A novel approach for optimizing the benefits of cereal-legume cover crop mixtures in vegetable cropping systems under organic management

Final Report to the Ceres Trust Organic Research Initiative

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Abstract/Summary

The unique and complementary traits of cereal rye (*Secale cereale L.*) and the legume hairy vetch (*Vicia villosa Roth*) make winter annual cover crop mixtures of the two species promising for vegetable cropping systems. Informed management of the relative species proportions in the mixture could provide an important means of optimizing performance to serve various farmer goals. A variation of the replacement series experimental design was used to investigate 1) how relative species proportions (seeding rates) influence biomass characteristics of cover crop mixtures, and 2) the interactive effects of mixture residues and the use of black polyethylene mulch (PM) on cover crop mixture performance in bell pepper and slicing cucumber cropping systems. Although relative biomass yields of vetch in mixture can vary greatly with planting date, total residue C:N generally decreased with increasing proportion of vetch. All cover crop mixtures provided significant winter weed suppression, but incorporated residues exhibited little effect on subsequent summer weed communities. Cover crop mixtures with higher proportions of vetch generally resulted in higher soil nitrate concentrations during the growing season, but both the magnitude and duration of the increases in soil nitrate following cover crop incorporation were greater under PM than without. In general, total bell pepper and cucumber yields were higher following cover crop mixtures with greater proportions of vetch. However, total yields were uniformly higher for vegetables grown on PM. Our results suggest that PM may be an important tool for maximizing N fertility benefits from incorporated cover crop residues, but evaluations of overall mixture performance must ultimately be based on a systems-level consideration of the numerous services that cover crops can provide, as well as their relative costs.

Introduction

The environmental and economic sustainability of organic production rests largely on the application of ecological understanding to farm management. Within the general practice of cover cropping, a conservation technique widespread among organic growers, there is significant room for improving performance based on ecologically-informed management. Multi-species cover crop mixtures may provide a means of combining the strengths of different plant functional groups in a single field while also moderating their individual weaknesses. Cereal-legume cover crop mixtures are of particular interest because they provide the opportunity to effectively suppress weeds, control erosion, and scavenge leachable nitrate while also fixing atmospheric nitrogen.

Winter annual cover crop mixtures of cereal rye (*Secale cereale* L.) and the legume hairy vetch (*Vicia villosa* Roth) have shown promise in previous studies, and their winter hardiness makes them well suited for production in the Midwest. Alone, the notable ability of a rye cover crop to suppress weeds, scavenge residual nitrate, and control erosion is often tempered by the high C:N ratio of residues and the threat of subsequent yield losses due to nitrogen immobilization (Allison 1966, Wagger et al, 1998). Rye-vetch mixtures, however, have exhibited moderation of the total C:N ratio of residues without sacrificing benefits characteristic of rye, all while contributing significant amounts of fixed nitrogen to the system (Clark et al., 2007a, 2007b, 2007c; Ranells and Wagger, 1996, 1997a, 1997b; Teasdale and Abdul-Baki, 1998). In addition, total dry matter yields in rye-vetch mixtures can be greater than yields of either species in monoculture, and total N release from mixture residues can approach the amount released from vetch monocultures (Rannells and Wagger, 1996).

The performance of any 2-species cover crop mixture with respect to traits of interest (e.g. total biomass production and residue quality, weed suppression, nitrogen recycling and mineralization dynamics, and yields of subsequent crops) will theoretically vary along a continuum from 100% species A to 100% species B. For certain environmental conditions and farmer goals, an optimum mixture rate should exist somewhere between the two extremes, where the respective strengths of each species are balanced to provide maximum benefit. Few studies to date (Clark et al, 1994) have evaluated rye-vetch cover crops based on more than a single mixture proportion, and more thorough research on the relationship between mixture proportion and cover crop performance could ultimately lead to more-informed seeding rate recommendations that consider growing conditions, farmer goals and crop management practices.

The replacement series is an experimental design where treatments consist of a pure stand of each component species and a gradient of species mixtures, allowing the researcher to observe how species proportions influence interspecific competition and mixture performance. The design has been applied in agricultural contexts most often to evaluate crop-weed interactions and the performance of cash crop bicultures, but with appropriate interpretation, the design is also suited for investigating cover crop mixtures (Jolliffee, 2000).

The use of black polyethylene mulch (PM) is an industry standard for large-scale commercial organic and conventional production of bell peppers and slicing cucumbers. By distinctly altering the soil microclimate through increasing soil temperatures and improving retention of soil moisture derived from drip irrigation, PM may have a substantial effect on the relative performance of cover crop mixtures, particularly with respect to nutrient mineralization and leaching (Clarkson et al, 1960; Tarara, 2000). Because many smaller scale organic growers reject the use of PM based on economic and environmental grounds related to its use and disposal, results for cover crop performance derived under both management practices will provide for broader applicability across the spectrum of organic growers.

The overall objective of this study was to improve our understanding of how species proportions (based on seeding rates) of a mixture of cereal rye and hairy vetch influence cover crop performance in a vegetable production system with respect to crop grown and plastic mulch use. Performance was evaluated based on a systems-level approach to data collection, encompassing the following specific objectives:

1. *Quantify trends in cover crop establishment and total residue quantity and quality across rye-vetch mixture rates.*
2. *Study the effect of mixture rate on winter annual and summer annual weed populations.*
3. *Quantify trends in soil inorganic N dynamics across mixture treatments and PM use.*
4. *Evaluate the effects of mixture rate and PM use on soil microbial biomass and community functional diversity.*
5. *Evaluate the effects of mixture rate and PM use on vegetable yield and fruit quality.*

Materials and Methods

The study was conducted from 2009-2010 on a sandy soil at Michigan State University's Horticulture Teaching and Research Center (HTRC) in Holt, Michigan. Preliminary data was collected in 2008-2009. The experiment was a split-split plot randomized complete block design with 4 replications. The whole plot factor was cover crop mixture treatment, with levels following a proportional replacement series design including the following proportions of rye:vetch (by seeding rates): 100:0, 83:17, 67:33, 50:50, 33:67, 17:83, 0:100 and 0:0 (a no cover crop control). The rye monocrop was seeded at 94 kg/ha and the vetch monocrop at 42 kg/ha.

Table 1. Timeline of field activities, 2009-2010.

Activity	Date
Cover crops seeded	9/1/2009
Cover crop and winter weed density and biomass sampling	5/10/2010
Cover crop termination (by flail mower)	5/10/2010
Cover crop incorporation (by rototiller)	5/17/2010
Soil sampling (2-week intervals)	5/24/2010 – 8/16/2010
Bed preparation, pepper and cucumber transplanting	6/3/2010
Seeding of *Amaranthus powellii* and *Chenopodium album*	6/4/2010
Germination sampling	6/22/2010
Biomass sampling	7/9/2010
Summer field weed community sampling	6/28/2010
Cucumber harvests	7/12/2010 – 8/2/2010
Pepper harvests	7/27/2010 – 8/31/2010

The subplot factor was cash crop, with two levels: bell pepper (*Capsicum annum*) and slicing cucumber (*Cucumis sativus*). The sub-subplot factor was black polyethylene mulch (PM) use, with two levels: crop grown with or without PM. Following cover crop kill by flail mowing and residue incorporation by rototilling in the spring, two rows of each crop were grown during the summer in each main plot, with one row grown on PM and one row grown on bare ground.

All aspects of field management were carried out in accordance with USDA organic guidelines. Bell pepper and slicing cucumber were chosen for inclusion in the study because of industry significance, their common culture on PM, and as model crops for evaluation of the cover crop mixtures due to their contrasting nutrient requirements and timing of peak nutrient demand.

Figure 1. Cover crop seeding by hand using grid system (image enhanced to highlight location of guide strings).

Cover crop treatments were broadcast sown by hand on 1 September 2009 into 6.1 x 7.6 m (20 x 25 ft) whole plots and lightly incorporated to a depth of 5 cm. A grid system was used during seeding to help ensure uniformity (**Figure 1**).

Cover crop density by species and both above- and below-ground biomass were sampled on 10 May 2010 (prior to kill) from 4 20x25 cm quadrats in each whole plot. Roots and shoots were subsequently separated and dried. Dry weights were measured, and samples of shoot biomass were analyzed for total carbon and nitrogen. Cover crops in the field were flail mowed 10 May 2010 and incorporated into the soil using a rototiller 17 May 2010.

Figure 2. Bell pepper grown with and without plastic mulch in 2010, following vetch monoculture cover crop treatment. Cucumber bed is visible to the left.

At the time of cover crop biomass sampling, winter annual weed density and biomass were also sampled from the 4 quadrats in each whole plot. Total weed density and dry weight were measured for all treatments. Following cover crop incorporation and cash crop establishment, total summer weed density and species composition was sampled on 28 June 2010 from 2 20x25 cm quadrats established in each non-plastic pepper row. In addition, supplemental seeds of the summer annual weed species *Chenopodium album* (common lambsquarters) and *Amaranthus powellii* (powell amaranth) were sown into 70 cm rows in each whole plot at the time of crop transplanting. Germination rate was quantified by counting and removing germinated seedlings on 22 June 2010. Ten seedlings of each species were left in each row to grow for 4 weeks, followed by harvest and average biomass dry weight measurement.

Bell pepper (variety *Paladin*) and slicing cucumber (variety *Cobra*) transplants were grown in the greenhouse according to organic practices prior to field transplanting on 3 June 2010. Bell peppers were grown in staggered double rows (18 inch plant spacing and 12 inch inter-row spacing) with each treatment (cover crop mixture x PM use) consisting of 20 data plants. Slicing cucumbers were grown in single rows (18 inch plant spacing) with each treatment containing 12 data plants. Both PM and no PM crop rows were drip irrigated and otherwise managed according to accepted commercial organic practices. Following vegetable harvests, fruit was graded according to market specifications and average yields were quantified in terms of fruit number and weight.

Figure 3. Field overviews showing cover crop treatments in May 2010 (top) and bell pepper and cucumber growing with and without plastic mulch in July 2010 (bottom).

Composite soil samples were collected from each whole plot prior to cover crop seeding and following cover crop incorporation. In addition, soil samples were collected bi-weekly throughout the 2010 growing season from each treatment (cover crop mixture x PM use) for bell pepper rows, omitting cucumber rows in the interest of time constraints and costs of analysis. All soil samples were analyzed for NO_3^- and NH_4^+ concentration by extraction with 1 M KCl and subsequent colorimetric analysis.

Subsamples of soil collected on 21 June 2010 (3 weeks following bed preparation and transplanting) from PM and no PM treatments within pepper rows for select cover crop mixture treatments (Rye:Vetch 100:0, 50:50, 0:100, and 0:0) were used for microbial analyses. Soils were transported from the field and stored at 4°C until analysis. After sieving, soil microbial biomass carbon was estimated in the lab following the chloroform fumigation-incubation (CFI) method as described in Horwath et al (1996), and functional diversity of microbial communities was evaluated through community-level physiological profiling (CLPP) using Biolog EcoPlates™ (Garland, 1997; Stefanowicz, 2006).

Results and Discussion

1. Quantify trends in cover crop establishment and total residue quantity and quality across rye-vetch mixture rates.

As expected, rye and vetch seeding rates were highly correlated with observed field densities (**Figure 4**, top). In 2010, spring densities across mixture treatments varied from 0 to 137 plants/m^2 for vetch and 0 to 268 plants/m^2 for rye. Data on the effects of mixture rate on relative establishment and winter survival for each species are currently being analyzed.

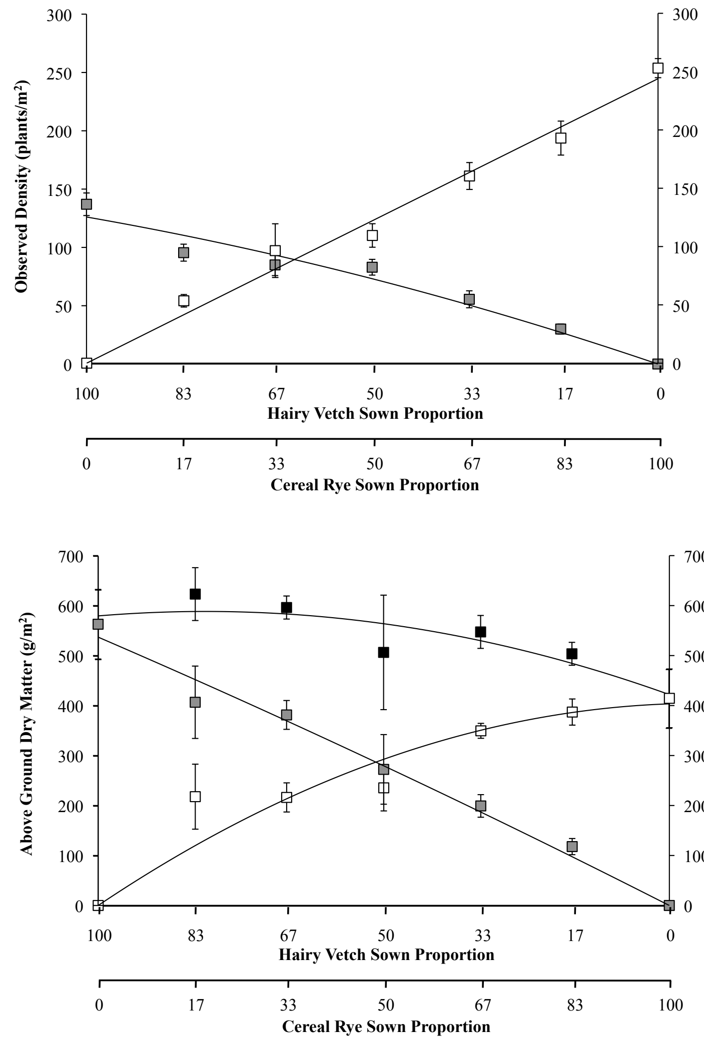

Figure 4. Observed density (top) and biomass production (bottom) for vetch (gray squares), rye (white squares) and species total (black squares) across cover crop mixture treatments. Treatment means presented ±SE.

Total cover crop biomass yields across mixture proportions also followed a gradient generally intermediate to the vetch and rye monoculture yields (**Figure 4**, bottom). However, total cover crop residue quality varied significantly across mixture treatments. The total amount of N in the cover crops (vetch and rye combined) generally increased with higher proportions of vetch in mixture while the total residue C:N generally decreased (**Table 2**). All mixture treatments, with the exception of the rye monoculture, had total residue C:N less than 30:1.

It is interesting to note that relative biomass yields of vetch across mixtures varied greatly between the 2009-2010 experiment and preliminary data collected in 2008-2009. While monoculture dry matter yields of 5030 lb/A were observed in 2010 after a 1 September planting date (**Figure 3**), vetch monocultures only yielded 950 lb/A on average in 2009 after a late 29 September planting date (data not presented). Rye biomass production was less sensitive to planting date, yielding 3320 lb/A and 3700 lb/A in monoculture in 2009 and 2010, respectively.

Table 2. Total cover crop residue shoot N content and C:N across mixture proportions.

Cover Crop Treatment	Total Residue N	Total Residue C:N
	kg/ha	
100 HV : 0 R	175.4	11.2
83 HV : 17 R	151.9	15.4
67 HV : 33 R	142.2	15.2
50 HV : 50 R	110.5	17.2
33 HV : 67 R	102.0	20.6
17 HV : 83 R	76.1	25.1
0 HV : 100 R	38.4	41.7

Changing species proportions in a cereal-legume mixture has the potential to alter competitive dynamics in ways that could influence patterns of total density and biomass production in the resulting cover crop stands. Various facilitative mechanisms have been proposed for cereal-legume mixtures, including improved winter survival and nitrogen fixation for the legume and increased growth and nitrogen economy for the cereal (Smith, 1975; Giller and Cadisch, 1995). Possible support for these mechanisms is currently under investigation, but for the most part, our data suggests that the proportion of each species sown in mixture is a good predictor of species proportions (for both density and biomass) in the resulting cover crop stands. However, other management decisions, particularly planting date, can also have profound impacts on the biomass composition of rye-vetch mixtures.

2. Study the effect of mixture rate on winter annual and summer annual weed populations.

Table 3. Effect of cover crop mixture proportion on winter weed density and biomass dry weight.

Cover Crop Treatment	Density	Dry Weight
	plants/m²	*g/m²*
Control	584.0	144.12
100 HV : 0 R	162.5	14.82
83 HV : 17 R	214.5	20.99
67 HV : 33 R	191.0	14.33
50 HV : 50 R	184.5	11.81
33 HV : 67 R	187.5	8.22
17 HV : 83 R	147.0	9.79
0 HV : 100 R	94.0	7.47

All cover crop treatments significantly suppressed winter weed populations, with average density reductions ranging from 63 to 84 percent, and reductions in average weed biomass per plant from 65 to 76 percent, compared to the no cover crop control (**Table 3**). Among the cover crop treatments, those containing greater proportions of rye tended to exhibit lower winter weed densities and biomass.

However, no significant cover crop effect was observed on the total density of native field populations of summer weeds sampled 5 weeks following cover crop incorporation (**Table 4**). Similarly, the germination of sown seeds of *Amaranthus powellii* and *Chenopodium album* were not significantly affected by cover crop treatment. Cover crop influence on average biomass production of the two species was also not significant, though variability in the data may be masking real effects (**Table 5**).

Table 4. Effect of cover crop mixture on summer weed density.

Cover Crop Treatment	Density
	plants/m²
Control	830.0
100 HV : 0 R	884.0
50 HV : 50 R	968.0
0 HV : 100 R	727.0

Table 5. Effect of cover crop mixture on sown summer weed species germination and biomass dry weight.

	Amaranthus retroflexus		*Chenopodium album*	
Cover Crop Treatment	Germination	Dry Weight	Germination	Dry Weight
	# plants	*g/plant*	*# plants*	*g/plant*
Control	91.5	0.57	19.8	0.52
100 HV : 0 R	107.8	0.78	16.8	0.59
83 HV : 17 R	109.0	0.77	32.3	1.13
67 HV : 33 R	93.3	1.15	29.3	1.37
50 HV : 50 R	80.3	0.57	24.3	0.52
33 HV : 67 R	56.3	0.64	23.8	0.63
17 HV : 83 R	105.8	0.67	19.5	0.32
0 HV : 100 R	71.3	0.27	19.8	0.25

Our results demonstrate that the living cover crops are excellent weed suppressors, and mixtures with higher proportions of rye tended to provide greater control. Interestingly, these mixtures also exhibited lower light interception (less shading of the soil surface; data not presented), suggesting that weed suppression from rye is likely derived in large part from allelopathic effects and/or the depletion of soil resources (water and nutrients). However, the practical effectiveness of incorporated residues at suppressing weeds during the growing season (through allelopathy or nitrogen effects on weed germination and/or growth, for example) appears to be minimal.

3. Quantify trends in soil inorganic N dynamics across mixture treatments and PM use.

Cover crop mixtures with higher proportions of vetch generally resulted in higher soil nitrate concentrations over the course of the summer, though the general pattern of nitrate availability over time appeared to be largely unaffected by the mixture proportion. Soil nitrate concentrations following the rye monoculture were lower than for the no cover crop control. However, both the magnitude and duration of the increases in soil nitrate following cover crop incorporation were overall greater under PM than without (**Figure 5**).

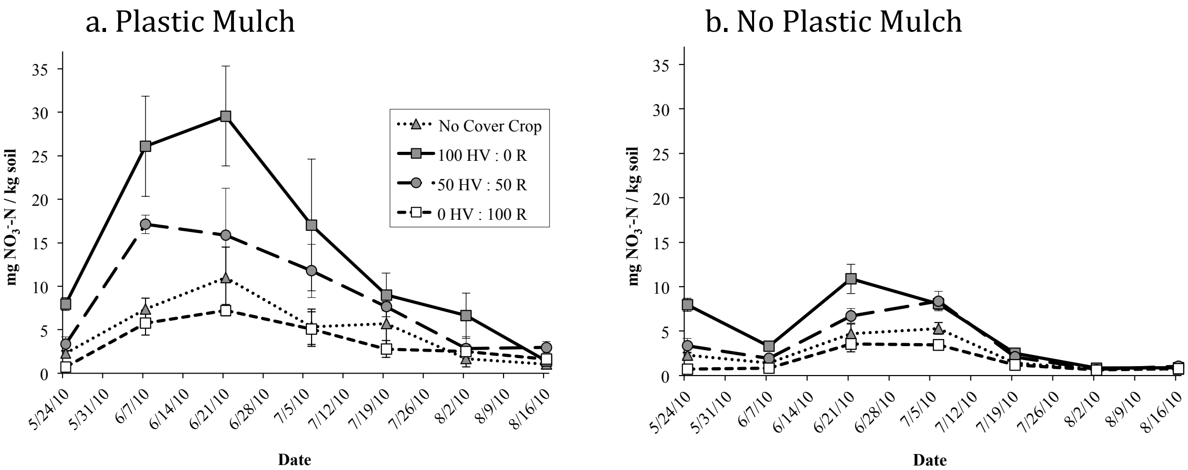

Figure 5. Effect of cover crop mixture on soil nitrate concentrations during summer 2010 under PM (a) and without PM (b). Treatment means presented ± SE.

The effect of mixture treatment on soil nitrate concentrations generally reflects the differences in total N content of the cover crop residues. Furthermore, the rye monoculture was the only cover crop treatment with a total residue C:N greater than 30:1, suggesting that N immobilization may also be playing a role in the low soil nitrate concentrations observed following that treatment. The general increases in soil nitrate concentration observed with PM are likely due to a combination of higher mineralization rates and lower rates of nitrate leaching under PM. Our results suggest that PM can be an important tool for maximizing fertility benefits from incorporated cover crop residues, particularly for high N, readily decomposable materials like hairy vetch. Additional research is needed to evaluate the relative nitrate leaching risk across rye-vetch mixture proportions, as well as the extent to which it is mitigated by PM use.

4. Evaluate the effects of mixture rate and PM use on soil microbial biomass and community functional diversity.

The microbial community data are currently being analyzed; however, preliminary review has revealed lower estimates for microbial biomass under PM compared to bare soil at the chosen sampling date (data not presented). The implications of this finding are under investigation.

5. Evaluate the effects of mixture rate and PM use on vegetable yield and fruit quality.

In general, total yields of both bell pepper and cucumber tended to be higher following cover crop mixtures with greater proportions of vetch, though some practical yield consistency was observed across cover crop treatments containing greater than 50 percent vetch, particularly for cucumber. All cover crop treatments, with the exception of the rye monoculture, produced average yields numerically greater than the no cover crop control. PM use had a considerable effect on vegetable yields—peppers and cucumbers grown on PM yielded more than twice as much as those grown without PM for most cover crop treatments (**Figure 6**).

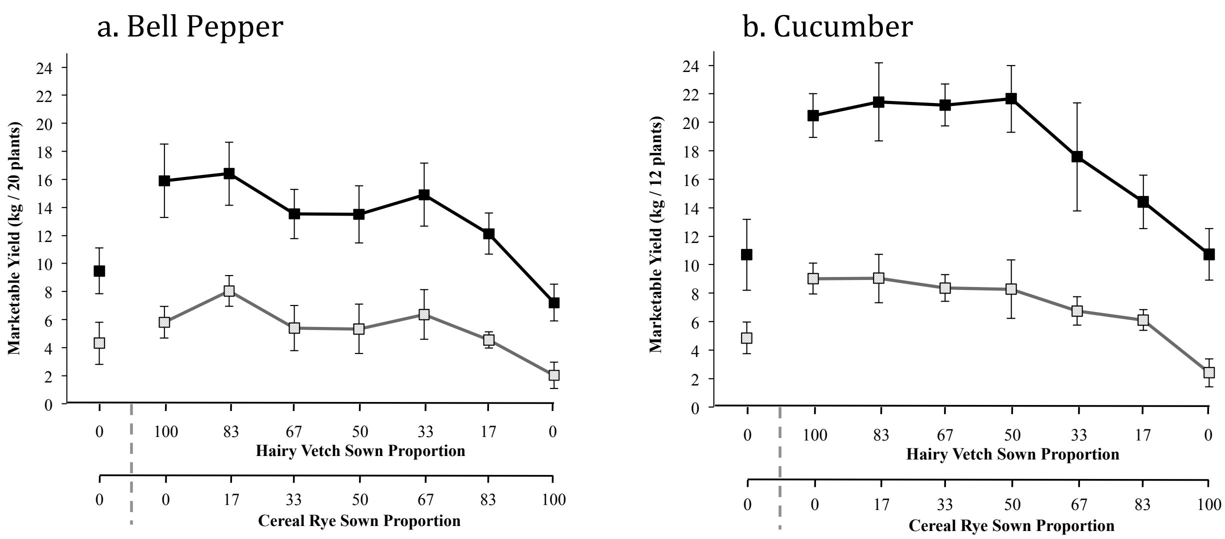

Figure 6. Effect of cover crop mixture proportion on total marketable yield for (a) bell pepper and (b) slicing cucumber grown on PM (black squares) and without PM (gray squares). Treatment means presented ± SE.

These yield results appear to mirror the previously presented soil nitrate data, particularly with respect to the effect of PM. The correlation suggests that nitrogen fertility is likely a dominant mechanism behind the yield increases observed with PM use. Similarly, the total N content of the cover crop residues is likely a driving factor in the effect of the cover crop mixture on vegetable yields. A partial budget analysis would be useful in quantifying the relative economic benefits of any observed yield gains across the various cover crop mixtures and PM use. Where practical yield consistency is observed across mixture proportions, the lowest proportion of vetch would likely be preferable due to the higher cost of vetch seed. Yield consistency across high vetch cover crop treatments appears to be more pronounced for cucumber than for pepper. This may be due to the shorter duration of the cucumber crop and an earlier peak demand for N that better coincides with the timing of peak availability in the soil.

Conclusions and Project Outputs

Perhaps more than any other agricultural sector, continued increases in the profitability and environmental sustainability of organic agriculture depend on furthering our knowledge of ecological cycles and their operation within cropping systems. In the case of rye-vetch cover crop mixtures— weather, soil conditions, plant competition, and dynamics of organic matter decomposition all interact with our management decisions (including species proportion sown, plastic mulch use, and cash crop grown) to determine performance outcomes. Predicting these outcomes in the face of environmental variability is a challenging task, but a greater understanding of how such management decisions broadly affect services within a production system is a first step toward more-informed and adaptive seeding rate recommendations that consider site-specific conditions, farmer goals, and crop management practices. Taking a systems-level approach to data collection, our research is contributing to this goal while also educating the scientific and grower communities of our findings. **Table 6** provides an outline of notable project outputs to date.

Table 6. Project outputs—scholarly and educational products disseminated to date.

Conference Presentations
- 2010 International Horticulture Congress, Lisbon, Portugal - 2010 Great Lakes Fruit, Vegetable, and Farm Market Expo, Grand Rapids, MI - 2011 Weed Science Society of America (WSSA) Annual Meeting, Portland, OR
Publications
- Hayden, Z.D., Ngouajio, M., and Brainard, D.C. 2010. Investigating component species proportions in a cereal-legume cover crop mixture under organic management. *Acta Horticulturae*. *In review*.
Field Tours
- 2011 Ag Expo Organic Tour, Michigan State University, 20 July, 2011. 40 farmers, gardeners, and researchers in attendance.

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