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The following project cooperators are not listed in the project, but have provided help and guidance during the research. I wish to extend sincere gratitude to Nicole Hampton, Heather Havens and Kristin Pool for their hard work on the project, and also to Heather for telling me about the rice hulls. Thanks to Dan Sullivan for his extensive guidance and valuable support as my faculty mentor, and to John Luna for demonstrating the "standard laboratory method" used in his research, and for presenting his research at grower field days.

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1. SUMMARY

Several cover crops were selected by organic growers in the North Willamette Valley of Oregon for use in this study. Four on-farm methods for estimating nitrogen contributions from cover crops were compared with a standard laboratory method. Regression analysis was used to compare estimates of total nitrogen contribution from each on-farm method with estimates from the standard lab method. First-year results showed that lab analysis of bulked species samples gave comparable estimates of total nitrogen and plant-available nitrogen contributions to the standard lab method when the same fresh weight ratios of cover crop species were tested and weeds were omitted. Second-year results were very similar when grab samples of the cover crop mixture including weeds were tested. The published fresh weight method was inconsistent with the standard lab method, but we were able to adjust the method with 2007 data and found a reasonable fit between the adjusted fresh weight method and the laboratory method in 2008. Estimates based on dry weight of the cover crop gave moderate to strong correlations with estimates using the standard lab method. Again, data from 2007 was used to develop this new method and the correlation to the laboratory method was strong with the 2008 data. Measurements of canopy height and density provided little to no correlation when compared to results from the standard laboratory method.

Based on the results of this study we advise growers to submit bulked cover crop samples to the laboratory to estimate total nitrogen contributions. If a laboratory is unavailable, species could be separated, and the dry weight of each species can provide a reasonable estimate of nitrogen contributions. If drying is not feasible the fresh weight of separated species can be used to provide what may be a satisfactory estimate of nitrogen contribution. We do not recommend using canopy height and density to estimate nitrogen contribution.

2. INTRODUCTION

Organic and ecological farmers aim to improve soil quality and fertility. Certified organic farmers are required the USDA National Organic Standards to implement a crop rotation that "maintain(s) or improve(s) soil organic matter content" and "manage(s) deficient or excess plant nutrients". They must "maintain or improve the physical, chemical, and biological condition of soil and minimize soil erosion". Cover cropping is listed as a central method to reach these objectives (§205.203 and 205.205). These rules are consistent with the values of many non-certified farmers who use ecological methods, and with the values of their customers.

Nitrogen management in organic or ecological systems is complicated by difficulties involved in measuring various nitrogen sources. These include soil mineralization, slow release of N from organic amendments and N contributions of cover crops. Various methods have been proposed in the extension literature for estimating total N contributions from cover crops. A preferred accurate method is to cut a known area of the above ground cover crop, separate and weigh individual species, then dry and re-weigh them and submit them to a laboratory for C/N analysis. This method is thought to be reasonably accurate, but is not widely used by farmers in the Pacific Northwest. Sattell and Dick (1998) describe a method that estimates total N content on a per acre basis using the fresh weight of individual species from a 16ft^2 quadrat. Sarrantonio (1994) described a method that estimates N content from the dry weight of cover crops. Most of the farmers we work with use seed mixtures of grasses and legumes. The methods listed above require that growers harvest the cover crop and separate the individual species. Collaborating growers and others have explained that they don't have time to separate cover crop samples especially in the spring. Two additional methods were included that do not require separating cover crop species. First, an unseparated sample of the cover crops from the quadrat can be submitted to the lab for C/N testing. Second, the canopy height and canopy density method can be used to generate estimates (Sarrantonio 1994). This does not require separating species, or submitting samples to a lab. To our knowledge, none of these methods have been compared.

3. OBJECTIVES:

The main objective of this project was to compare on-farm measurement techniques for estimating N-contributions from cover crops using 1) separated species lab tests (a standard experimental method), 2) bulked species lab tests, 3) fresh weight, 4) dry weight and 5) canopy height and density. We also recorded relative weed biomass in different cover treatments. After the project started, collaborating growers said they were interested in predicting available N from cover crops. We used a mineralization model to compare the ability to predict plant-available nitrogen (PAN) from bulked species and separated species sampling methods.

4. METHODS

4.1 Cover crops

A grower meeting was held on April 14th, 2006 to identify research priorities, discuss cover crop testing methods, select cover crops and launch the project. Cover crop species were chosen by participating growers, species and seed rates are listed in table 1. A second grower meeting was held in July 2007 to review the first year data, explain the final testing methods used, and identify 2007/08 research priorities. Participating growers decided to test the same cover crops as in year 2006/07. Ayers Creek Farm opted to test only residential vegetation from different areas of the farm in 2007/08. They were also interested in the contribution of roots and nitrogen mineralization from cover crops. We found unpublished data from an unfinished PhD in the 1990's on root biomass and nitrogen content and are analyzing that data outside the scope this project. We also secured additional funding to study nitrogen mineralization from cover crops.

Farm name	Reps/ farm	Treatments	2007 Seed rates (lb/A)	2008 Seed rates (lb/A)
Sauvie Island Organics[a] (SIO) 47th Avenue Farm[a] (47th)	3	1. C: Crimson clover	30	30
		2. RVP: Cereal rye, common vetch, Austrian field peas	30, 30, 50	30, 30, 50
		3. OVP: Walken oats, common vetch, Austrian field peas	30, 30, 50	30, 30, 50
Praying Mantis Farm[b] (PMF) Mustard Seed Farm[b] (MSF)	3	1. C: Crimson clover	30	30
		2. OV: Walken oats and common vetch	40, 50	30, 60
		3. OC: Walken oats and crimson clover	40, 20	30, 25
Hinsvark Farm (HF)	4	1. C: Crimson clover	20	20
		2. RP: Cereal rye, Austrian field peas	30, 80	30, 80
		3. RV: Cereal rye, common vetch	30, 40	30, 40
Ayers Creek Farm (ACF)	4	1. PhRcSc: Phacelia, Kenland red clover, subterranean clover	3, 20, 20	Fallow (FW) only
		2. PhNSc: Phacelia, Persian Nitro clover, subterranean clover	3, 8, 20	
		3. FW: Fallow	N/A	

Table 1. Treatments and seeding rates used on each farm. Farms followed by the same treatments are paired trials. All farms also had one plot of Phacelia and common vetch and one plot of triticale and common vetch for observation only.

In 2006 cover crops were inoculated using a sugar and water solution and appropriate inoculum, then seeded the same day using the standard equipment available on that farm, HF drilled seed, the rest broadcast their seed (table 2). In 2007 the cover crops were inoculated and seeded with a ground driven Gandy drop spreader, except at HF where they were drilled again. Beds were prepared to varying degrees. SIO, 47th Ave., MSF and HF prepared relatively fine seedbeds. ACF went through the berry alleys with a spader only, leaving a rough seedbed. PMF disced a mature tall fescue seed stand, leaving a relatively rough seedbed with high residue. SIO, MSF, PMF and HF irrigated their cover crops, ACF and 47th Ave. did not. Fall rains were delayed in 2006 so unirrigated cover crop stands were very thin and full assessments could not be made at ACF and 47th Ave.. Fall rains were more timely in 2007, but cover crop stands were very thin at HF and spring assessments were not made.

Farm	Seeding date	Seedbed preparation	Seeding method	Incorporated	Irrigation
MSF	9/6/06	Fine	Broadcast	Yes	Yes
PMF	9/13/06	High residue	Broadcast	Yes	Yes
47th Ave	9/15/06	Fine	Broadcast	No	No
SIO	9/27/06	Fine	Broadcast	Yes	Yes
HF	9/27/06	Fine	Drilled	Yes	Yes
ACF	10/6/06	Rough	Broadcast	No	No
MSF	9/14/07	Fine	Drop spreader	Yes	Yes
PMF	9/18/07	Fine	Drop spreader	Yes	Yes
47th Ave	9/13/07	Fine	Drop spreader	Yes	No
SIO	9/21/07	Fine	Drop spreader	Yes	Yes
HF	10/6/07	Fine	Drilled	Yes	No
ACF	Residential vegetation only	--	--	--	No

Table 2. Cover crop stand establishment on participating farms.

Plot sizes were chosen to fit in with farm operations and the seeding equipment used. They ranged from 1170 – 2275 ft^2 per plot, all plots were large enough to allow enough room for all samples to be more than 5’ from the edges of plots. Stand establishment was recorded as % ground cover and canopy height a few weeks after seeding and late fall (data not shown).

Stands of some cover crops that had large and small seeds sometimes appeared uneven during the first year of the study (table 3). Rice hulls are sometimes mixed with seed when seeding native grasses in restoration projects (St. John et al. 2005). This novel seeding method was used in the 2007 trials and provided more even stands. Rice hulls were mixed with seed at about a 1:1 ratio by volume and the seeder was recalibrated.

Soil nitrate tests were taken from the trial area on each farm in the fall or early winter from the top 12” of the soil. 15-20 cores were taken from each farm, they were stored frozen before analysis by OSU’s Central Analytical Laboratory (2007) and Agri-Check Inc. (2008).

4.2 On-farm methods used to estimate N-contribution

The following methods were used to estimate N-contribution from cover crops. In spring 2007 bulk samples were prepared at the same weight ratio (fresh weight basis) as that determined in the separated species method, weeds were excluded from the comparisons. Results showed the first two methods gave similar results, so in spring 2008 grab samples that included weeds were compared with the separated species method.

1. *Separated species lab test* (Luna personal communication)
    a. $4ft^2$ frames were built from aluminum stock. All above ground plant material was cut from four representative samples from each plot (figure 1). Cover crop species were separated, weeds were separated from cover crop species, but not separated by species.
    b. Total fresh weight of each cover crop species and weeds from the $16ft^2$ area sampled in each plot were recorded.
    c. Approximately 7-10 oz subsamples of each species were bagged separately and dried until crisp. Total dry weight of each subsample were recorded.
    d. Total nitrogen and carbon were analyzed at a laboratory with a LECO Combustion Analyzer.
    e. Total nitrogen and carbon contributions were calculated to a per acre equivalent for each plot using an Excel spreadsheet.
2. *Bulked species lab test 2007*
    a. The ratio of each species in all plots sampled for method 1 was calculated on a fresh weight basis.
    b. A subsample of approximately 7-10 oz consisting of the same ratio of each cover crop species (excluding weeds) was combined and dried.
3. *Bulked species lab test 2008*
    a. The mixed species field sample including weeds was spread on a table and thoroughly mixed, an approximately 10 oz representative grab sample was quickly taken, weighed and dried.
    b. Total nitrogen and carbon were analyzed at a laboratory with a LECO Combustion Analyzer.
    c. Total nitrogen and carbon contributions were calculated to a per acre equivalent for each plot using an Excel spreadsheet.
4. *Fresh weight* (Sattell and Dick 1998 and personal communication)
    a. Total fresh weight of each species from the $16ft^2$ area sampled in each plot was recorded.
    b. Total fresh weight was multiplied by the N-factors shown in table 5, these N-factors estimate total nitrogen per acre using the above ground fresh weight of a legume crop from a $16ft^2$ sample.
    c. New N-factors were calculated for all species used in the trial.
5. *Dry weight*
    a. Total dry weight of each species from the $16ft^2$ sample was measured.
    b. Average estimates of %N on a dry weight basis were determined from the 2007 data.
    c. These averages were used to estimate total N contribution in 2007 and 2008.
6. *Canopy height and density* (Sarrantonio 1994 and personal communication).
    a. Measure % ground cover of each species with “beaded string method” (figure 2)
        i. Cut 30’ long pieces of string (thinner than a pencil)

ii. Draw dots every 6” (each dot no wider than ¼”) for 24 ½’ = 50 dots/string.
iii. Lay out string in 2 places (x pattern if small plot) in each plot.
iv. Count number of dots lying directly over or under some part of a cover crop plant.
v. Count each species in the mixture and weeds separately (identify weeds if common)

b. Measure representative canopy height for each species
c. Look up dry matter estimates % ground cover and height – (Sarrantonio tables pp 31-34).
d. Note whether each species is pre-flowering or flowering and use estimated %N chart (Sarrantonio pg 41).

Figure 1. Using aluminum quadrats to sample above ground cover crop biomass for use in methods 1-4. Photos by Kristin Pool.

Figure 2. Estimating percent ground cover and canopy height for use in method 5. Photos by Kristin Pool.

4.3 Analysis

All testing methods were compared with the separated species lab test using regression analysis. Plant-available Nitrogen (PAN) was estimated using data from the most promising methods (separated species lab test and bulked species lab test), N-mineralization was estimated using a mineralization model developed for the OSU Organic Fertilizer Calculator http://smallfarms.oregonstate.edu/organic-fertilizer-calculator. Data was managed using Excel 2003, statistical analysis was completed using Sigma Plot v. 10.

5. OUTCOMES AND IMPACTS: Results and discussion

In 2006 stands on some farms were uneven depending on planting date, planting equipment (broadcast vs. drilled), fineness of the seed bed and whether irrigation was used. October 2006 was relatively dry so unirrigated fields had thinner stands. Mixtures that combined small and large seeds (table 3 and figure 3) resulted in uneven stands because small seed settled to the bottom of the hopper. In 2007 four farms had good stands. One farm (ACF) opted to evaluate resident vegetation only, and one farm (HF) drilled cover crops late and the cover crop did not establish well.

Seed Species	Rep 1 (seed/lb)	Rep 2 (seed/lb)	Rep 3 (seed/lb)	Average	Rounded
Kenland Red Clover	210,012	215,909	212,280	212,734	212,700
Phacelia	196,858	201,394	198,672	198,975	199,000
Crimson Clover	90,718	90,718	88,450	89,962	90,000
Sub Clover	62,822	60,101	65,544	62,822	62,800
Walken Oats	14,515	14,333	14,687	14,512	14,500
Rye	12,383	12,383	12,111	12,292	12,300
Common Vetch	6,985	6,758	6,758	6,834	6,800
Austrian Field Pea	4,019	3,960	3,960	3,980	4,000

Table 3. Seed size expressed as number of seeds per pound and sort from small seed to large seed.

Figure 3. Cover crop seed from small (Kenland Red Clover) to large (Austrian Winter Pea) relative to a dime. Photos by Nick Andrews.

Results from soil nitrate tests are shown in table 4. Sufficient soil nitrate levels for most crops is between 20-30 ppm. These samples were taken at the end of the growing season. Most farms except PMF and ACF in 2006 had fairly high residual nitrate levels.

Farm name	Sampling date	pH	SMP buffer	NO_3-N (ppm)	NO_3-N (lb/A) (ppm x 4)
Sauvie Island Organics (SIO)	9/27/06	5.9		33.0	132
47th Avenue Farm (47)	9/26/06	6		24	96
Praying Mantis Farm (PMF)	12/27/06	6.4		2.6	10.4
Mustard Seed Farm (MSF)	9/26/06	5.6		143.4	574
Hinsvark Farm (HF)	9/27/06	6.2		34.7	139
Ayers Creek Farm (ACF)	10/6/06	5.6		13.6	54
Sauvie Island Organics (SIO)	September 2007	5.9	6.4	25.4	102
47th Avenue Farm (47)	September 2007	5.7	6.4	28.4	114
Praying Mantis Farm (PMF)	September 2007	6.7	6.8	13.3	53
Mustard Seed Farm (MSF)	September 2007	5.4	6.2	122.2	489
Hinsvark Farm (HF)	September 2007	6.7	6.9	23.7	95
Ayers Creek Farm (ACF)	September 2007	6.9		21.3	85

Table 4. Soil nitrate test results (12” soil cores)

5.1. Comparison of on-farm cover crop N testing methods

5.1.1. Separated species laboratory analysis vs. bulked species lab analysis (method 1 vs. method 2)

Total nitrogen estimates from separated species samples were very similar to estimates from bulked species samples in 2007 (figure 4). Bulk species samples were submitted at the same fresh weight ratio as separated species samples and excluded weeds. Regression analysis showed a very strong correlation between the two methods.

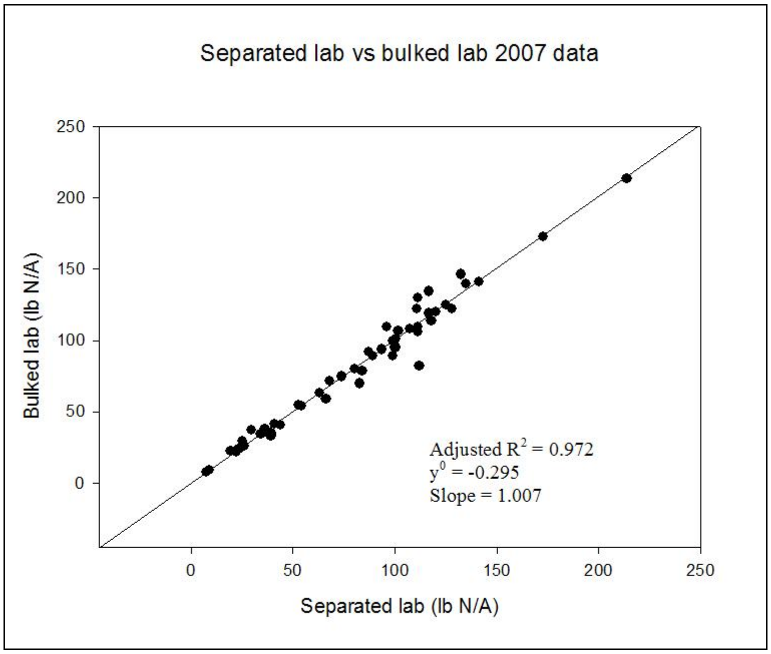


Figure 4. Method 1 vs. method 2 2007 data. Separated species lab test and bulked species lab test comparison of total N contribution, all farms, all species.

In 2008 the bulked samples were prepared as quick grab samples and included weeds. Again, total nitrogen estimates from separated species samples were very similar to estimates from bulked species samples (figure 5). Similarly, combining the data from 2007 and 2008 illustrated a very strong correlation between the two methods (figure 6).

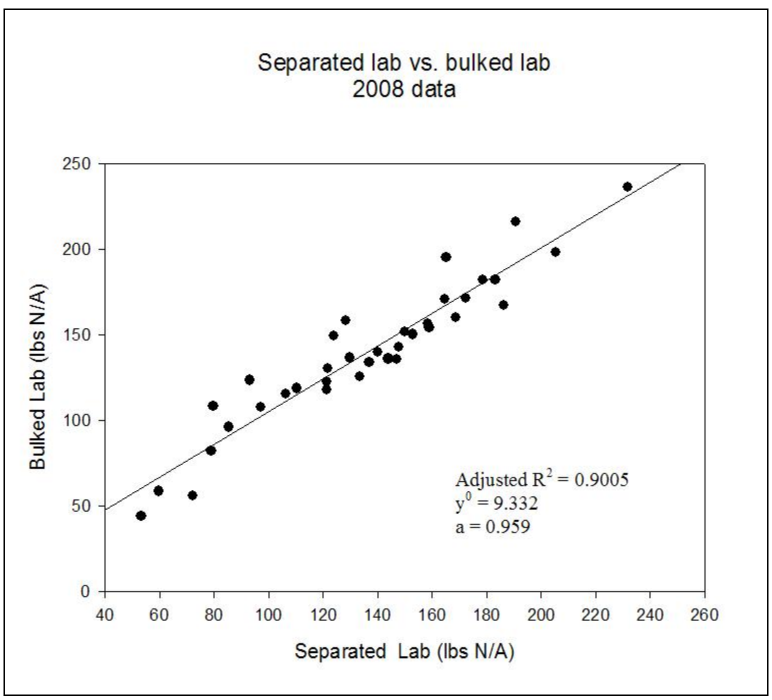


Figure 5. Method 1 vs. method 2, 2008 data. Separated species lab test and bulked species lab test comparison of total N contribution, all farms, all species.

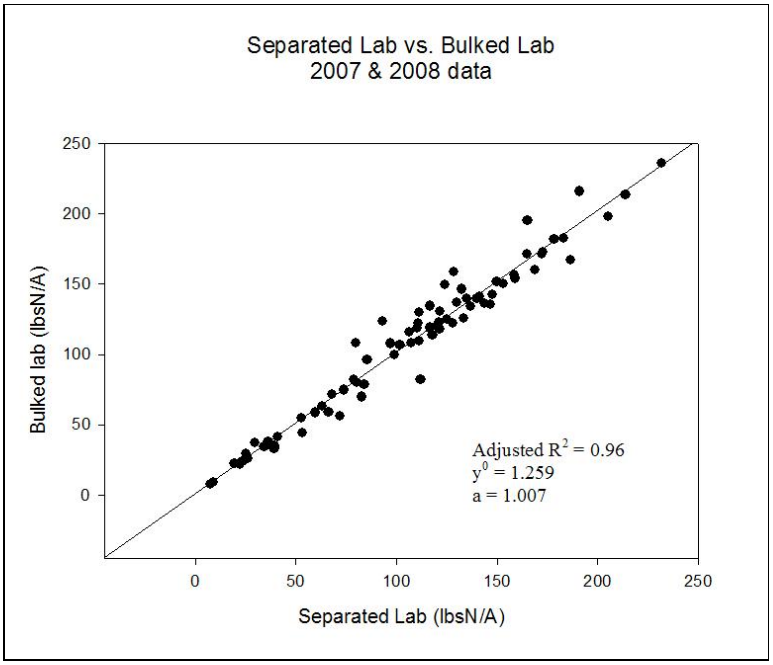


Figure 6. Method 1 vs. method 2, 2007 and 2008 data. Separated species lab test and bulked species lab test comparison of total N contribution, all farms, all species.

Although total nitrogen estimates from bulked samples may be similar, it was not clear whether plant-available nitrogen (PAN) estimates would be similar. 25-50% of the nitrogen in legumes is known to become available to crops as cover crop residues decompose. However, little to no nitrogen in non-legumes are thought to become available to crops the year of incorporation (Bowman et al 1998, Sarrantonio 1994, Sattell and Dick 1998). Therefore, it has been assumed that the ratio of legumes to non-legumes is needed in order to estimate PAN contributions from cover crops. This hypothesis was tested using 2007, 2008 and combined 2007 and 2008 data. The mineralization model in the OSU Organic Fertilizer Calculator was used to estimate PAN contributions. PAN estimates for the separated species test results were added together at the appropriate ratios and compared with PAN estimates from the bulked species. The correlation was very strong with a slope and adjusted R^2 that were close to 1. The OSU mineralization model was developed using data from lab and field incubations of organic amendments. It has not been validated for cover crops. However, it provides science based mineralization estimates based on total nitrogen content, and generates different predictions of mineralization rates for grasses and legumes. Therefore, it can test the hypothesis that separated species are needed to get useful estimates of PAN from mixed stands. Results from this project reject the hypothesis that species must be separated to provide accurate PAN estimates (figure 7-9), and support our recommendation that bulked species samples could be used to estimate PAN from cover crops when a mineralization model has been validated for cover crops in the Pacific Northwest.

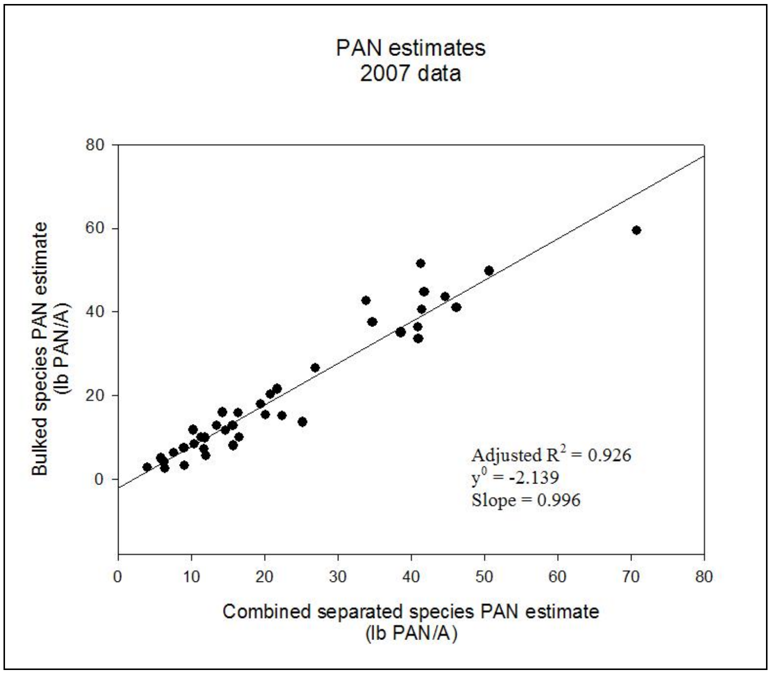


Figure 7. Method 1 vs. method 2. 2007 separated species estimated PAN and bulked species estimated PAN, all farms, all species.

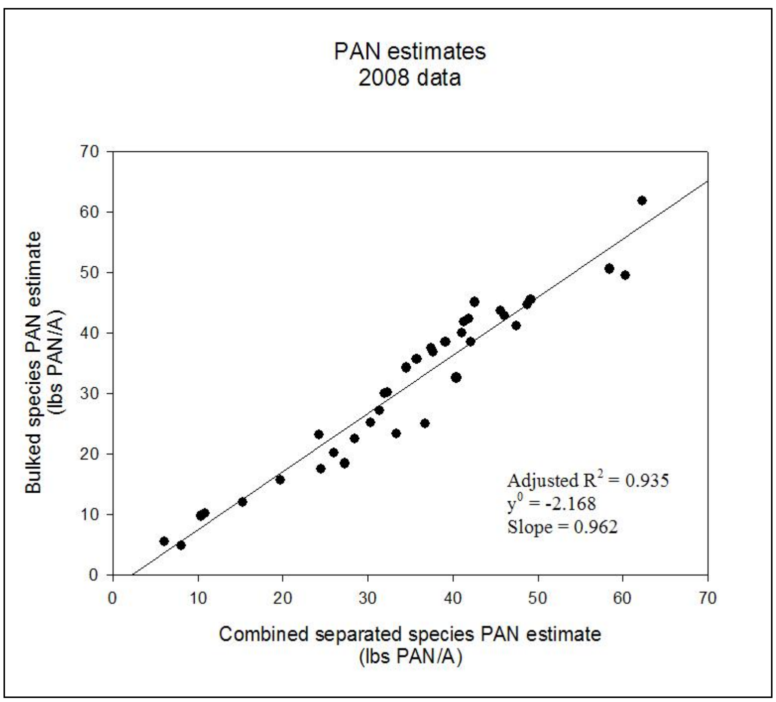


Figure 8. Method 1 vs. method 2. 2008 separated species estimated PAN and bulked species estimated PAN, all farms, all species.

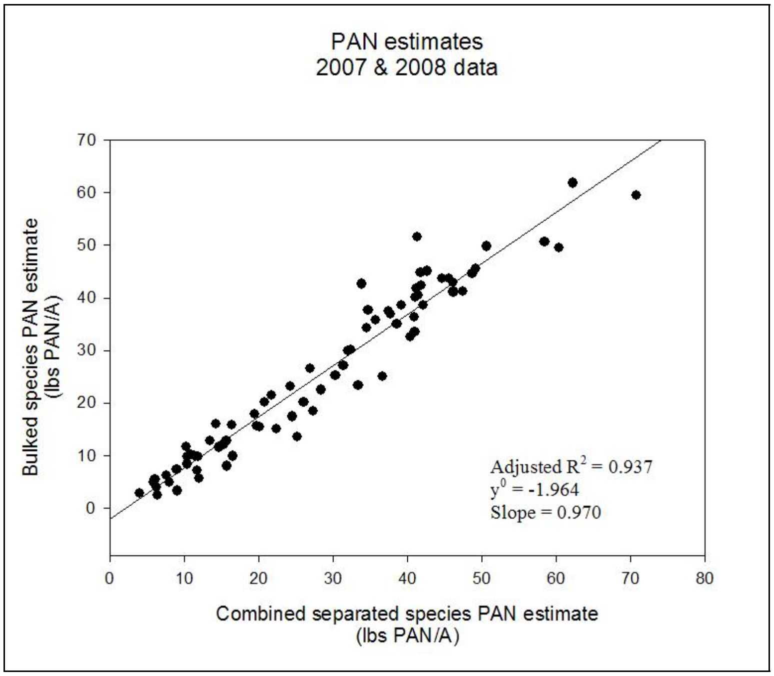


Figure 9. Method 1 vs. method 2. 2007 and 2008 separated species estimated PAN and bulked species estimated PAN, all farms, all species.

Other methods for estimating total N had weaker correlations than the bulked lab species, but the dry weight and fresh weight methods were accurate enough to be useful when laboratories are unavailable. These methods both require the time consuming work of separating cover crop species. The canopy height and density method did not provide reliable estimates of cover crop N contribution.

5.1.2 Separated species laboratory analysis vs. fresh weight method (method 1 vs. method 3)

Published N-factors (Sattell and Dick 1998) for the fresh weight method gave lower nitrogen estimates than the standard lab method (figure 10). However the adjusted R^2 value had a reasonably strong correlation that could be useful with modified N-factors.

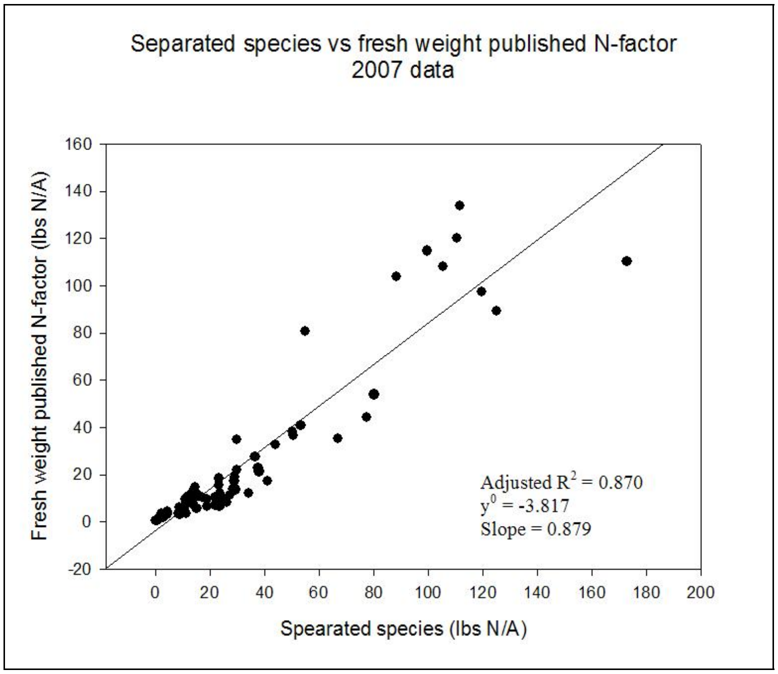


Figure 10. Method 1 vs. method 3, 2007. Separated species lab test and fresh weight comparison, all farms, all species using published N-factors (table 5).

The published N-factors were adjusted to fit the 2007 harvest data, these new N-factors (table 5) gave improved estimates for all species on all farms (figure 11).

	Fresh Weight N-factor		
Cover crop	**Published N-factor**	**2007 Adjusted N-factor**	**2008 Adjusted N-factor**
Austrian winter pea	8	8	13
Crimson clover	5	8	8
Fava bell bean	9	--	--
Hairy or lana vetch	9	13	13
Karridale subclover	6	--	--
Kenland red clover	10	--	--
Grasses (grass & weeds in 2008)	--	8	8

Table 5. Published N-factor and N-factors that fit fresh weight and dry weight data from 2007 data, and 2007/08 data for Austrian winter peas. N-factor uses weights of above-ground material from $16ft^2$ samples and gives a total N estimate in lbs/acre.

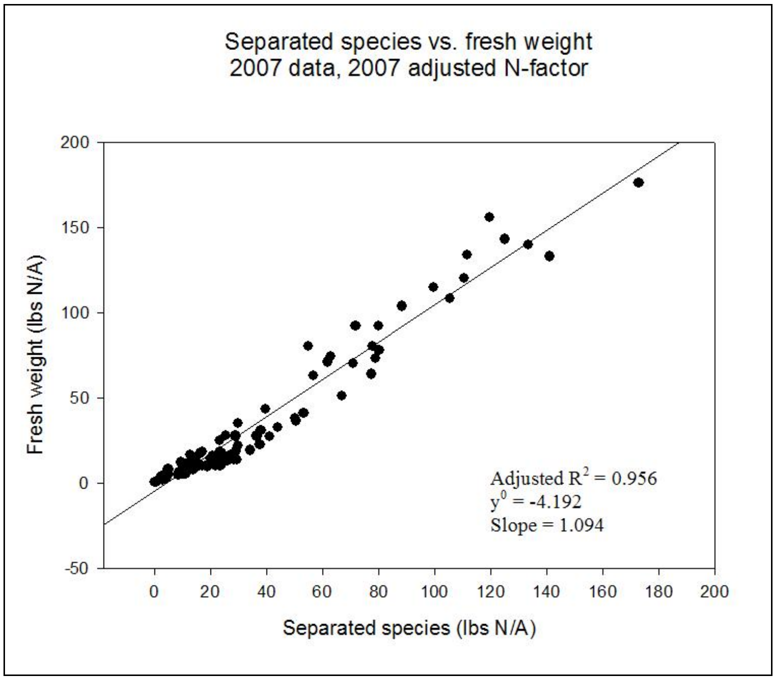


Figure 11. Method 1 vs. method 3, 2007 data. Separated species lab test and fresh weight comparison, all farms, all species using adjusted 2007 N-factors (table 5).

The 2008 data also had a good correlation with most of the 2007 adjusted N-factors (figure 12). In 2007 there was insufficient data from Austrian Winter Peas to adjust the published N-factor, so that N-factor was adjusted with data from both years. The oats and rye N-factor was also adjusted in 2008 to include weeds. The 2008 N-factors were strongly correlated with separated species results. We were concerned that wet cover crops from rain or heavy dew may distort results. However, wet cover crops dried reasonably well when they were being separated by species indoors. If they had remained wet, results may have been less accurate.

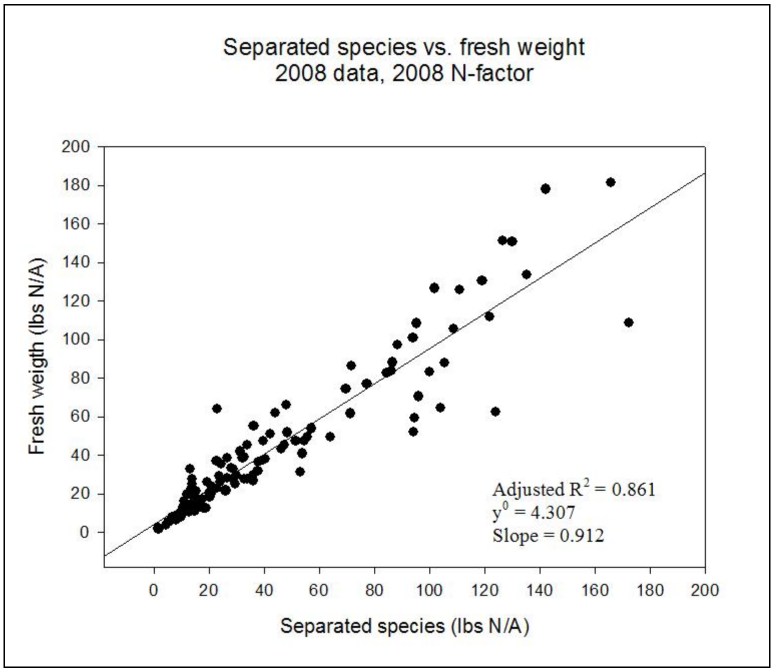


Figure 12. Method 1 vs. method 3, 2008 data. All farms all species adjusted 2008 N-factor.

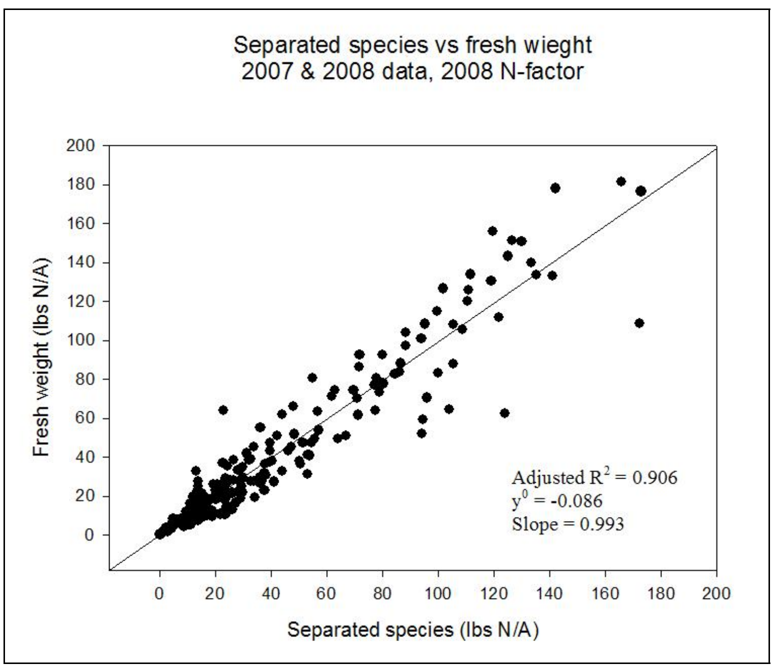


Figure 13. Method 1 vs. method 3 combined 2007 and 2008 data. Separated species vs. adjusted 2008 fresh weight N-factor using all farms, all species.

5.1.3 Separated species laboratory analysis vs. dry weight method (method 1 vs. method 4)

Correlations between total N estimates using method 1 compared to method 4 (dry weight) were very similar to the fresh weight method (using adjusted N-factors), so the extra effort of during cover crop samples may not be worthwhile unless perhaps cover crops are very wet. Based on the 2007 data, grasses and weeds were estimated to contain 2%N on a dry weight basis, legumes were estimated to contain 3.3%N on a dry weight basis. Results illustrate the utility of this method when laboratories are not available (figures 14-16).

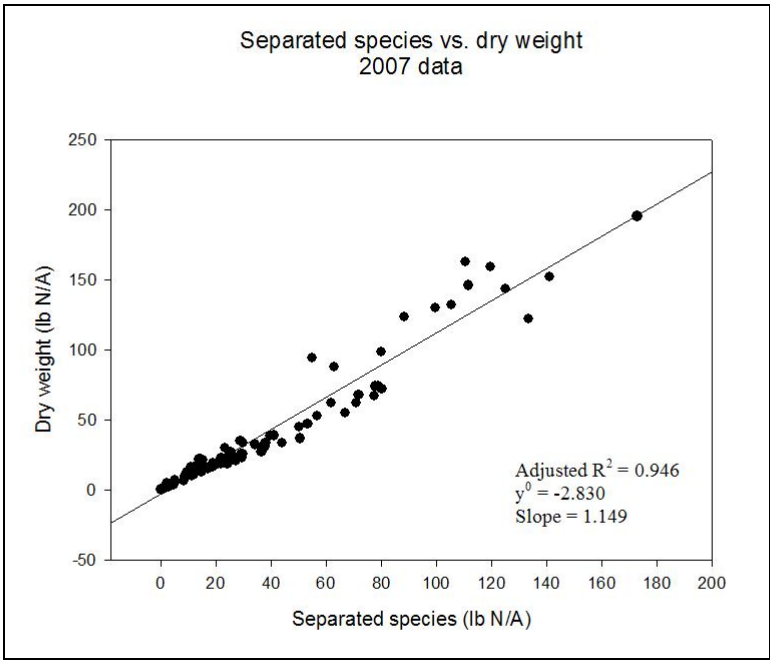


Figure 14. Method 1 vs. method 4. Separated species lab test and dry weight comparison using 2% N for grass (dry weight basis) and 3.3% N for legumes (dry weight basis). 2007 data all farms, all species, including weeds.

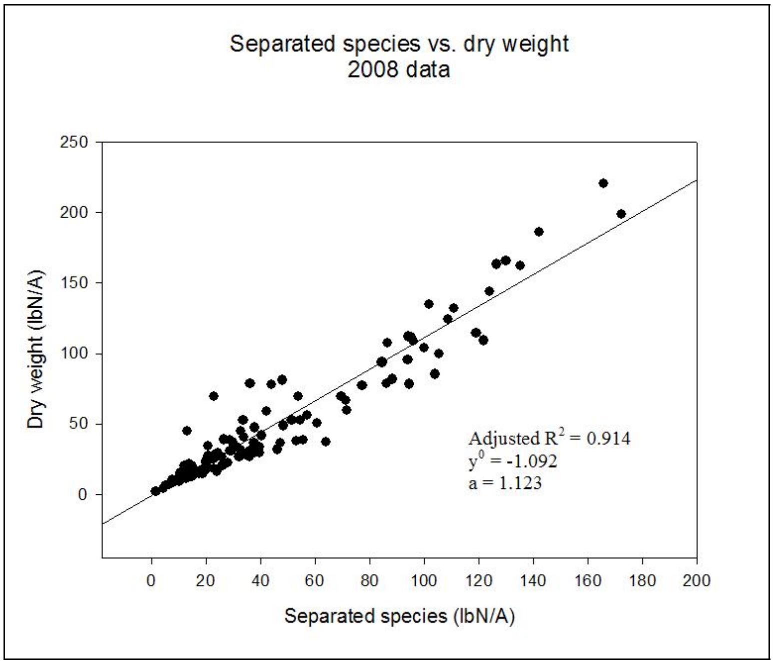


Figure 15. Method 1 vs. method 4. Separated species lab test and dry weight comparison using 2% N for grass and weeds (dry weight basis) and 3.3% N for legumes (dry weight basis). 2008 data all farms, all species, including weeds.

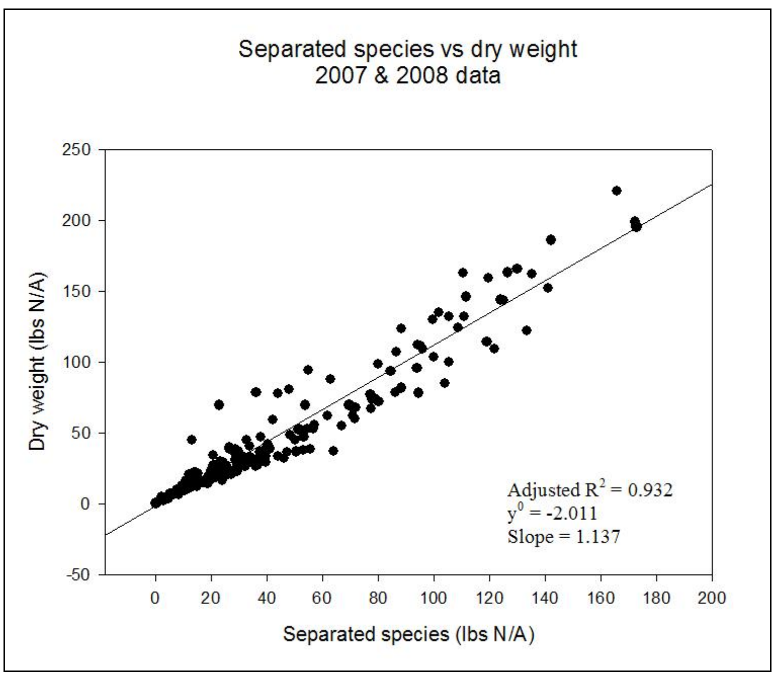


Figure 16. Method 1 vs. method 4. Separated species vs. dry weight using all species from 2007 and 2008. Legumes = 3.3%N, grasses and weeds = 2%N.

5.1.4 Separated species laboratory analysis vs. canopy height and density method (method 1 vs. method 5)

Fresh weight and dry weight estimates may prove useful in some cases since they don't require lab testing, but they do require separating cover crop species. Estimates based on canopy height and density do not require separating species or sending samples to the lab. Unfortunately this method did not correlate well with method 1. This was disappointing to the project team since we had originally envisioned developing a “cover crop stick” similar to pasture sticks used to estimate the feed value of pastures. These findings suggest that such a tool would not be very valuable. Comparisons of all species from all farms in both years gave a slope of 0.905, an adjusted R2 of 0.592, and a y intercept of 62 (figure 19). Comparisons of individual species ranged from none (Austrian peas) to an adjusted R^2 of 0.977 for cereal rye, most species had an adjusted R^2 less than 0.8 (data not shown). This method was not accurate enough to recommend. However, if a grower uses consistent cover crop mixtures, and uses a more accurate method to estimate N contribution for a few years (i.e. bulk species method), they may be able to estimate the N contribution of cover crops reasonably accurately by eye. Then return to testing every once in a while to calibrate their eyeball estimates or when they change cover crop species. One weakness of the canopy height and density method was that it was not practical to develop a canopy height and density table for weeds since different weed species have very different canopy heights, but an experienced and calibrated farmer’s eyeball estimate may be able to account for this.

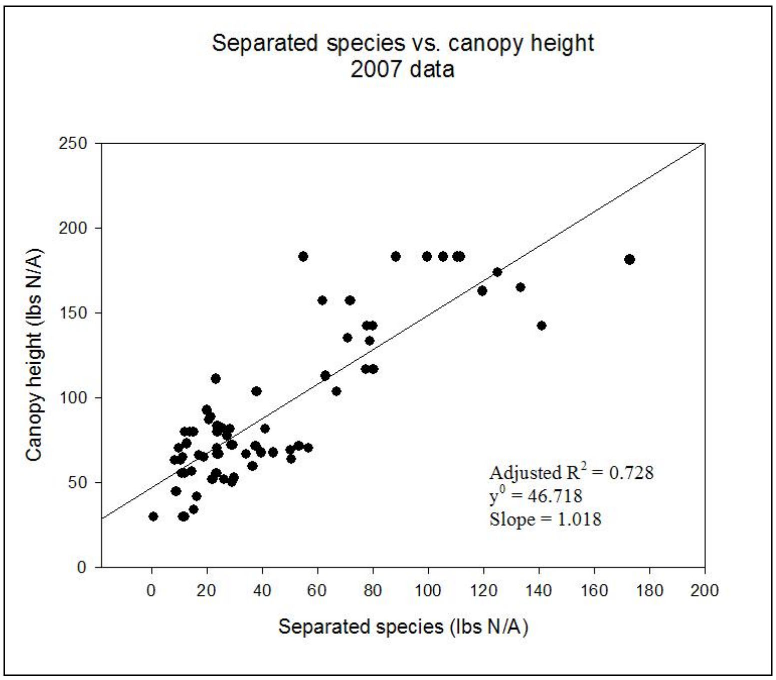


Figure 17. Method 1 vs. method 5. Separated species lab test and canopy height and density comparison,2007 data.

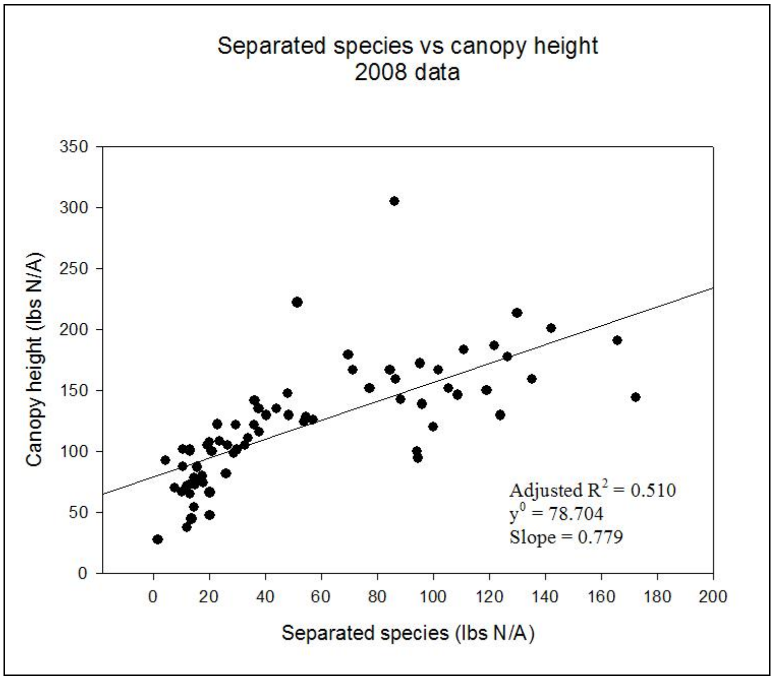


Figure 18. Method 1 vs. method 5. Separated species vs. canopy height and density, 2008 data.

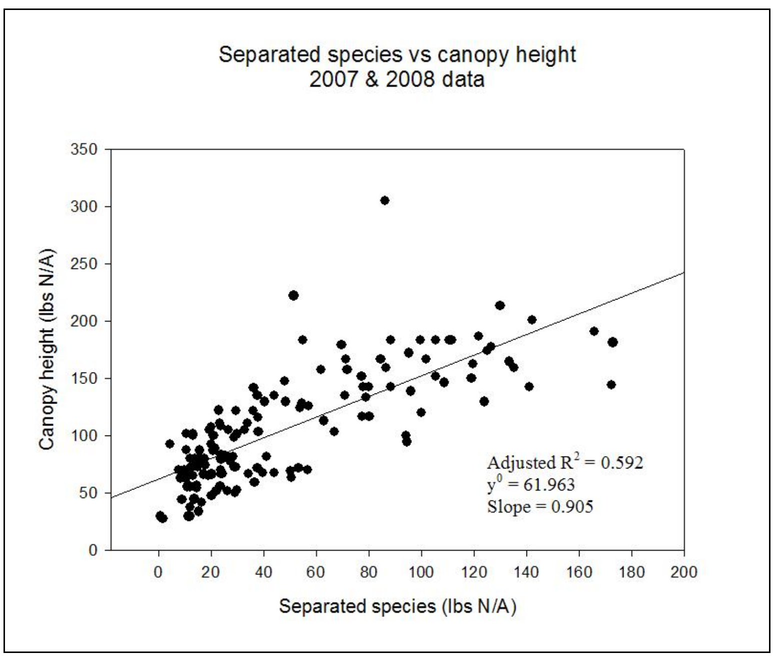


Figure 19. Method 1 vs. method 5. Separated species vs. canopy height and density, 2007 and 2008 data.

5.1.5 Combined results

Comparisons with separated species method				
Year	**Method**	**Adj. R^2**	**y^0**	**Slope**
2007	Bulk	0.972	-0.295	1.007
2008	Bulk	0.901	9.332	0.959
2007/08	Bulk	0.960	1.259	1.007
2007	PAN	0.926	-2.139	0.996
2008	PAN	0.935	-2.168	0.962
2007/08	PAN	0.937	-1.964	0.970
2007	Fresh weight (Publ. N-factor)	0.870	-3.817	0.879
2007	Fresh weight (2007 N-factor)	0.956	-4.912	1.094
2008	Fresh weight (2008 N-factor)	0.861	4.307	0.912
2007/08	Fresh weight (2008 N-factor)	0.906	-0.086	0.993
2007	Dry weight	0.946	-2.830	1.149
2008	Dry weight	0.914	-1.092	1.123
2007/08	Dry weight	0.932	-2.011	1.137
2007	Canopy height and density	0.728	46.718	1.018
2008	Canopy height and density	0.510	78.704	0.779
2007/08	Canopy height and density	0.592	61.963	0.905

Table 6. Correlations between estimated total N/acre results from separated species lab tests compared to other methods.

5.2 Comparisons between cover crops

This project was established to compare methods for estimating N contribution from commonly used cover crops, not to compare or demonstrate the value of different cover crop mixtures. Nevertheless, the replicated side-by-side cover crop stands did provide a good opportunity for participating farmers and their visitors to make anecdotal comparisons between the cover crops (table 7 and 8 and figures 20-26). Performance varied more widely between farms and between years than between cover crop species. This illustrates the importance of the current approach to develop practical on-farm methods for evaluating cover crop performance within a cropping system. Strong cover crops in these trials contained 100-175 lbs N/acre, 1500-3000 lbs C/acre, and 3000-7000 lbs dry matter/acre.

The fallow plots at ACF provided lower estimated PAN contributions than other cover crops in all comparisons. They also provided lower total N, C and dry matter contributions at all sites except for the similar yields from all three cover crops at PMF in 2007 and the crimson clover at HF in 2007 where cover crop stands were thin.

Pure stands of crimson clover may have been expected to yield more total N and PAN than mixtures with grasses. However, this was only the case in four of the eight total N comparisons (MSF in 2007 and 47th, PMF and SIO in 2008), and three of the eight PAN comparisons (MSF in 2007 and 47th and PMF in 2008). Mixtures including cereal rye and vetch or oats and vetch were just as likely to provide the most total N and PAN in any one comparison. Mixtures that included grasses consistently yielded higher C and dry matter than crimson clover plots in all but two comparisons (PMF and SIO in 2008).

The ability of cover crops to suppress weeds varied between farms and years. However, weed biomass was generally lower in cover cropped plots. Cover crops that included grasses also appeared to suppress weeds better than crimson clover alone. The dry matter of weeds and % of the cover crop dry matter accounted for by weeds was the highest in crimson clover plots in five of the eight comparisons. The exceptions were SIO in 2007 and 47th and MSF in 2008 when oats and vetch or oats, vetch and pea plots had higher weed biomass.

2007 Summary of Results							
Farm	**Trtmt**	**Average N (lbs/A)**	**Estimated full season PAN (lbs/A)**	**Average C (lb/A)**	**Average Total Dry Wt. (lb/A)**	**Weeds dry wt. basis (lb/A)**	**Weeds % of total**
ACF	FW1	27	2	743	1915	N/A	100%
ACF	FW2	33	4	734	1813	N/A	100%
ACF	FW3	49	3	1129	3282	N/A	100%
ACF	FW4	48	4	1052	3228	N/A	100%
ACF	FW5	49	8	951	2402	N/A	100%
HF	C	40	12	580	1146	723	49%
HF	RP	72	21	1126	2641	188	5%
HF	RV	107	38	1421	3340	156	2%
MSF	C	151	39	2398	5673	637	11%
MSF	OC	110	11	3020	6977	12	0.1%
MSF	OV	110	10	3119	7234	45	0.6%
PMF	C	39	12	587	1428	743	52%
PMF	OC	42	9	886	2099	547	25%
PMF	OV	42	13	735	1707	466	26%
SIO	C	100	26	1526	3676	251	7%
SIO	OVP	114	39	1523	3729	359	9%
SIO	RVP	117	49	2124	5294	136	3%

Table 7. Average total N, available N, C and dry weight contributions of different cover crops and weeds and % weed dry weight in 2007. Results of combined separated species data (method 1). FW = fallow with resident vegetation, C = crimson clover, O = oats, R = cereal rye, P = Austrian Field Pea, V = common vetch. At ACF fallow plots were from different fields: FW1 = blackberries, FW2 = corn, FW3 = chicory, FW4 = plum orchard, FW5 = beans.

2008 Summary of Results							
Farm	**Trtmt**	**Average N (lbs/A)**	**Estimated full season PAN (lbs/A)**	**Average C (lb/A)**	**Average Dry Weight (lb/A)**	**Weeds dry wt. basis (lb/A)**	**Weeds % of total**
47th	C	133	31	2172	5180	990	18.7%
47th	OVP	114	19	2286	5376	1781	31.7%
47th	RVP	130	25	2375	5801	1517	26.9%
ACF	FW1	32	2	926	2236	N/A	N/A
ACF	FW2	35	2	982	2426	N/A	N/A
ACF	FW3	28	1	754	2231	N/A	N/A
ACF	FW4	39	3	1000	2450	N/A	N/A
ACF	FW5	33	3	870	2086	N/A	N/A
ACF	FW6	44	2	1356	3365	N/A	N/A
MSF	C	162	40	2523	6110	2188	38.6%
MSF	OC	171	43	2643	6371	1204	23.6%
MSF	OV	173	49	2499	6004	1515	24.7%
PMF	C	122	30	2018	4731	1911	38.6%
PMF	OC	99	18	1925	4561	1144	23.6%
PMF	OV	97	17	1932	4598	2292	54.8%
SIO	C	174	37	3114	7214	1981	21.1%
SIO	OVP	132	39	1923	4426	421	9.3%
SIO	RVP	145	24	3008	6866	557	8.3%

Table 8.Average total N, available N, C and dry weight contributions of different cover crops and weeds and % weed dry weight in 2008. Results taken from bulked species tests (method 2), weeds data from separated species results (method 1). FW = fallow with resident vegetation, C = crimson clover, O = oats, R = cereal rye, P = Austrian Field Pea, V = common vetch. At ACF fallow plots were from different fields: FW1 = blackberries, FW2 = corn, FW3 = grapes, FW4 = plum orchard north, FW5 = plum orchard south, FW 6 = shell beans.

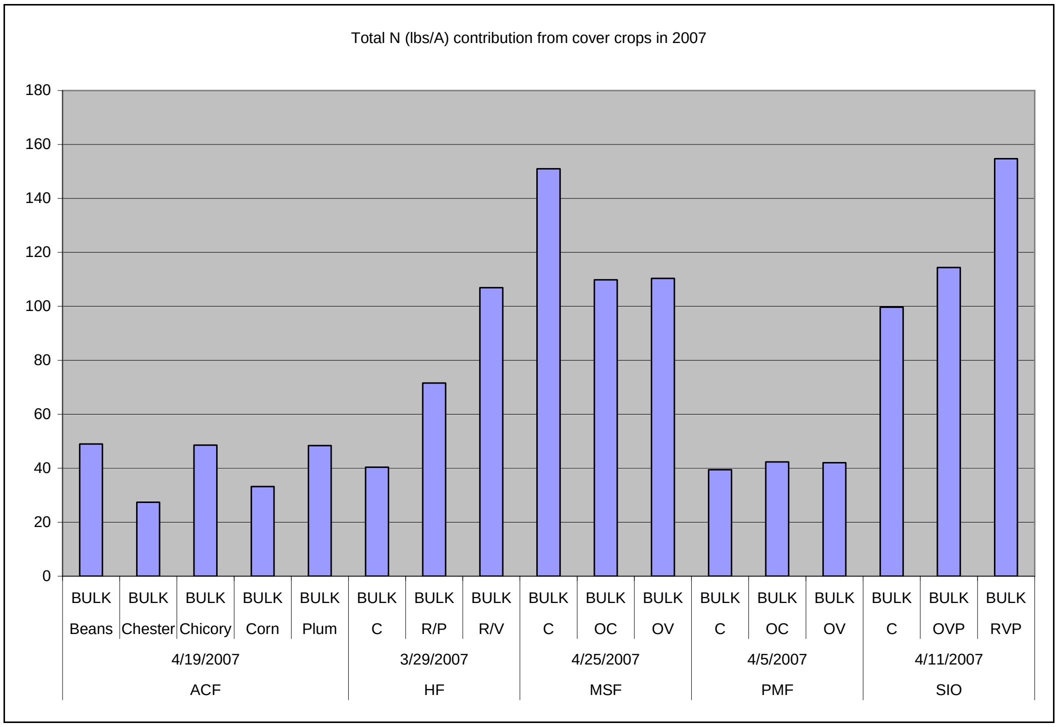


Figure 20. Total nitrogen contributions (lbs/A) from cover crops in 2007. ACF cover crops are resident vegetation in various areas of the farm.

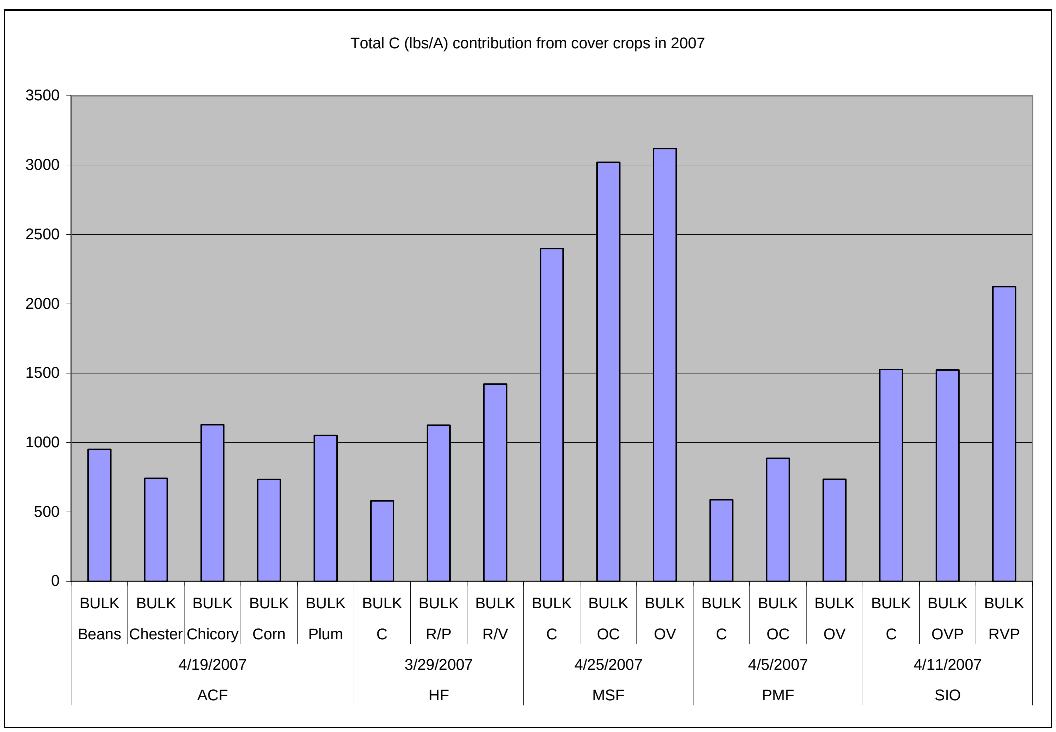


Figure 21. Total carbon contributions (lbs/A) from cover crops in 2007. ACF cover crops are resident vegetation in various areas of the farm.

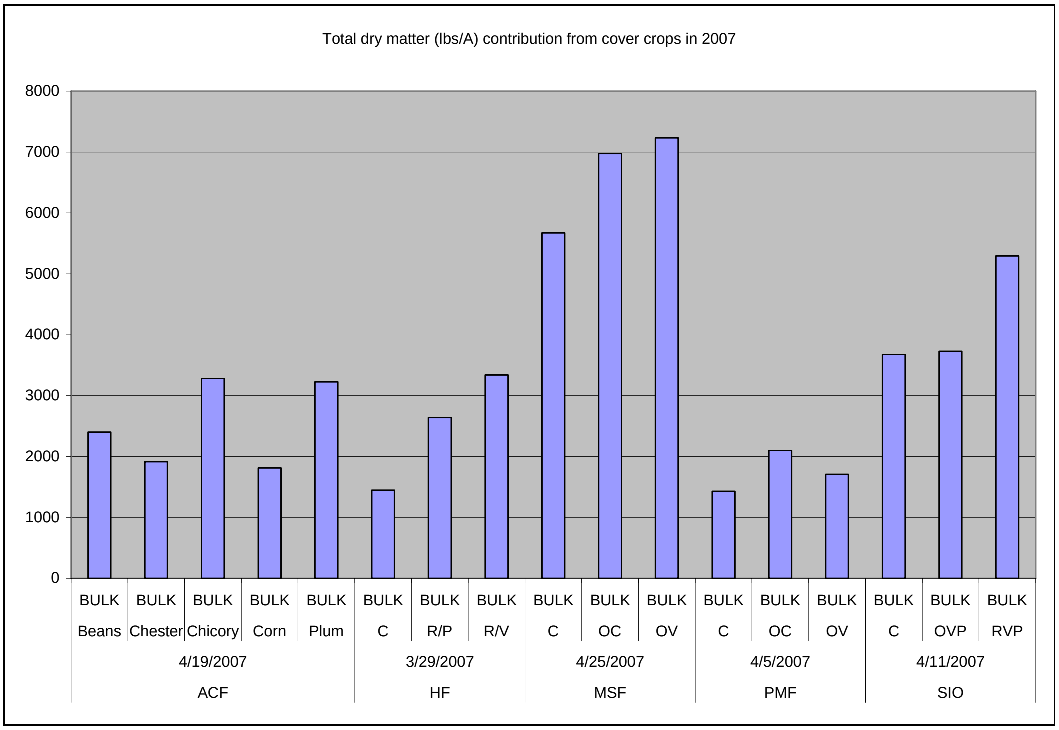


Figure 22. Total dry matter contributions (lbs/A) from cover crops in 2007. ACF cover crops are resident vegetation in various areas of the farm.

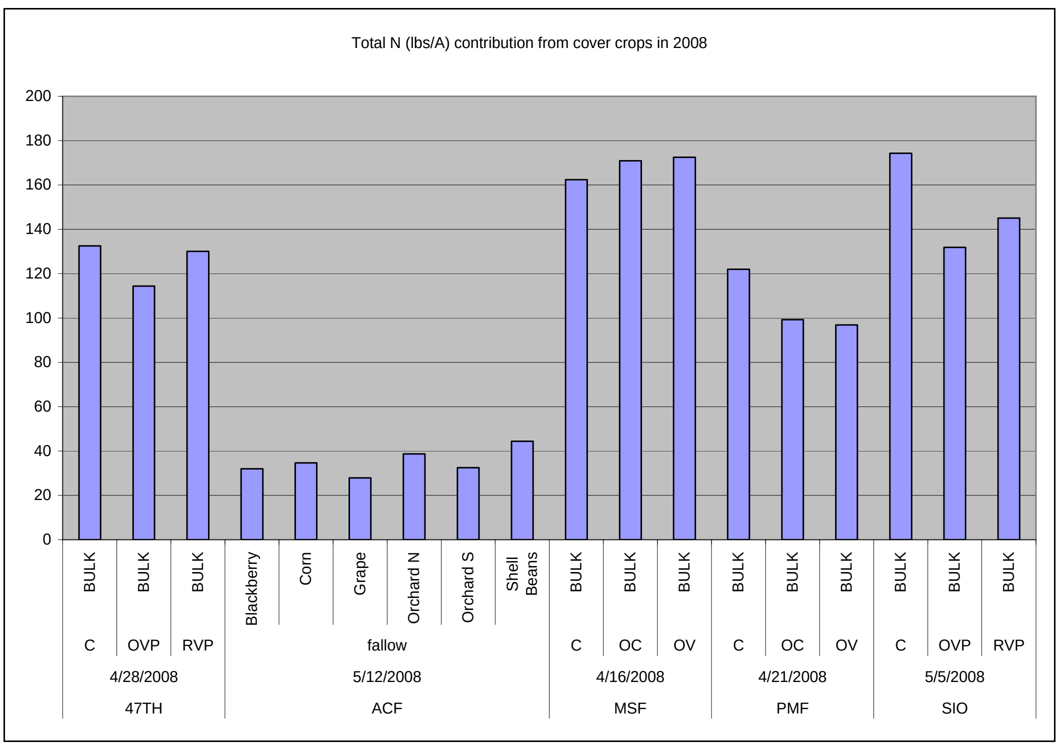


Figure 23. Total nitrogen contributions (lbs/A) from cover crops in 2008. ACF cover crops are resident vegetation in various areas of the farm.

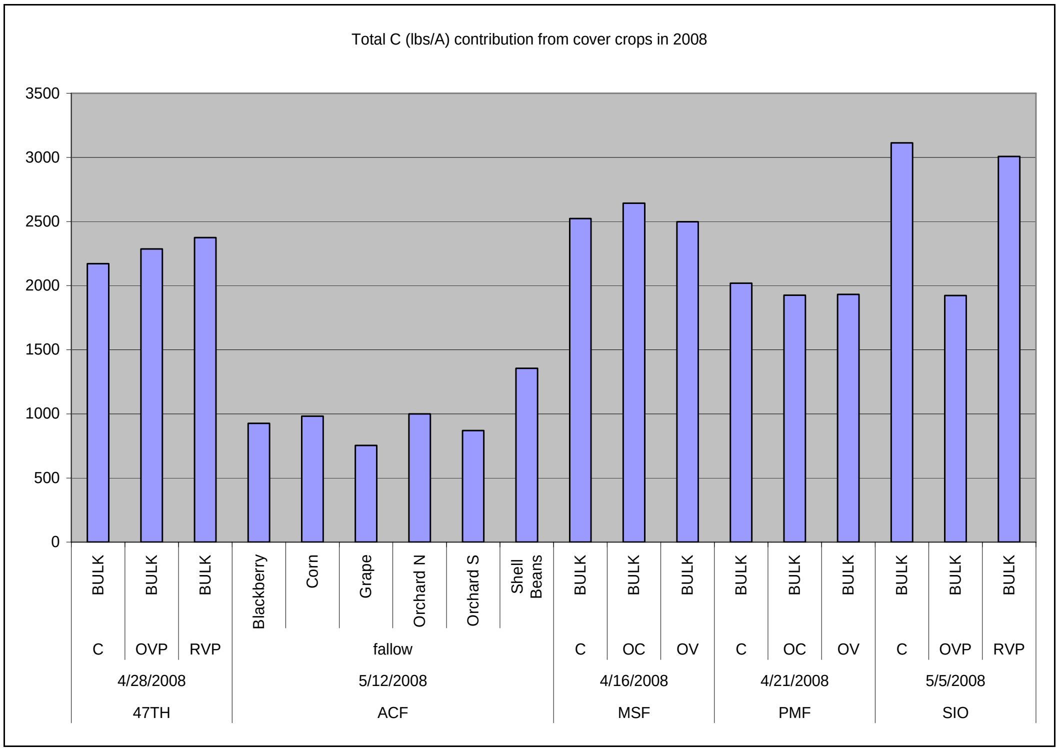


Figure 24. Total carbon contributions (lbs/A) from cover crops in 2008. ACF cover crops are resident vegetation in various areas of the farm.

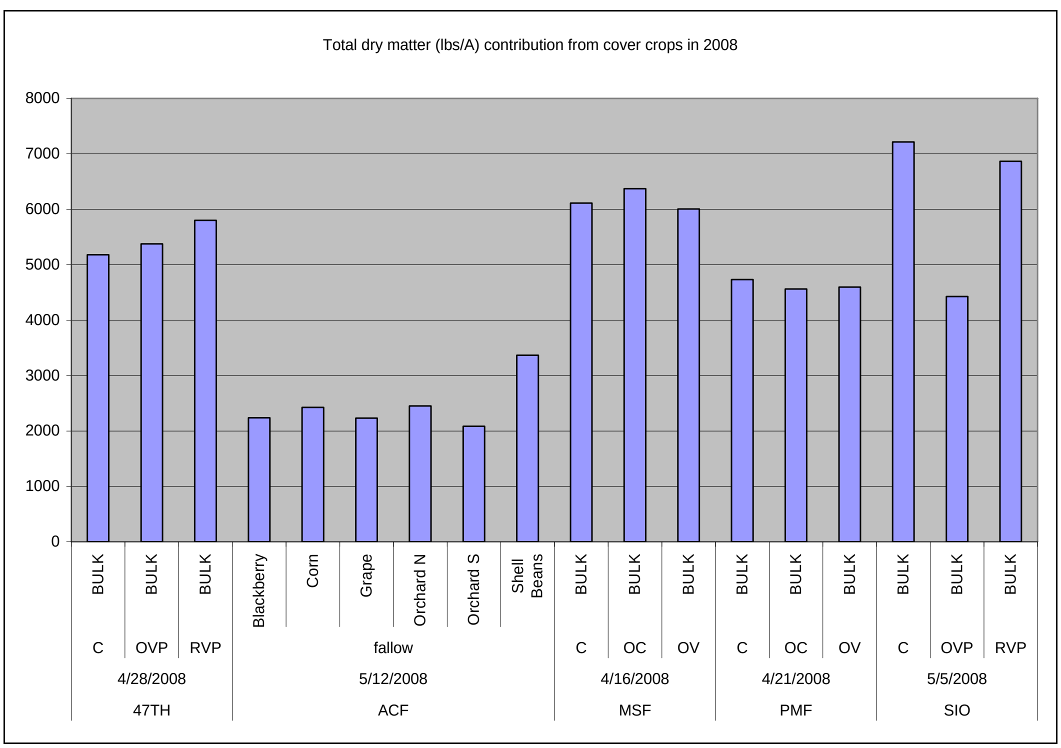


Figure 25. Total dry matter contributions (lbs/A) from cover crops in 2008.

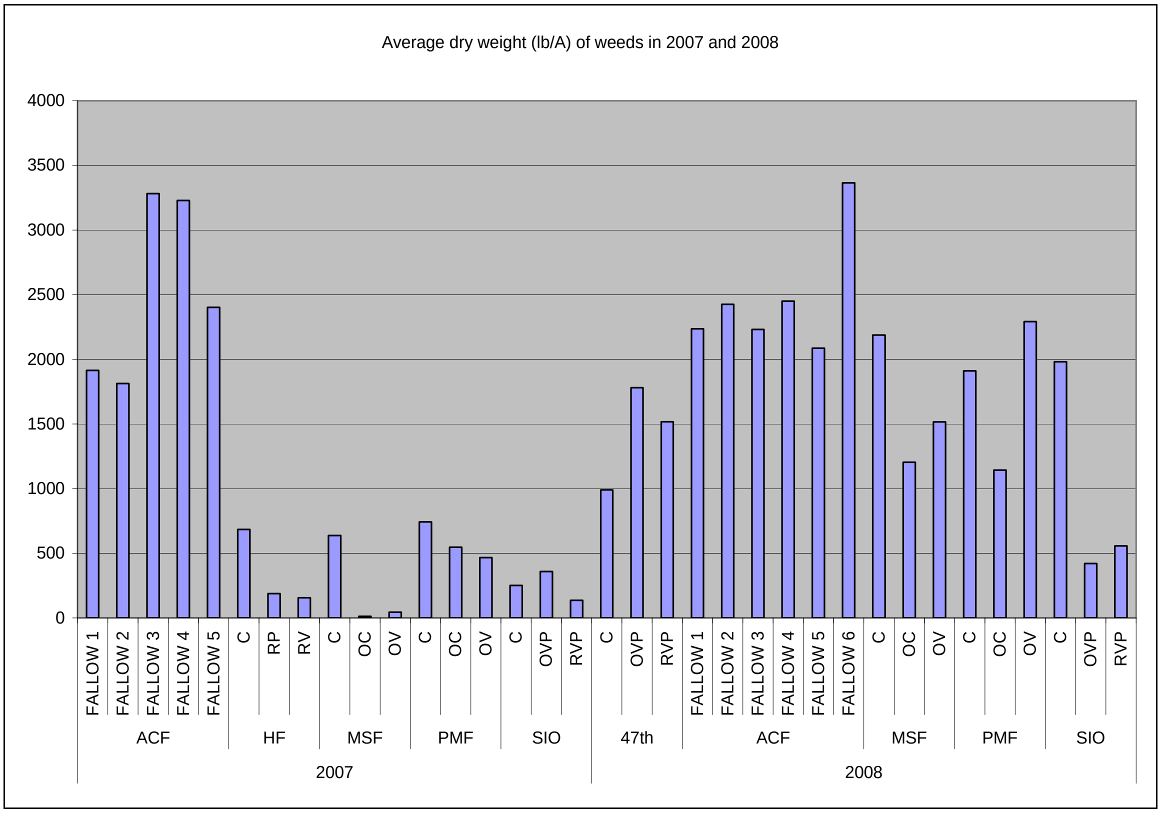


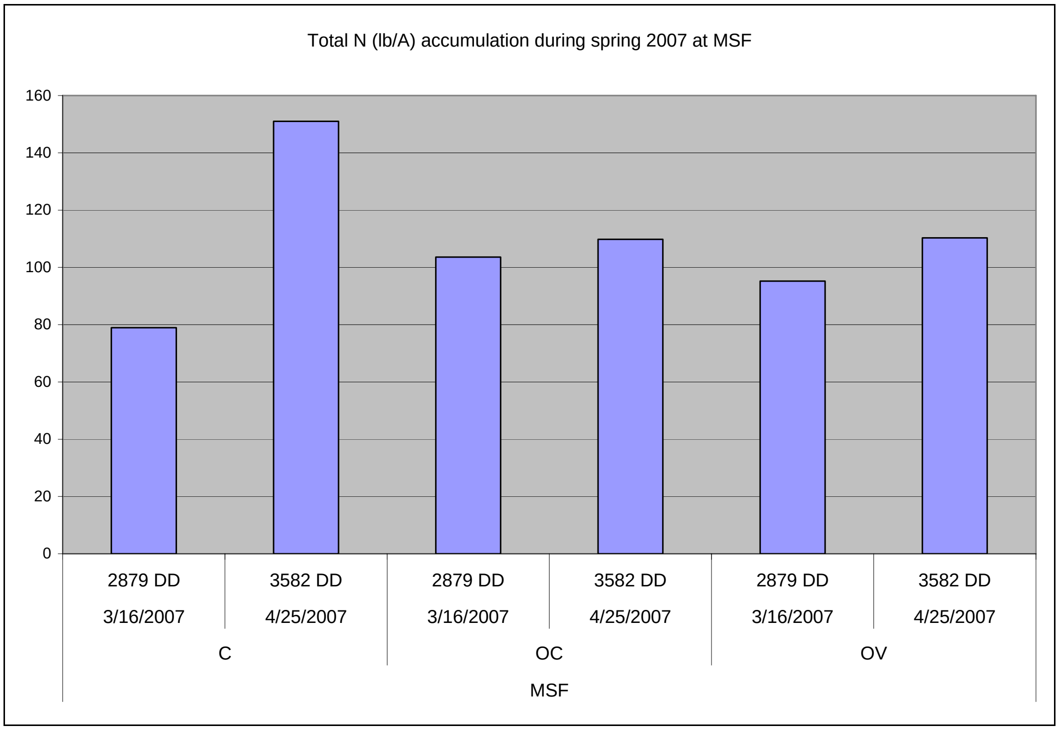
Figure 26. Average dry weight of weeds in 2007 and 2008.

5.3 Observations on Nitrogen, Carbon and Dry Matter accumulation during the spring

Growers are often faced with the choice of incorporating cover crops as soon as possible to work up a field early, or leaving cover crops to develop longer so that nitrogen and dry matter can accumulate and improve soil fertility and quality. Cover crop development was monitored during the spring of 2007 and 2008 at Mustard Seed Farm (MSF) to compare cover crop nitrogen, carbon and dry matter content at 2 dates in 2007 and 3 dates in 2008 (Figure 26-28). Day degrees were recorded with the nearest weather station (North Willamette Research & Extension Center), and a base temperature (T_{base}) of 32ºF.

We did not develop degree day calculators for the various cover crop species. The OSU Integrated Plant Protection Center hosts degree day calculators for wheat, winter wheat, peas, canola and oats. All of these calculators use a T_{base} of 32°F, so we used the same threshold for our cover crops. This conclusion was supported by Russ Karow (personal communication). Clover appeared to reach maximum N content at around 2600 DD. Total C and dry matter content did not level off in any one year, so we could not confirm whether more C and dry matter would have accumulated. In comparisons between both years however, it appears that most dry matter and C had accumulated by 3000-3500 DD. The clover had just started flowering.

Tentative conclusions about the development of individual cover crop species are impossible in the mixed species plots since all species require different numbers of heat units to mature. However, N accumulation appeared to level off somewhere around 3000DD, C and dry matter appeared to continue accumulating throughout the study.



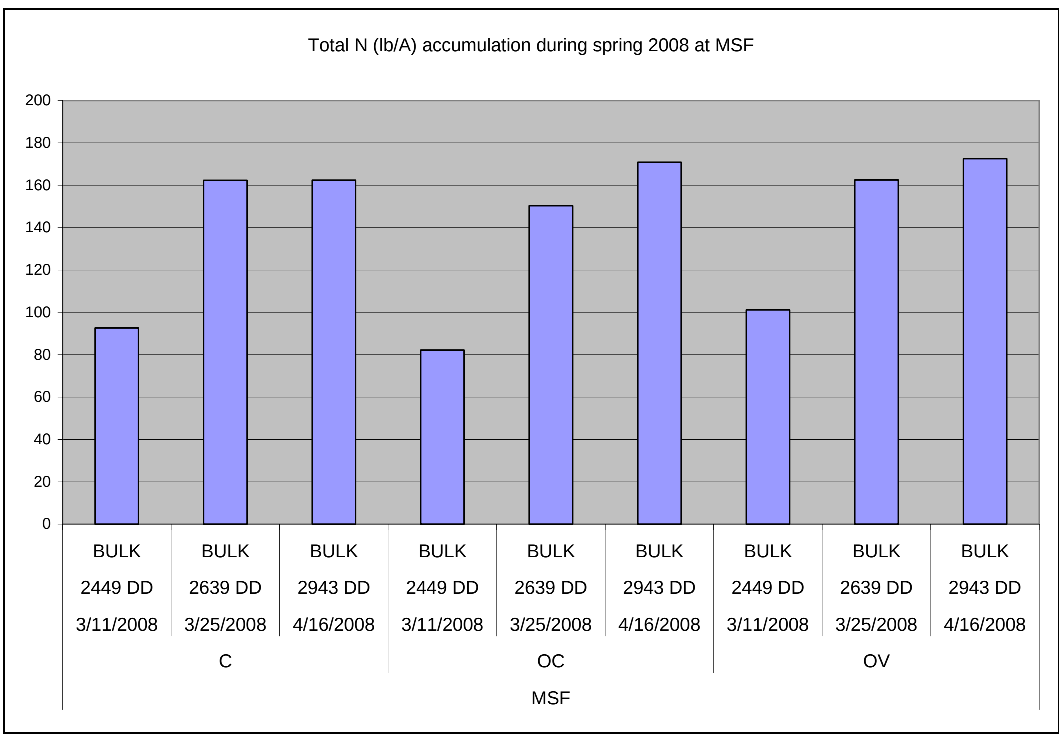
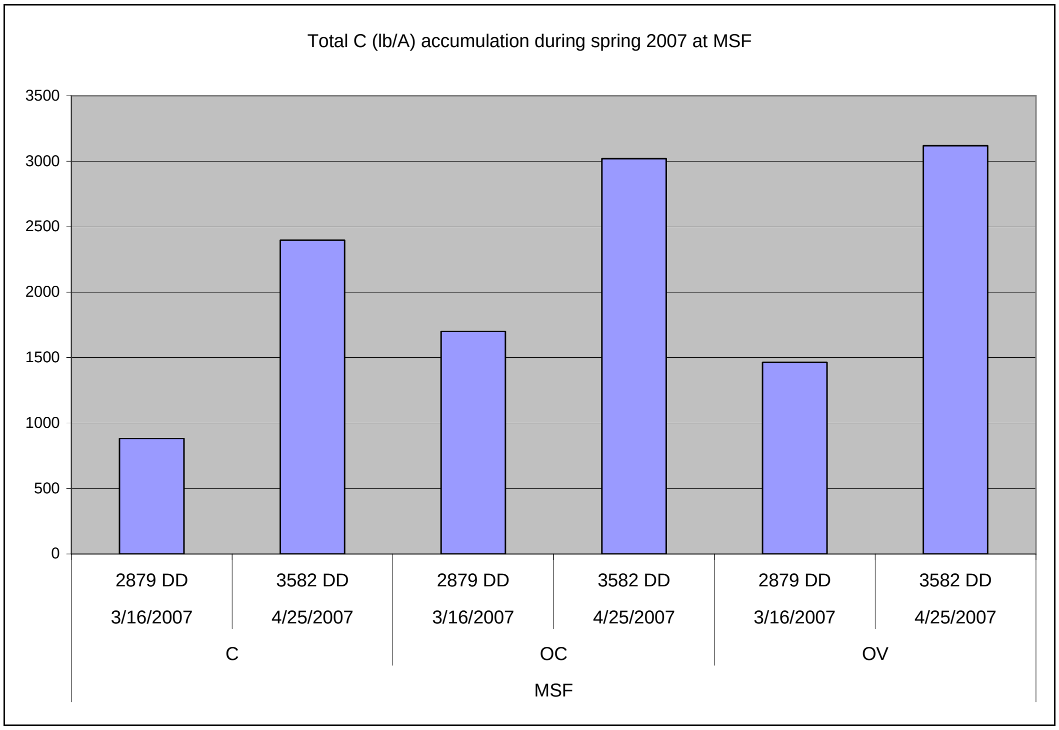


Figure 26. Relative nitrogen content in cover crops at Mustard Seed Farm at two dates during spring 2008 and three dates in spring 2008. DD = Degree days using a T_{base} of 32ºF. Degree days are based on weather data from the nearby weather station at OSU's North Willamette Research & Extension Center in Aurora, OR.



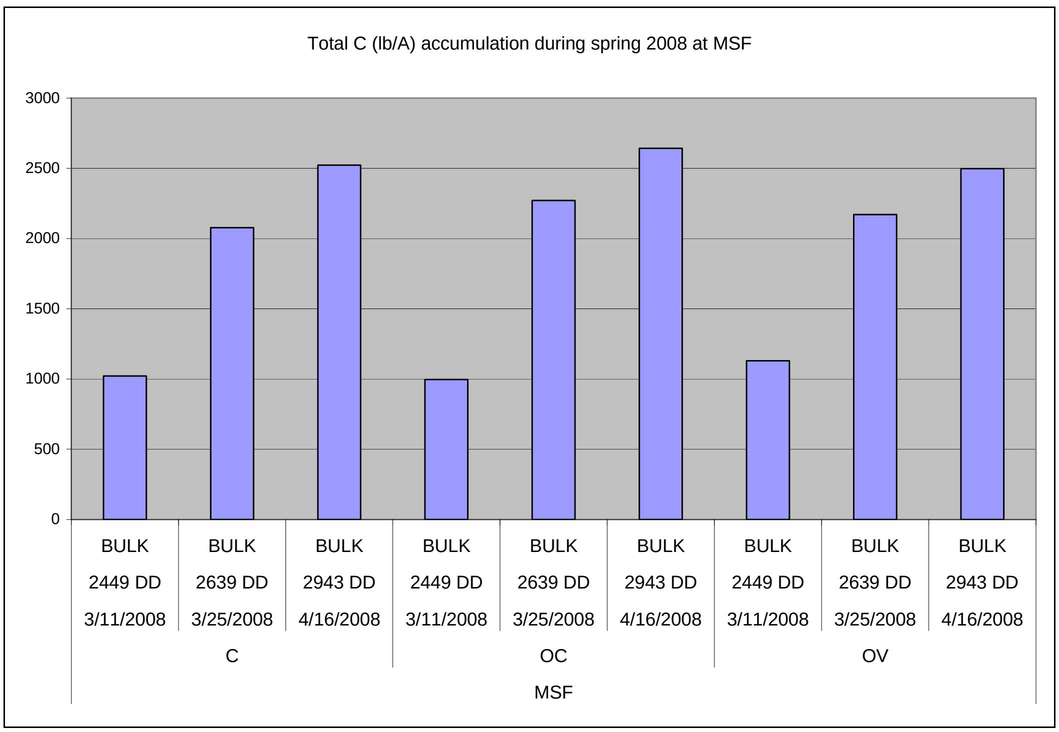
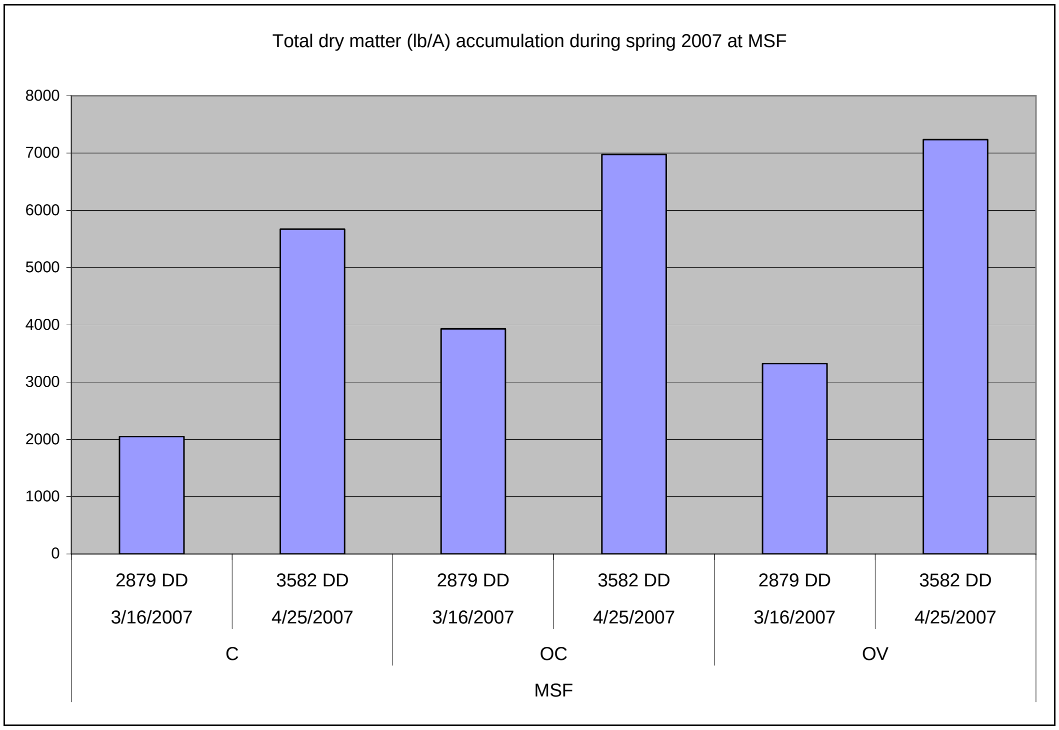


Figure 27. Relative carbon content in cover crops at Mustard Seed Farm at two dates during spring 2008 and three dates in spring 2008. DD = Degree days using a T_{base} of 32ºF. Degree days are based on weather data from the nearby weather station at OSU's North Willamette Research & Extension Center in Aurora, OR.



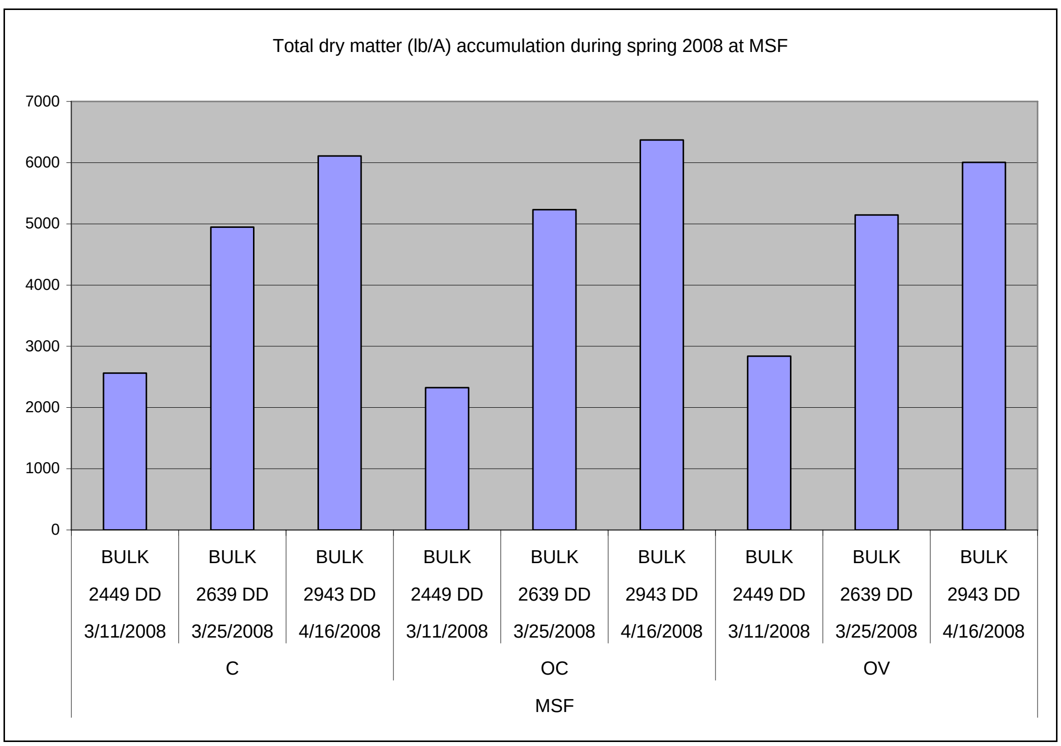


Figure 28. Relative dry matter content in cover crops at Mustard Seed Farm at two dates during spring 2008 and three dates in spring 2008. DD = Degree days using a T_{base} of 32ºF. Degree days are based on weather data from the nearby weather station at OSU's North Willamette Research & Extension Center in Aurora, OR.

6. ACCOMPLISHMENTS, IMPACTS AND CONTRIBUTIONS

N contributions from cover crops vary widely (figures 31 and 32), and growers need a simple science-based method to account for this N supply. Estimates of total nitrogen contribution from cover crops were very similar from lab tests of separated species samples and bulked species samples. This held true when the same fresh weight ratio was submitted to the lab as in 2007 and when a quick representative grab sample was submitted to the lab as in 2008. Use of the PAN model in the OSU Organic Fertilizer Calculator to predict PAN from separated species and bulk species lab results demonstrated that the bulk species lab results can provide accurate PAN estimates. These results are useful for farmers, agricultural extension and crop consultants since the time required to separate cover crop species when estimating cover crop nitrogen contributions is generally prohibitive. The bulk species method described in section 4.2 has been demonstrated to be an excellent method for on-farm use.

If laboratories are not available, total nitrogen estimates can be made. Cover crop species could be separated and if possible dried to estimate N contributions based on average N content of different species. The 2008 adjusted N factors in table 5 are recommended for use with fresh cover crops. Average values of 2%N for grasses and non-leguminous weeds and 3.3%N for legumes are recommended for legumes. These values assume the cover crops are vegetative or early flowering. We do not recommend using a canopy height and density method to estimate N content.

This project is expected to have clear economic and environmental benefits for agriculture. Cover crops are used by growers when their perceived benefits outweigh their costs. Use of cover crops enhance the ecosystem services provided by sustainable farms. These include reduced non-point source pollution, reduced soil erosion and improved soil quality. Some of these benefits of cover crops also benefit the individual farm, but they generally do not improve the economic competitiveness of the farm in the short term.

As a result of this study, MSF reported in 2008 that they reduced fertilizer application costs by 60% as a result of this work. David continues to see high yields and experienced lower insect pest pressure in 2008. SIO reported their best fall brassica crop ever with very little additional fertilizer in the trial area. Other collaborators had similar experiences.

Nitrogen contributions from cover crops can help growers save money spent on fertilizers. For organic growers these savings can be substantial since organic nitrogen sources cost between $3.00 and $5.00 or more per pound of available N. Growers in Oregon were not able to accurately estimate N contributions from their cover crops. This project appears to be identifying convenient and cost effective methods growers can use to estimate nitrogen contributions from mixed cover crop stands.

The cost of seeding and incorporating cover crops is estimated to be less than $40/acre, this estimate did not include the cost of irrigation (Seavert et al. 2007). Assuming a cover crop provides 50lbs plant available nitrogen to the subsequent crop, cover crop nitrogen costs around $0.80 per pound. Fuel prices have risen and fallen during the project causing the price of synthetic N to fluctuate from around $0.50 to over $1.00 per pound. Cover crops are an increasingly competitive N source for non-organic farms as the cost of synthetic fertilizer rises. If available N from NOP compliant fertilizer costs $4.00 per pound, and a cover crop provides 50lbs PAN/A at $0.80/lb, fertilizer savings can be more than $150/A. If these findings are implemented on 1000 new acres per year, project impacts would accumulate at the rate of $150,000 per year. The results from this study are being combined with a new project to provide the basis for a Cover Crop Calculator that predicts PAN from cover crops. Based on experience with the Organic Fertilizer Calculator, we are confident that the online Cover Crop Calculator will realize these impacts.

As growers adopt these testing methods, they will be better able to include nitrogen provided by cover crops in their fertility plans and reduce fertilizer expenses. Cover crops provide an alternative to manure (often the cheapest organic fertilizer). This is important since manures have a lower N/P ratio than required by crops. Therefore, if manure is applied in quantities required to supply sufficient nitrogen, phosphorous application rates are often excessive. As phosphorous builds in the soil, increased phosphorous pollution becomes more likely. This contributes to eutrophication of surface water.

Growers using reliable methods to estimate nitrogen contributions from cover crops will also be able to evaluate one important aspect of cover crop performance from year to year. This will give them the tools to improve cover cropping practices such as seed bed preparation, seeding date, seeding rate, irrigation, etc.. They will also be able to evaluate the performance of new cover crop species and mixtures over time. It is expected that when a grower has experience testing nitrogen contributions from preferred cover crop species, they will be able to make reasonable estimates of nitrogen contributions by visual assessment of the cover crop stand.

In addition to the direct benefits of the research, this project has also provided a forum for growers to discuss their cover cropping practices and has facilitated some detailed observations. It has also provided an opportunity for OSU faculty to work with organic farmers in the North Willamette Valley, this has been a previously underserved group. The use of rice hulls to improve cover crop stands is helpful when seeding mixtures that include seeds of different sizes, i.e. oats and crimson clover, phacelia and common vetch, etc.. Phacelia has generated some interest among participating growers since it provides an early spring flower that may enhance populations of beneficial insects, it appears to be easier to incorporate than grasses, and in 2007 and 2008 trials it provided thicker ground cover and more growth than any other species in the fall. It is more frost sensitive though and was damaged but survived when temperatures fell below about 18°F. Observations from this study indicate that maximum N accumulation in cover crops may be between 2,600 and 3,000 day degrees using a T_{base} of 32°F. The ability of cover crops to suppress weeds has been demonstrated, especially mixtures containing grasses.

Figure 29. Bumble bees and hover flies visiting phacelia flowers. Photos by Nick Andrews.

Figure 30. Mature cereal rye and common vetch cover crop at SIO, May 2008. Photo by Lynn Ketchum.

Figure 31. Cereal rye, common vetch and Austrian field pea cover crop with strong vetch stand, 20” canopy and estimated 155 lbs N/A and 50 lbs PAN/A. Photo by Nick Andrews.

Figure 32. Oats and common vetch cover crop with strong oat stand, 26” canopy and estimated 110 lbs N/A and 10 lbs PAN/A. Photo by Nick Andrews.

7. PUBLICATIONS AND OUTREACH

7.1 Grower meetings and conferences

Findings have been presented to participating growers at to project meetings. A farmer field day was held at Mustard Seed Farm on April 23, 2008. Nick Andrews presented the first year results of this project and gave a tour of the 2008 cover crop plots. John Luna gave a presentation on cover crops and conservation tillage methods. Dan Sullivan (OSU) participated in the discussions. An estimated 30 farmers attended including conventional and organic vegetable farmers and nursery operators, an ODA CAFO inspector and NRCS professional.

Figure 33. The 2008 field day at Mustard Seed Farm. Photos by Dan Sullivan.

Nick Andrews is incorporating the findings from this project and related work into presentations and workshops. The information is being incorporated into the new OSU Small Farms workshop series "Growing Farms" (http://smallfarms.oregonstate.edu). To date he has presented the work at the following conferences:

- Aspects of Nitrogen Management on Organic Farms: Cover Crops and the Organic Fertilizer Calculator. GS Long Company Inc. Organic Workshop January 8, 2009. Invited.
- Nitrogen Management and Cover Crops on Organic Farms. Pacific Northwest Vegetable Association. November 20th, 2008. Estimated 60 participants.

- Nutrient Management on Organic Farms. Oregon Association of Conservation Districts. November 1st, 2008. Estimated 60 participants.
- Nitrogen Management in Organic Seed Production: Shortcourse and presentation at Organic Seed Alliance Conference. Feb 13-15, 2008. Estimated 80 participants. Findings also incorporated in a separate talk by Jim Bronec (collaborating farmer).

7.2 Articles and publications

An article introducing the study has been published in *Oregon Small Farm News*, the OSU state-wide small farm newsletter: Andrews, N (2007). *Estimating Nitrogen & Dry Matter from Cover Crops*. Oregon Small Farm News **2**(1), p. 6 (http://smallfarms.oregonstate.edu/newsletter/). Content based on the results of this project has been prepared for the cover crop section of the new eOrganic website, a national eXtension website that is under development and expected to go online soon. The interim report from this project has been posted on http://smallfarms.oregonstate.edu/oregon-small-farms-technical-reports, and the final report will be posted there.

A cover crop mineralization model is being developed that will be incorporated into a cover crop calculator. The calculator will be based on this project and related field and lab tests from a new project that is now underway. When completed, a new OSU Extension Publication will be written, and the cover crop calculator will be posted online at: http://smallfarms.oregonstate.edu/.

Additional articles describing project results, recommended cover crop testing methods and the cover crop calculator will be submitted to *Oregon Small Farm News*, *In Good Tilth* and other publications.

8. FUTURE RECOMMENDATIONS

Preliminary results from the vegetables grown following the 2007/08 cover crops in this study demonstrate that nitrogen from soil mineralization and cover crops can provide sufficient nitrogen for vegetable crop production on farms that have built up active soil organic matter fractions. Additional work is needed to determine whether such reliance on cover crops is sufficient to maintain active organic matter within intensive vegetable rotations. If findings are to be adopted, such work should be done within the context of intensive vegetable rotations and should include an economic component whenever possible.

A mineralization model is already being developed to estimate cover crop PAN contributions to subsequent crops. Incorporation of day degrees into such a mineralization model would be useful.

Additional information is required on the contribution of cover crop roots and mineralization rates from different cover crops as they decompose. Another useful area of study is the evaluation of new cover crop species and varieties adapted to different regions. Research into the impact of cover crops on soil quality and pest management is useful.

Results from this study and the cover crop calculator could be included in other SARE publications including future revisions of Managing Cover Crops Profitably.

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