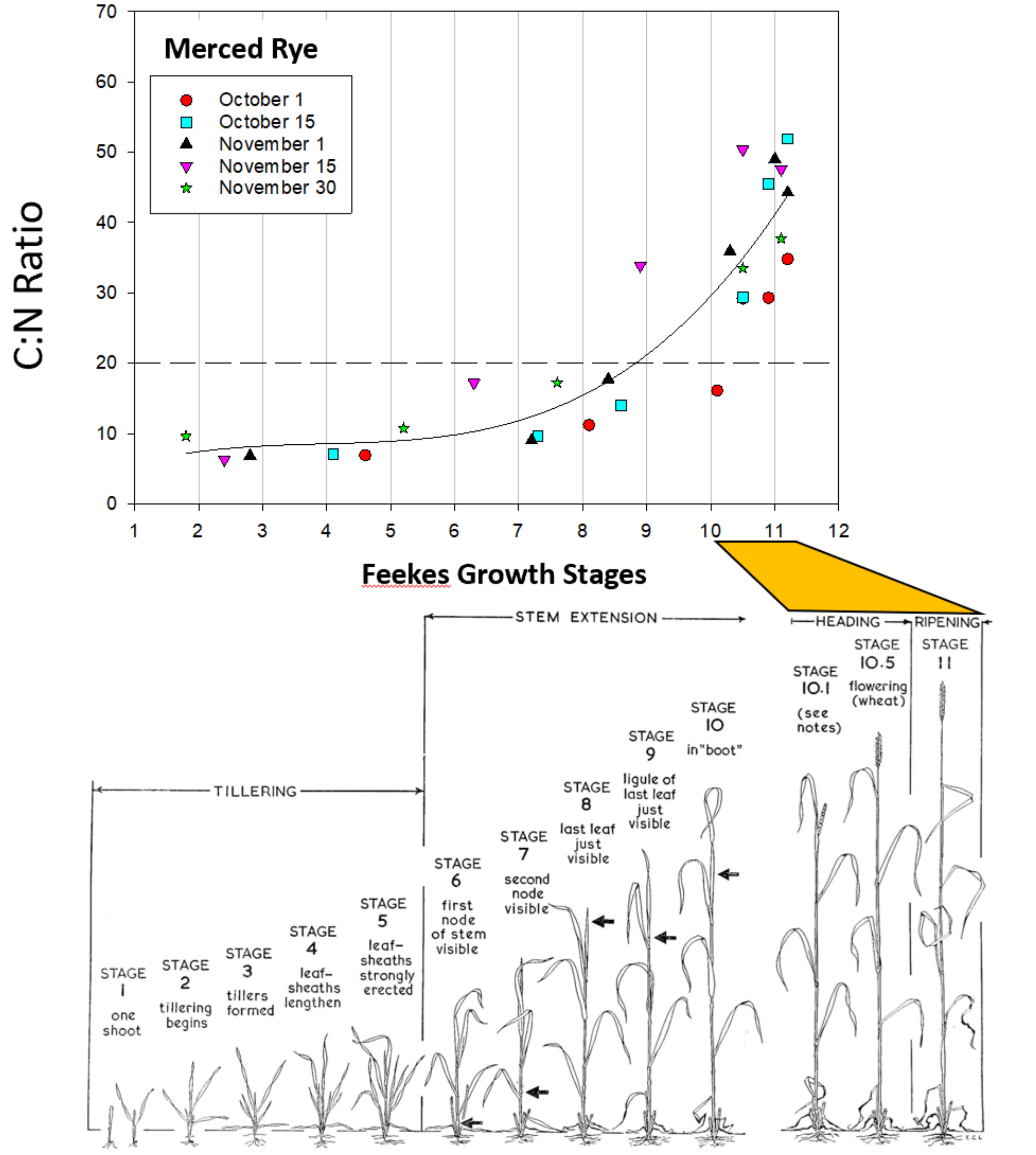
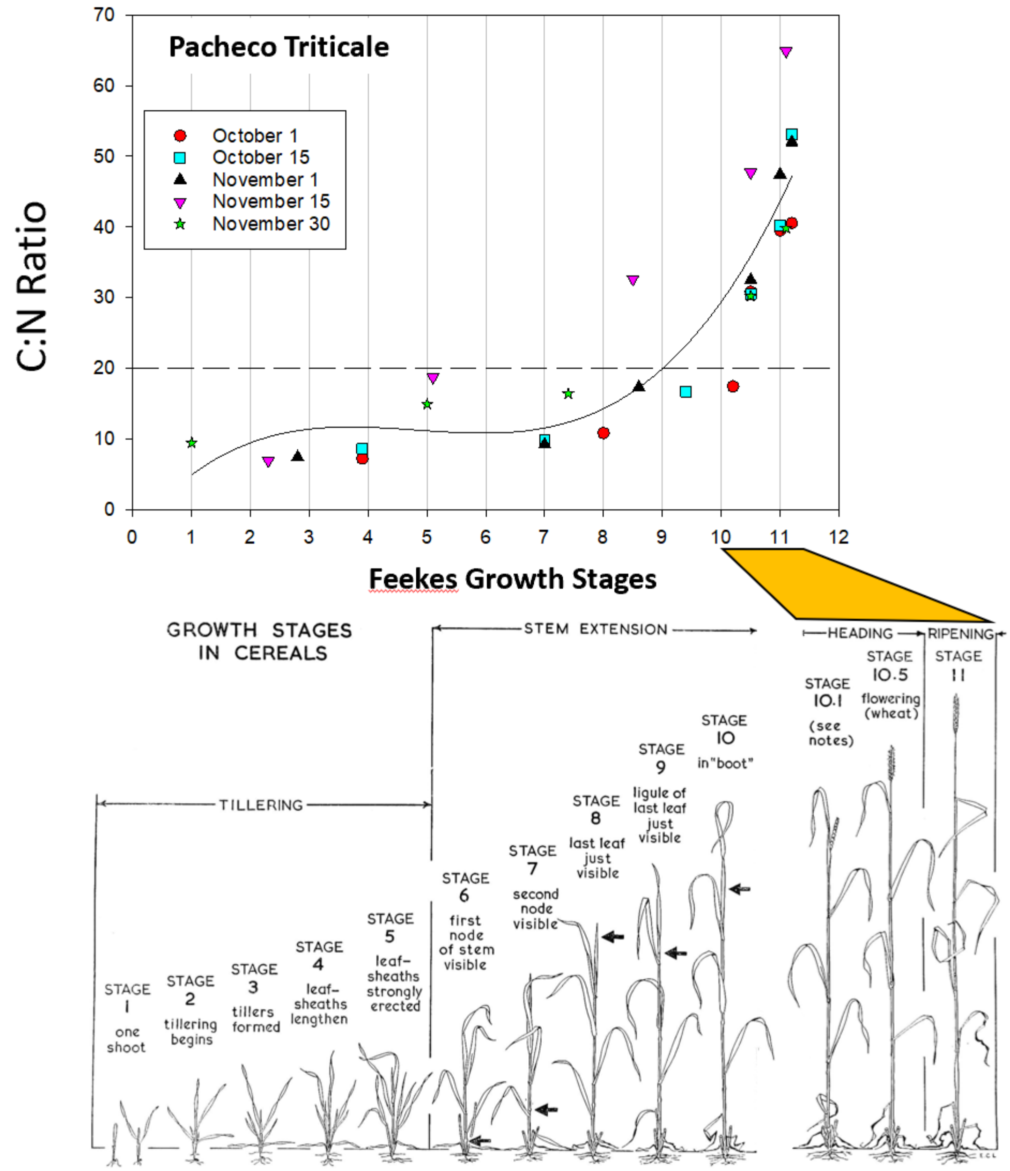


Figure 4. Relationship between Feekes growth stage and cover crop shoot C:N ratio for Merced rye and Pacheco triticale. The raw data were from the five over-winter cover crop trials at the USDA-ARS (planted Oct. 1, Oct. 15, Nov. 1, Nov. 15, Nov. 30) The R^2 values were 0.81 for both cover crops indicating that 81% of the variability in cover crop shoot C:N ratio was explained by Feekes growth stage.



Adapted from Large, E.C. (1954). Growth stages in cereals - illustration of the Feekes scale. *Plant Pathology 3*, ***128-129***.

Figure 5. Illustration of the Feekes growth stages relative to the regression curve for Merced rye shown in Figure 4. Note that the yellow shape indicates multiple Feekes stages from heading to kernel ripening including Feekes 10.1-10.5 (heading), 10.5.1-10.5.3 (flowering), 10.5.4 (Kernel watery ripe), 11.1 (Kernel milky ripe), 11.2 (Kernel mealy ripe, soft dough), 11.3 (Kernel hard), and 11.4 (Ripe for cutting).



Adapted from Large, E.C. (1954). Growth stages in cereals - illustration of the Feekes scale. *Plant Pathology 3*, ***128-129***

Figure 6. Illustration of the Feekes growth stages relative to the regression curve for Pacheco triticale shown in Figure 4. Note that the yellow shape indicates multiple Feekes stages from heading to kernel ripening including Feekes 10.1-10.5 (heading), 10.5.1-10.5.3 (flowering), 10.5.4 (Kernel watery ripe), 11.1 (Kernel milky ripe), 11.2 (Kernel mealy ripe, soft dough), 11.3 (Kernel hard), and 11.4 (Ripe for cutting).

DISCUSSION

This study provides the most comprehensive data set on the relationships between cover crop biomass production, C:N ratios and plant development in California. This augments previous research on non-legume cover crops in the Salinas valley such as (1) the studies that showed the ability of cover crops to dramatically reduce nitrate leaching (Jackson et al. 1993; Wyland et al. 1996), and (2) the more recent work from the on-going long-term organic systems study at the USDA-ARS on cover crop biomass production (Brennan and Boyd, 2012a), N uptake (Brennan and Boyd, 2012b), residue quality (Brennan et al. 2013), and nitrogen dynamics (White et al. 2022) in vegetable rotations.

How to use this information to calculate the cover crop nitrogen credit. The unique and robust research information presented here will help farmers to determine when their cover crops have produced the required amounts of biomass and residue quality to meet the requirements of the new Ag. Order 4.0 regulation that affects over 540,000 acres of land in the Central Coast region of California. To simplify and facilitate this process a set of reference tables were developed for Merced rye and Pacheco triticale showing the relationship between Feekes growth stages, C:N ratios and percent nitrogen of cover crop shoots (Tables 1 and 2), and the relationship between cover crop stem height and oven-dry shoot biomass (Tables 3 and 4).

The following is an example of how this information in these tables can be used by growers to get the cover crop nitrogen scavenging credit in Ag Order 4.0. This involves first determining the cover crop biomass, C:N ratio, and nitrogen concentration. Our data indicates that the biomass threshold of 4500 lbs/acre will typically occur before the C:N ratio threshold (≥20:1) is met. Fortunately, determining when a cover crop reaches the Feekes growth stage of 9, and thus meets the C:N requirement, is relatively simple because Feekes 9 is one of the easiest stages to identify by the presence of the flag leaf (i.e. last leaf of the stem) (Figures 5 and 6). This can be done by uprooting 10 randomly chosen plants in the field. Once the majority of the plants in the field have flag leaves that are fully expanded (i.e., the ligule or collar of the flag leaf is showing), the height (i.e., main stem length) of 10 randomly chosen plants can be measured. In this example let's assume that the average height of 10 rye plants at Feekes growth stage 9 is 33 inches. Table 3 shows that at 33 inch tall rye cover crop has 5005 lbs/acre of oven-dry shoot biomass, and Table 1 shows that rye at Feekes growth stage 9 has 2.2% nitrogen. We then multiply 5005 lbs of biomass per acre by 2.2% N which equals 110 lbs of shoot nitrogen uptake per acre. This value (110 lb N/acre) is multiplied by 97% to get the N scavenging credit (110 x 97% = 107 lbs N/acre); 97% is the standard percentage credit that is given in the Ag Order to cover crops with a C:N ratio of 20:1. Similarly, Pacheco triticale at Feekes 9 and 33 inches height would have 6585 lbs / acre of oven-dry shoot biomass x 2.2% N=145 lb N uptake, that gives a N scavenging credit of 141 lbs N/acre (based on N uptake x 97%). This illustrates that triticale produces more biomass than rye per unit of stem height.

As an alternative to doing these calculations manually, we developed Google Sheet calculators that do these calculations. These calculators are available at this link for Merced rye and Pacheco triticale, or by emailing Eric.Brennan@usda.gov . In addition, an online form (Cover Crop Nitrogen Scavenging Credit Form for Growers) was created to help growers keep records on cover crop plantings. To use these online calculators and this form, users will need to save a copy to a personal Google drive which will allow one to edit and share these with others as needed.

Other Benefits of learning Feekes Growth Stages. While learning to identify the Feekes growth stages will help growers to get the cover crop nitrogen scavenging credit under Ag Order 4.0, Feekes information will also allow growers to better understand their cover crops and get the most out of other important cover crop benefits such as maximizing organic matter additions. For example, in some of the grower fields that we monitored on a weekly or biweekly basis, we were impressed by how much more biomass (as indicated by cover crop height) cover crops produced when they were allowed to grow just one or two more weeks than originally planned. We were also struck by the relatively long time required for the cover crops to proceed through the latter stages of development. For example, with the October 1 trial at the USDA-ARS, Merced rye reached Feekes 10 (boot stage) at 90 days after planting (DAP), Feekes 10.5.1 at 120 DAP, and Feekes 11.2 (soft dough) by 179 DAP. The following are several visual online guides to help growers learn to identify and understand these Feekes growth stages: Broeske et al. 2020; Lollato, 2018.

CONCLUSION

The adoption of Ag. Order 4.0 in 2021 is the beginning of a new era of cover cropping in the Central Coast region of California because it provides incentives for growers to increase their use of cover cropping. This study provides practical information to help growers to get the cover crop nitrogen scavenging credit in this new regulation. While the research presented here only applies to Merced rye and Pacheco triticale, the general findings likely apply to other cereal cover crops. We plan to expand this type of research in future studies to include other important nitrogen scavenging cover crops such as mustards and barley, and to cover crop mixtures.

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Table 1. Feekes growth stages, C:N ratios and % N used to calculate the Cover Crop Nitrogen Scavenging Calculator for **Merced Rye**

Feekes Growth Stage #	Growth stage description	Predicted C:N	Predicted % N
6	**1st node of stem visible at base of shoot**	10:1	4.2
7	**2nd node of stem visible**	11:1	3.6
8	**Last leaf (flag leaf) just visible, but still rolled up**	14:1	3.1
9	**Ligule of flag leaf just visible**	**20:1**	2.2
10	**Boot. Head is inside flag leaf giving it a swollen appearance**	27:1	1.6
10.1	**Heading begins, 1st awns of head are just visible**	29:1	1.4
10.2	1/4 of heading process complete	29:1	1.4
10.3	1/2 of heading process complete	31:1	1.4
10.4	3/4 of heading process complete	32:1	1.3
10.5	**Head completely out of flag leaf sheath**	33:1	1.3
10.5.1	**Flowering begins; starts in the center of the head**	33:1	1.3
10.5.2	Flowering complete to top of head	33:1	1.3
10.5.3	Flowering complete at base of head	33:1	1.3
10.5.4	**Kernel watery ripe; Flowering complete;**	33:1	1.3
11.1	**Milk stage, Kernel milky ripe; Milk stage**	41:1	1.1
11.2	**Soft dough; Kernel mealy ripe; soft but dry consistency**	42:1	1.1

Table 2. Feekes growth stages, C:N ratios and % N used to calculate the Cover Crop Nitrogen Scavenging Calculator for **Pacheco Triticale**

Feekes Growth Stage #	Growth stage description	Predicted C:N	Predicted % N
6	**1st node of stem visible at base of shoot**	11:1	3.8
7	**2nd node of stem visible**	11:1	3.8
8	**Last leaf (flag leaf) just visible, but still rolled up**	14:1	3
9	**Ligule of flag leaf just visible**	**20:1**	2.2
10	**Boot. Head is inside flag leaf giving it a swollen appearance**	30:1	1.5
10.1	**Heading begins, 1st awns of head are just visible**	31:1	1.5
10.2	1/4 of heading process complete	32:1	1.4
10.3	1/2 of heading process complete	33:1	1.4
10.4	3/4 of heading process complete	35:1	1.3
10.5	**Head completely out of flag leaf sheath**	36:1	1.3
10.5.1	**Flowering begins; starts in the center of the head**	36:1	1.3
10.5.2	Flowering complete to top of head	36:1	1.3
10.5.3	Flowering complete at base of head	36:1	1.3
10.5.4	**Kernel watery ripe; Flowering complete;**	36:1	1.3
11.1	**Milk stage, Kernel milky ripe; Milk stage**	46:1	1
11.2	**Soft dough; Kernel mealy ripe; soft but dry consistency**	47:1	0.9

Table 3. Relationship between height (i.e., total stem length from crown roots (soil surface) to the tip of the most distal leaf or head) and shoot biomass used in Cover Crop Nitrogen Scavenging Calculator for **Merced Rye**. The height highlighted in red (30.5 inches) is the minimum rye height needed for a shoot biomass of 4500 lbs/acre.

Height in inches	Height in cm	Predicted biomass (oven-dry) lb/acre	Height in inches	Height in cm	Predicted biomass (oven-dry) lb/acre	Height in inches	Height in cm	Predicted biomass (oven-dry) lb/acre
20	50.8	2,560	40.5	102.9	6,416	57.5	146.1	9,615
20.5	52.1	2,654	41	104.1	6,511	58	147.3	9,709
21	53.3	2,748	41.5	105.4	6,605	58.5	148.6	9,803
21.5	54.6	2,842	42	106.7	6,699	59	149.9	9,897
22	55.9	2,936	42.5	108	6,793	59.5	151.1	9,991
22.5	57.2	3,030	43	109.2	6,887	60	152.4	10,085
23	58.4	3,124	43.5	110.5	6,981	60.5	153.7	10,179
23.5	59.7	3,218	44	111.8	7,075	61	154.9	10,273
24	61	3,312	44.5	113	7,169	61.5	156.2	10,367
24.5	62.2	3,406	45	114.3	7,263	62	157.5	10,461
25	63.5	3,500	45.5	115.6	7,357	62.5	158.8	10,555
25.5	64.8	3,594	46	116.8	7,451	63	160	10,650
26	66	3,688	46.5	118.1	7,545	63.5	161.3	10,744
26.5	67.3	3,783	47	119.4	7,639	64	162.6	10,838
27	68.6	3,877	47.5	120.7	7,733	64.5	163.8	10,932
27.5	69.9	3,971	48	121.9	7,827	65	165.1	11,026
28	71.1	4,065	48.5	123.2	7,922	65.5	166.4	11,120
28.5	72.4	4,159	49	124.5	8,016	66	167.6	11,214
29	73.7	4,253	49.5	125.7	8,110	66.5	168.9	11,308
29.5	74.9	4,347	46.5	118.1	7,545	67	170.2	11,402
30	76.2	4,441	47	119.4	7,639	67.5	171.5	11,496
30.5	**77.5**	**4,535**	47.5	120.7	7,733	68	172.7	11,590
31	78.7	4,629	48	121.9	7,827	68.5	174	11,684
31.5	80	4,723	48.5	123.2	7,922	69	175.3	11,778
32	81.3	4,817	49	124.5	8,016	69.5	176.5	11,872
32.5	82.6	4,911	49.5	125.7	8,110	70	177.8	11,967
33	83.8	5,005	50	127	8,204	70.5	179.1	12,061
33.5	85.1	5,099	50.5	128.3	8,298	71	180.3	12,155
34	86.4	5,194	51	129.5	8,392	71.5	181.6	12,249
34.5	87.6	5,288	51.5	130.8	8,486	72	182.9	12,343
35	88.9	5,382	52	132.1	8,580	72.5	184.2	12,437
35.5	90.2	5,476	52.5	133.4	8,674	73	185.4	12,531
36	91.4	5,570	53	134.6	8,768	73.5	186.7	12,625
36.5	92.7	5,664	53.5	135.9	8,862	74	188	12,719
37	94	5,758	54	137.2	8,956	74.5	189.2	12,813
37.5	95.3	5,852	54.5	138.4	9,050	75	190.5	12,907
38	96.5	5,946	55	139.7	9,144			
38.5	97.8	6,040	55.5	141	9,239			
39	99.1	6,134	56	142.2	9,333			
39.5	100.3	6,228	56.5	143.5	9,427			
40	101.6	6,322	57	144.8	9,521			

Table 4. Relationship between height (i.e., total stem length from crown roots (soil surface) to the tip of the most distal leaf or head) and shoot biomass used in Cover Crop Nitrogen Scavenging Calculator for **Pacheco Triticale.** The height highlighted in red (27 inches) is the minimum triticale height needed for a shoot biomass of 4500 lbs/acre.

Height in inches	Height in cm	Predicted biomass (oven-dry) lb/acre	Height in inches	Height in cm	Predicted biomass (oven-dry) lb/acre			
20	50.8	2,639	40	101.6	9,362			
20.5	52.1	2,761	40.5	102.9	9,578			
21	53.3	2,886	41	104.1	9,796			
21.5	54.6	3,014	41.5	105.4	10,017			
22	55.9	3,143	42	106.7	10,240			
22.5	57.2	3,275	42.5	108	10,465			
23	58.4	3,410	43	109.2	10,692			
23.5	59.7	3,546	43.5	110.5	10,922			
24	61	3,685	44	111.8	11,154			
24.5	62.2	3,826	44.5	113	11,389			
25	63.5	3,970	45	114.3	11,626			
25.5	64.8	4,116	45.5	115.6	11,865			
26	66	4,264	46	116.8	12,106			
26.5	67.3	4,415	46.5	118.1	12,350			
27	**68.6**	**4,568**	47	119.4	12,596			
27.5	69.9	4,723	47.5	120.7	12,845			
28	71.1	4,881	48	121.9	13,096			
28.5	72.4	5,041	48.5	123.2	13,349			
29	73.7	5,203	49	124.5	13,604			
29.5	74.9	5,367	49.5	125.7	13,862			
30	76.2	5,534	50	127	14,122			
30.5	77.5	5,704	50.5	128.3	14,385			
31	78.7	5,875	51	129.5	14,650			
31.5	80	6,049	51.5	130.8	14,917			
32	81.3	6,225	52	132.1	15,186			
32.5	82.6	6,404						
33	83.8	6,585						
33.5	85.1	6,768						
34	86.4	6,954						
34.5	87.6	7,141						
35	88.9	7,332						
35.5	90.2	7,524						
36	91.4	7,719						
36.5	92.7	7,916						
37	94	8,116						
37.5	95.3	8,318						
38	96.5	8,522						
38.5	97.8	8,729						
39	99.1	8,937						
39.5	100.3	9,149						