The Ceres Trust Organic Research Initiative

Project title: Keystone Cover Crop Species: Understanding the Relative Contribution of Individual Species to Soil Health

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Non-technical Executive Summary:

Cover crop mixtures are popular among farmers because of the perception that mixtures will provide a greater quantity and quality of ecosystem services. We know that **c**over crop biomass is usually greater in diverse mixtures compared to component monoculture plantings, but information about ecosystem services provided by cover crop mixtures is lacking. The objective of this study was to assess the relative contribution of 18 cover crop species to mixture productivity and ecosystem services including, soil microbial activity, soil nitrogen retention, nitrogen fixation, and weed suppression. Six individual cover crop species and all possible five-way mixture combinations of those species were planted in each of three possible rotational phases (spring, summer, and fall) on two organic vegetable farms in central and northern Illinois. Soil microbial activity was sometimes greater in cover-cropped plots compared to bare fallow, but did not vary by species or mixture composition. After eight weeks of growth, cover crops reduced soil nitrate by up to 70% compared to bare fallow, but again, there was no difference among species or mixture composition. Legume root nodule biomass per plant was usually not different between legume monocultures and mixtures; however, legume shoot biomass often decreased in mixture indicating the potential for reduced nitrogen fixation. Mustard, sudangrass, buckwheat, and tillage radish were among the most weed suppressive species when planted in monoculture, and when these species were removed from five-way mixtures, weed biomass increased (suggesting species-specific contributions to weed suppression in mixtures). We did not detect allelopathic weed suppressive benefits of any species or mixture one month after residue incorporation in soil. Results from this study suggest that farmers can choose the least expensive cover crop species or mixture when the primary objective is to retain soil nitrogen or stimulate microbial activity. However, when the primary objective is weed suppression, farmers should carefully design cover crop mixtures to ensure weed suppressive species are included.

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Final Report

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Introduction

Cover crops are known to have beneficial effects on cropping systems and are a relatively low-input alternative to conventional methods for improving soil health and weed suppression. However, there is a need for research on how strong these effects are and how interactions among cover crop species may influence the system. The objective of this study was to characterize the effects of 5-way cover crop mixtures on soil fertility, soil microbial communities, plant biomass production and weed suppression compared to cover crop monocultures to help determine which species, called "keystone" species, have the largest overall effect on the system. A total of eighteen cover crop species were studied: six species for spring, summer, and fall each. Specifically, these treatments were evaluated for the following:

- Ability to recover soil nitrogen
- Nitrogen fixation capacity of legume species
- Productivity of each species in mixture and monoculture
- Weed suppressive capacity of soils after cover crop incorporation
- Influence on soil microbial activity

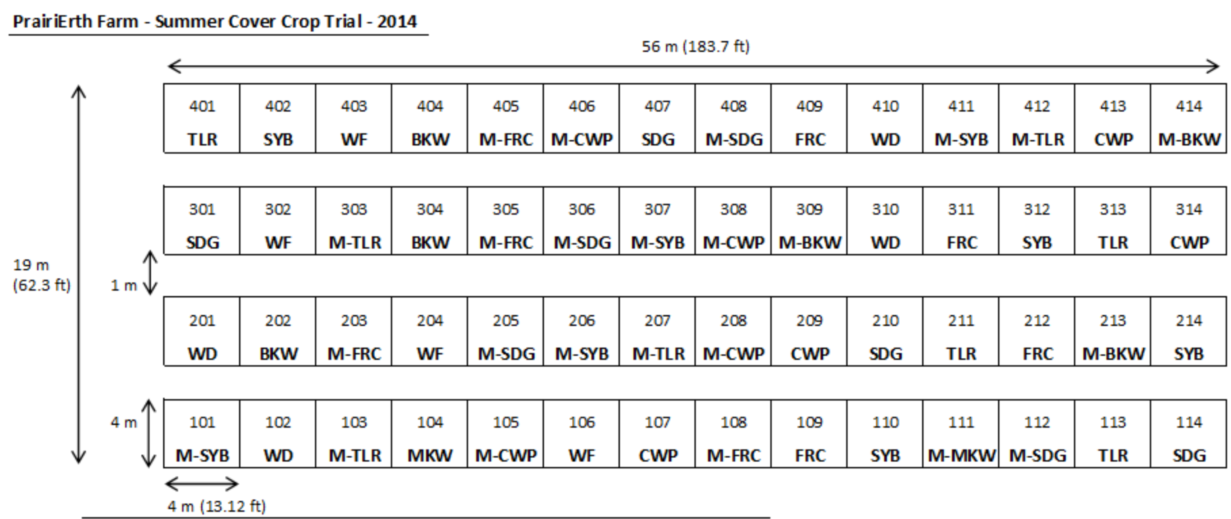
Ultimately, we wish to identify the *keystone cover crop species* that provide the greatest quantity and quality of positive soil health outcomes relative to the cost of the seed.

Research Activities

Table 1: Cover crop species tested in each rotation phase along with seeding rate used and cost for certified organic or non-treated seed.

Common name	Scientific name	Seeding rate	Seed cost[#]
Spring		-lb/acre-	-$/acre-
Oats – OAT	*Avena sativa*	150	141
Spring wheat – SPW	*Triticum aestivum*	100	144
Idagold mustard – MUS	*Sinapis alba*	10	33
Purple top turnip – PTT	*Brassica campestris*	4	8
Field pea – PEA	*Pisum sativum*	100	235
Faba bean – FAB	*Vicia faba*		
Summer			
Sudangrass – SDG	*Sorghum bicolor var. Sudanese*	40	102
Forage corn – FRC	*Zea mays*	25	25
Tillage radish – TLR	*Raphanus sativus*	15	50
Buckwheat – BKW	*Fagopyrum sagittatum*	60	86
Soybean – SYB	*Glycine max*	100	144
Cowpea – CWP	*Vigna unguiculata*	50	72
Fall			
Cereal rye – RYE	*Secale cereal*	120	88
Triticale – TRI	*x. Triticosecale*	100	150
Forage kale – KAL	*Brassica napus*	6	30
Yellow blossom clover – CLO	*Melilotus officinalis*	10	22
Hairy vetch – VCH	*Vicia villosa*	40	138
Austrian winter pea – WPE	*Pisum sativum*	100	235

Treatments for each season were composed of monocultures of each cover crop, all possible five-way combinations of crops, a weedy control, and a weed-free control. Treatments were planted in a randomized complete block design with four replicate blocks. Weedy treatments are annotated with "WD" and weeded treatments are annotated with "WF." WD plots were left unmanaged through each planting and WF plots were kept weeded with tillage (BCS tiller) 1 or 2 times each trial. Cover crops were planted in spring, summer, and fall of 2014 and 2015, and in spring and summer of 2016. All seed was broadcast by hand and mechanically incorporated to improve seed to soil contact.



	Treatments		Seeding rate (g/plot)	
			MONO	MIX
1	**SDG**	Sudan Grass	71.7	14.3
2	**FRC**	Silage Corn	71.7	14.3
3	**TLR**	Tillage Radish	26.9	5.4
4	**BKW**	Buckwheat	89.7	17.9
5	**SYB**	Soybean	134.5	26.9
6	**CWP**	Cowbean	89.7	17.9
7	**M-SDG**	5-way mix minus sudan grass		
8	**M-FRC**	5-way mix minus silage corn		
9	**M-TLR**	5-way mix minus tillage radish		
10	**M-BKW**	5-way mix minus buckwheat		
11	**M-SYB**	5-way mix minus soybean		
12	**M-CWP**	5-way mix minus cowpea		
13	**WD**	Weedy control		
14	**WF**	Weed free control		

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Figure 1: Plot map from PrairiErth Farm, summer 2014.

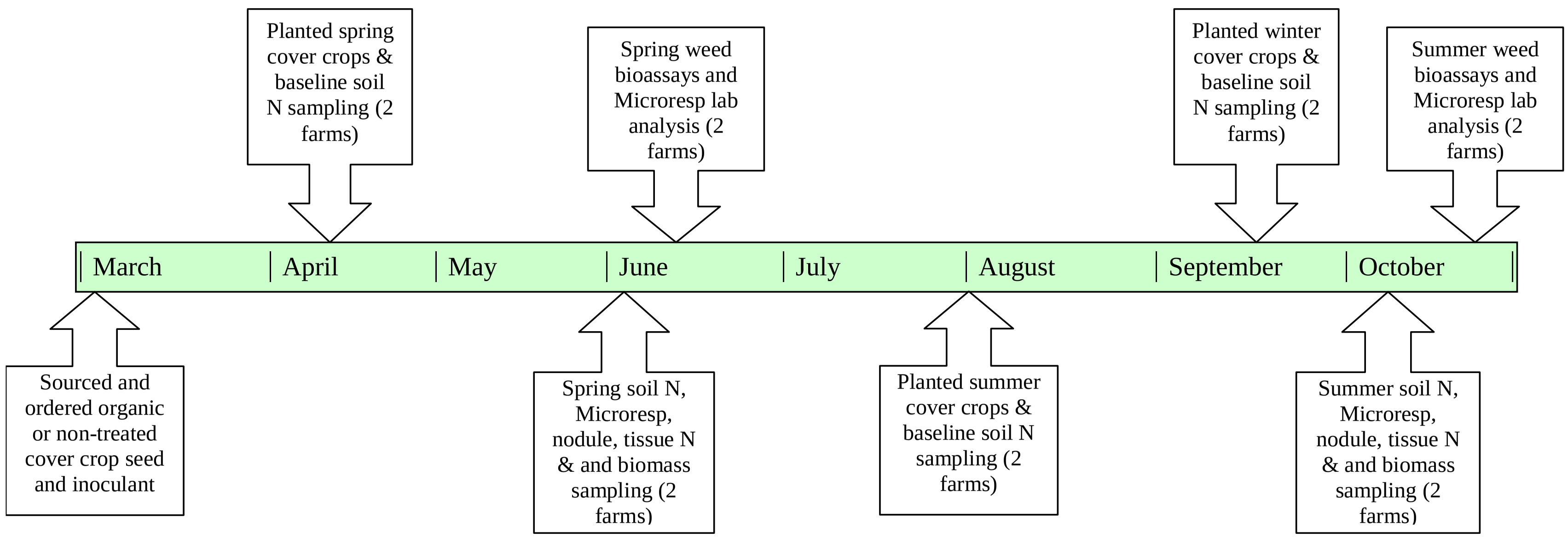
Cultipacking after planting the summer trial at Kinnikinnick Farm in August 2015

For each cover crop trial, the following was analyzed for each treatment: soil nitrate nitrogen before planting, during crop growth, and after incorporation; soil microbial respiration; weed suppression via ragdoll soil bioassays; fresh and dry plant biomass; plant tissue nitrogen; and root nodule counts and biomass for legume species in each mixture. Soil and plant tissue N analysis was conducted by Midwest Laboratories and Ward Laboratories. Soil microbial respiration was assessed with the MicroResp colorimetric method. Fresh biomass was sampled with two 0.5 m^2 quadrats placed at random in plots by cutting aboveground biomass to within 2 inches above the soil surface, separating biomass out by species (weeds were separated into a general weed collection bag), and weighed on site. Samples were then dried in paper bags on the UIUC campus for 10 days and then weighed. Weed suppression was measured through the ragdoll weed bioassay method. Root nodules were sampled by selecting three individual legumes per plot for removal with a 4" diameter golf-hole cutter to a depth of 6". Roots were washed in the lab, and nodules were removed, counted, dried and weighed. Earthworm casts were not counted in this study due to tillage practices on both farms; both farmers have used rototillers frequently in our plot areas, which has resulted in negligible earthworm populations. Field maintenance was conducted biweekly to mechanically maintain weeded alleys and "weed free" plots. See timeline below for more details about the timing of field and lab work during the study.

Incorporating fall cover crop at PrairiErth Farm with rakes in September 2014

Plot maintenance at PrairiErth Farm using a Honda FG110 mini-tiller

Annual Ceres Trust Project Timeline



Research Project Results

Cover Crop Biomass and Competitive Weed Suppression

Mustard [*Brassica juncea* (L.) Czern.] and oat (*Avena sativa* L.) were among the most productive (as much as 4.48 and 3.95 Mg ha^{-1}, respectively) and weed suppressive spring cover crops (Tables 2-4). In two of five site-years, excluding mustard from five-way mixtures resulted in increased weed biomass. This suggests that the weed suppressive benefits of mustard we observed in monoculture were transferred, at least to some degree, when planted in diverse mixtures. Sudangrass (*Sorghum bicolor* L. *ssp. Drummondii*) and buckwheat (*Fagopyrum sagittatum* Moench) were typically the most productive summer cover crops (as much as 8.78 and 7.11 Mg ha^{-1}, respectively) and also reduced weed biomass. In two of six site-years, excluding sudangrass from the mixture led to increased weed biomass. As with mustard, this result suggests sudangrass may be a *keystone cover crop species* because the weed suppressive potential of the mixture collapses in its absence. Forage radish (*Raphanus sativus* L.) had less aboveground biomass, but reduced weed biomass by 45% to 100%. Fall cover crop establishment was only successful in one of four site years and could not be statistically analyzed. In general, the only tested species that over-wintered were rye, triticale, and hairy vetch (and biomass was not different among these species); thus, ecosystem services and soil health could not be reliably measured in five-way mixtures because at least two species were absent in each stand.

Spring and summer cover crop species that suppressed weeds well in monoculture also drove weed suppression in mixture. Many of the weed suppressive species were also productive and dominated mixtures, as indicated by partial land equivalent ratios (pLERs), which reduced weed biomass in the mixture community. In contrast, excluding weed suppressive monoculture species from mixtures often led to increased weed biomass. Understanding the ecosystem services provided by individual species within a mixture is important for designing cover crop mixtures. Results suggest that if weed suppression is a primary management goal, the cover crop mixture should contain productive species that thrive under conditions of interspecific competition, as demonstrated by high pLER values in mixture. Species exhibiting these ideal traits included mustard and oat in the spring, and sudangrass, buckwheat, and forage radish in the summer. While species-specific benefits of mixture components are often advertised by cover crop seed companies and advocates, these results are among the first to document species-specific contributions to biomass productivity and weed suppression in diverse cover crop mixtures.

Table 2: Aboveground biomass of all mixture and monoculture cover crop treatments and weeds, and the proportion of weed biomass (%) relative to the total community for spring and summer 2014 trials at PrairiErth and Kinnikinnick Farms in central and northern Illinois, respectively. Different letters within a column for each season indicate differences among treatment means.

		PrairiErth			Kinnikinnick		
Season	Species/Mix	Cover crop ($Mg\ ha^{-1}$)	Weeds ($Mg\ ha^{-1}$)	Weeds (%)	Cover crop ($Mg\ ha^{-1}$)	Weeds ($Mg\ ha^{-1}$)	Weeds (%)[z]
Spring	Oat	3.09 ab	1.02 bc	[z] 24.7 abcd	3.45 a	0.58	[z] 14.3 b
	Spring wheat	2.77 ab	0.48 bc	14.8 bcd	2.09 ab	0.76	26.8 ab
	Mustard	4.48 a	0.08 c	1.8 d	0.17 b	0.55	76.1 a
	Purple top turnip	3.27 ab	0.36 c	10.0 cd	0.08 b	2.27	96.5 a
	Faba bean	0.17 b	3.47 a	95.4 a	1.22 b	1.96	61.7 a
	Field pea	1.57 ab	2.11 ab	57.4 ab	1.53 ab	1.82	54.4 ab
	Mix-Oat	3.37 ab	0.24 c	7.0 bcd	1.44 ab	0.78	34.9 ab
	Mix-Wheat	4.00 a	0.22 c	5.3 cd	1.75 ab	1.08	38.2 ab
	Mix-Mustard	2.36 ab	0.99 bc	29.6 abc	1.81 ab	0.50	21.7 ab
	Mix-Turnip	4.27 a	0.10 c	2.4 d	2.02 ab	0.44	17.8 ab
	Mix-Faba	3.76 a	0.18 c	4.5 cd	1.99 ab	1.12	36.1 ab
	Mix-Pea	3.30 ab	0.79 bc	25.3 abcd	1.35 ab	0.46	25.5 ab
	Weedy control	-	2.99 a	-	-	1.54	-
	SE [y]	0.71	0.36	-	0.49	0.53	-
Summer	Forage corn	4.22 ab	2.66 abc	[z] 38.6 abcd	3.46 ab	1.60 abc	[z] 31.6 ab
	Sudangrass	8.78 a	0.79 c	8.3 de	3.42 ab	0.68 bc	16.6 bc
	Buckwheat	5.13 ab	0.31 c	5.7 e	4.63 a	0.51 bc	9.9 c
	Forage radish	0.68 b	1.91 abc	73.7 ab	2.27 abc	0.64 bc	21.9 bc
	Cowpea	0.71 b	3.42 ab	82.9 a	0.18 c	2.36 a	92.9 a
	Soybean	0.68 b	4.32 a	86.4 a	0.62 bc	1.86 ab	74.8 a
	Mix-Corn	4.78 ab	1.32 bc	21.6 abcde	3.69 a	0.65 bc	15.0 bc
	Mix-Sudan	2.28 b	1.77 bc	43.8 abc	2.28 abc	0.88 bc	27.8 abc
	Mix-Buck	4.55 ab	0.76 c	14.3 cde	2.56 abc	0.67 bc	20.9 bc
	Mix-Radish	4.98 ab	1.32 bc	21.0 abcde	3.79 a	0.92 bc	19.6 bc
	Mix-Cowpea	5.21 ab	1.44 bc	21.7 abcde	3.52 ab	0.44 c	11.1 bc
	Mix-Soybean	4.67 ab	1.09 bc	18.9 bcde	2.91 abc	0.62 bc	17.6 bc
	Weedy control	-	3.47 ab	-	-	2.41 a	-
	SE [y]	1.04	0.47	-	0.71	0.28	-

Table 3: Aboveground biomass of all mixture and monoculture cover crop treatments and weeds, and the proportion of weed biomass (%) relative to the total community for spring and summer 2015 trials at PrairiErth and Kinnikinnick Farms in central and northern Illinois, respectively. Different letters within a column for each season indicate differences among treatment means.

		PrairiErth			Kinnikinnick		
Season	Species/Mix	Cover crop ($Mg\ ha^{-1}$)	Weeds ($Mg\ ha^{-1}$)	Weeds (%)	Cover crop ($Mg\ ha^{-1}$)	Weeds ($Mg\ ha^{-1}$)	Weeds (%)
Spring	Oat	3.66 ab	0.68 c	[z] 15.8 ab	2.03 ab	1.97 ab	[z] 49.2 abcd
	Spring wheat	2.72 abc	0.56 c	17.0 ab	1.36 bc	0.89 ab	39.6 abcd
	Mustard	3.27 ab	0.31 c	8.8 b	3.33 a	0.57 b	14.6 e
	Purple top turnip	1.30 bc	1.54 bc	54.4 ab	1.18 bc	1.11 ab	25.6 cde
	Faba bean	0.54 c	3.04 ab	84.9 a	0.16 c	2.03 ab	92.3 a
	Field pea	1.36 bc	1.82 bc	57.2 ab	0.62 bc	1.90 ab	75.4 ab
	Mix-Oat	3.06 abc	1.15 c	27.2 ab	2.08 ab	0.88 ab	29.8 bcde
	Mix-Wheat	2.67 abc	0.51 c	16.1 b	2.13 ab	1.52 ab	41.6 abcde
	Mix-Mustard	1.87 abc	1.42 bc	43.2 ab	1.61 bc	1.43 ab	47.0 abc
	Mix-Turnip	2.98 abc	0.64 c	17.7 ab	2.27 ab	0.51 b	18.5 de
	Mix-Faba	2.65 abc	0.79 c	23.0 ab	2.07 ab	0.90 ab	30.4 abcde
	Mix-Pea	4.23 a	0.61 c	12.6 b	1.51 bc	0.91 ab	37.5 abcde
	Weedy control	-	4.04 a	-	-	2.31 a	-
	SE [x]	0.59	0.35	-	0.36	0.45	-
Summer	Forage corn	0.73 bc	3.09 ab	[y] 80.8 ab	1.33 b	2.28 a	[z] 63.1 ab
	Sudangrass	4.63 a	1.14 b	19.7 b	2.59 ab	1.39 ab	34.9 abcde
	Buckwheat	1.20 bc	2.70 ab	61.3 ab	3.60 a	0.48 b	11.7 ef
	Forage radish	1.58 abc	1.29 b	45.0 ab	2.32 ab	0.28 b	10.7 f
	Cowpea	0.38 c	3.28 ab	89.6 a	1.39 ab	1.61 ab	53.8 abc
	Soybean	0.56 c	2.46 ab	81.5 a	0.93 b	2.41 a	72.3 a
	Mix-Corn	1.91 abc	1.48 b	43.6 ab	2.73 ab	0.73 b	21.1 abcdef
	Mix-Sudan	1.27 bc	2.13 ab	62.6 ab	3.08 ab	0.60 b	16.4 cdef
	Mix-Buck.	3.26 abc	1.37 b	29.6 ab	2.74 ab	0.75 b	21.5 abcdef
	Mix-Radish	3.76 ab	1.52 b	28.8 ab	2.34 ab	1.34 ab	36.4 abcd
	Mix-Cowpea	2.67 abc	1.51 b	39.1 ab	2.82 ab	0.72 b	20.4 bcdef
	Mix-Soybean	2.07 abc	1.29 b	38.5 ab	3.06 ab	0.47 b	13.4 def
	Weedy control	-	4.08 a	-	-	2.18 a	-
	SE [x]	0.64	0.61	15.8	0.51	0.29	-

Table 4: Aboveground biomass of all mixture and monoculture cover crop treatments and weeds, and the proportion of weed biomass (%) relative to the total community for spring and summer 2016 trials at PrairiErth and Kinnikinnick Farms in central and northern Illinois, respectively. The spring trial at PrairiErth did not yield useable data due to contamination of cover crop stands with volunteer cover crop seed shattered the year prior. Different letters within a column for each season indicate differences among treatment means.

		PrairiErth			Kinnikinnick		
Season	Species/Mix	Cover crop (Mg ha^{-1})	Weeds (Mg ha^{-1})	Weeds (%)	Cover crop (Mg ha^{-1})	Weeds (Mg ha^{-1})	Weeds (%)
Spring	Oat	-	-	-	3.95 a	0.49 b	^{z} 11.0 cd
	Spring wheat	-	-	-	3.91 a	0.23 b	5.6 d
	Mustard	-	-	-	1.00 d	0.97 ab	49.7 ab
	Purple top turnip	-	-	-	1.24 cd	1.45 ab	54.0 ab
	Faba bean	-	-	-	0.54 d	1.26 ab	69.9 a
	Field pea	-	-	-	4.22 a	1.72 ab	29.0 abc
	Mix-Oat	-	-	-	2.05 bcd	0.83 b	28.8 abc
	Mix-Wheat	-	-	-	3.20 ab	0.72 b	18.3 bcd
	Mix-Mustard	-	-	-	3.90 a	0.98 ab	20.0 bc
	Mix-Turnip	-	-	-	2.97 abc	0.60 b	16.8 bcd
	Mix-Faba	-	-	-	3.08 ab	0.50 b	13.9 cd
	Mix-Pea	-	-	-	3.33 ab	1.07 ab	24.4 abc
	Weedy control	-	-	-	-	2.53 a	-
	SE ^{x}	-	-	-	0.34	0.34	-
Summer	Forage corn	7.26	4.19 a	^{y} 36.6	3.78 b	4.47 a	^{y} 54.2 a
	Sudangrass	7.44	1.81 ab	19.6	2.96 b	3.18 ab	51.8 a
	Buckwheat	5.89	1.30 b	19.0	7.11 ab	0.70 d	9.0 c
	Forage radish	3.30	1.04 b	24.1	3.57 b	0.00 d	0.0 c
	Cowpea	3.09	1.88 ab	37.8	3.75 b	2.37 abcd	38.7 ab
	Soybean	4.99	2.03 ab	29.0	3.55 b	2.73 abc	41.1 ab
	Mix-Corn	7.29	1.49 ab	17.1	6.86 ab	1.03 bcd	13.0 c
	Mix-Sudan.	8.56	1.97 ab	18.7	7.45 ab	0.82 bcd	9.8 c
	Mix-Buck.	7.74	1.65 ab	17.6	4.51 b	1.25 bcd	21.7 bc
	Mix-Radish	9.50	2.45 ab	19.1	10.24 a	1.25 bcd	10.9 c
	Mix-Cowpea	6.07	2.48 ab	29.0	5.86 ab	1.42 bcd	13.7 c
	Mix-Soybean	7.93	1.84 ab	18.9	6.83 ab	0.47 cd	6.5 c
	Weedy control	-	3.00 ab	-	-	4.55 a	-
	SE ^{x}	1.59	0.61	6.6	1.41	0.49	5.2

Allelopathic Weed Suppression

Cover crop species and mixture planted (treatments deployed) in this study had no significant effect on the germination or seedling development of velvetleaf, pigweed, foxtail, or lettuce in ragdoll bioassays. This generally suggests a lack of allelopathic weed suppressive potential of cover-cropped soils 4-5 weeks after cover crop residue soil incorporation (the time frame in which we collected field soil for ragdoll bioassays to determine allelopathic potential). A lack of observed differences in this study may be due to the sample time and approach to analyzing allelopathic interactions. Project co-PI Dr. Tony Yannarell is leading a complementary Ceres Trust research project to explore the relationship between cover crop residue species composition and biomass, soil microbial communities, N availability, and weed suppression in the first two weeks after soil incorporation of cover crops. Results of this project may provide greater insight into the possibility of using cover crops for residual, allelopathic weed suppression on organic farms.

Nitrogen Retention

By 8 weeks after planting cover crops, soil nitrate was generally five times greater in the weeded control plots (bare fallow) relative to cover-cropped and weedy plots (Figure 2). This result was generally consistent across all site-years and seasons, which suggests that all cover crop species and mixtures tested were equally capable of scavenging and retaining available soil nitrogen in the top 8 inches of the soil. High soil nitrate availability in the fallow control suggests a greater potential for nitrogen loss via leaching, runoff, or volatilization. In contrast, nitrogen in the cover-cropped plots was stored temporarily in plant tissue and available for slow mineralization in soil after termination and soil incorporation.

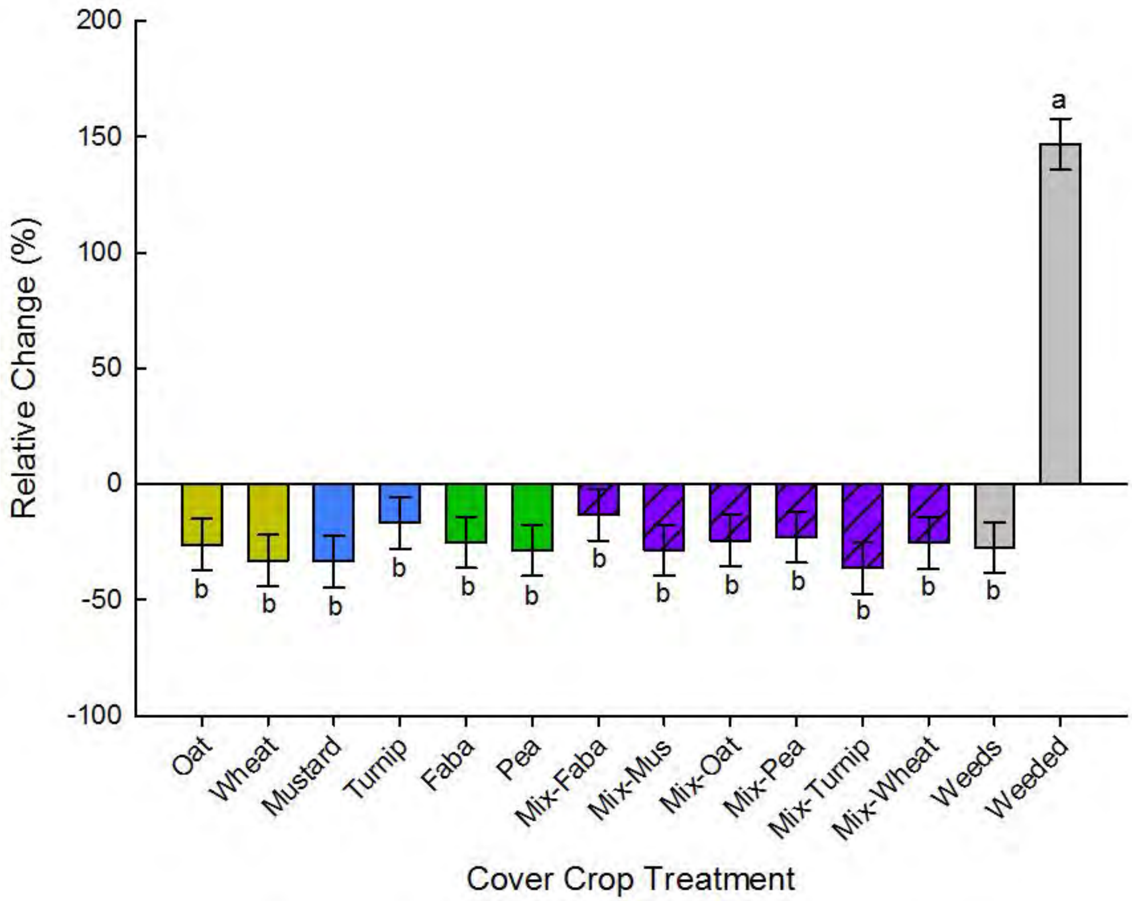


Figure 2: Percent change in soil nitrate (0-8 inch depth) from pre-plant to cover crop termination (approximately 8 weeks) at PrairiErth Farm in spring pooled across years. Different letters indicate significant differences among treatments.

Nitrogen Contribution from Cover Crop Tissue

Nitrogen contributions for spring cover crops ranged from 22 to 173 lbs N/acre, however, the % tissue N level among species was rarely different (likely due to sampling and termination at 8 weeks after planting prior to increased C:N in grass species). As a result, cover crop N contributions were largely a function of the aboveground biomass produced in each treatment. When mixtures were productive, a spring cover crop could contribute more than 100 lbs N/acre, but when mustard was decimated by insects, the N contribution was only 22 lbs N/acre (spring 2014 at Kinnikinnick).

Nitrogen contributions for summer cover crops ranged from 62 to 156 lbs N/acre. As with spring cover crops, the % tissue N was rarely different among treatments (this was also due in part to heavy contamination of cover crop residue with weedy tissue) and N contributions were a function of biomass. Not surprisingly, sudangrass and buckwheat were the largest producers of potential N. While these numbers represent the total organic N contained in the shoot tissue, it is important to consider that only a fraction (perhaps 50%) of this N will be plant available in the first season after soil incorporation. If 50% first-year availability is assumed, the cover crop treatments in this study would have provided between 11 and 87 lbs N/acre to subsequent cash crops, which is not sufficient for most production systems. This demonstrates the importance of integrating compost and manure applications with cover crop use for a well-balanced and sustainable nutrient management plan for organic agriculture.

Nitrogen Fixation

Nodule biomass, an indicator of nitrogen fixation potential, was not significantly different among treatments for pea, faba bean, soybean, and cowpea in this study. This suggests that legumes neither suffered antagonistic competitive effects nor synergistic beneficial effects when planted in diverse mixtures. This was surprising because we did observe reduced productivity of some legumes in mixture (as indicated by partial land equivalent ratios <0.2 because a species benefiting from mixture design would have a pLER >0.2; Table 5); because shoot biomass and leaf area are positively correlated with nodule biomass and nitrogen fixation, we expected reduced nitrogen fixation potential of legumes in mixture (however, this hypothesized decline in nodule biomass among treatments was not detected here).

Table 5: Partial land equivalent ratios (pLERs) and total land equivalent ratios (bottom line; sum of pLERs) for spring-sown cover crops at Kinnikinnick Farm in northern Illinois in 2014, 2015, and 2016. Different capital letters within rows indicate differences in pLERs for an individual species among mixtures, whereas different lowercase letters within columns indicate differences in pLERs among species within each mixture for a given year. A (*) next to an LER value indicates it is significantly different from 1.0 (when the LER value ± two standard errors does not overlap with 1.0; α = 0.05).

		Cover Crop Mixtures					
Year	Species	Mix-Oat	Mix-Wheat	Mix-Mustard	Mix-Turnip	Mix-Faba	Mix-Pea
2014	Oat		0.36	0.28	0.26	0.25	0.21 ab
	Wheat	0.36		0.23	0.26	0.28	0.24 a
	Mustard	0.22	0.28		0.34	0.86	0.19 ab
	Turnip	0.13	0.14	0.47		0.01	0.00 c
	Faba bean	0.11	0.08	0.12	0.11		0.06 bc
	Field pea	0.33	0.24	0.10	0.25	0.26	
	SE [y]	0.09	0.06	0.17	0.11	0.22	0.05
	Total LER [z]	1.15	1.1	1.21	1.22	1.65	0.71
2015	Oat		0.14	0.33	0.16 ab	0.13	0.15 ab
	Wheat	0.15 b		0.20	0.09 b	0.15	0.05 b
	Mustard	0.47 a	0.67		0.50 a	0.39	0.30 a
	Turnip	0.14 b	0.16	0.31		0.07	0.08 b
	Faba bean	0.18 b	0.05	0.26	0.15 ab		0.00 b
	Field pea	0.13 b	0.27	0.25	0.24 ab	0.28	
	SE [y]	0.07	0.16	0.08	0.10	0.09	0.04
	Total LER [z]	1.06	1.29	1.34	1.13	1.03	0.59
2016	Oat		0.65 a	0.54 a	0.37 a	0.43 a	0.40
	Wheat	0.30		0.31 ab	0.24 ab	0.24 b	0.32
	Mustard	0.27	0.15 b		0.10 c	0.09 c	0.40
	Turnip	0.02	0.00 b	0.03 c		0.01 c	0.04
	Faba bean	0.14	0.02 b	0.13 bc	0.05 c		0.07
	Field pea	0.12	0.11 b	0.11 bc	0.11 bc	0.08 c	
	SE [y]	0.09	0.05	0.06	0.03	0.03	0.10
	Total LER [z]	0.84	0.93	1.11	0.86	0.87	1.24

Microbial Respiration

Similar to results for nitrogen retention, there were no differences among cover crop species or mixtures for microbial respiration. However, in at least one site-year, glucose-induced respiration was greater in cover-cropped and weedy plots compared to the weeded (bare soil) plot. We observed a similar trend in other site-years, but it was only approaching significant levels. This suggests that plant roots, of any species or combination of species, may help to stimulate microbial activity during fallow periods. However, we do not know whether this potential activity provided any ecosystem services (e.g., enhanced nutrient cycling or disease suppression). Moreover, we do not know which species or functional groups were stimulated in the cover-cropped and weedy plot (only that it was species that can use glucose as a carbon substrate). While increased microbial activity is generally regarded as an indicator of soil health, further research is needed to determine what, if any, ecosystem services and functions are provided by these soil microbes.

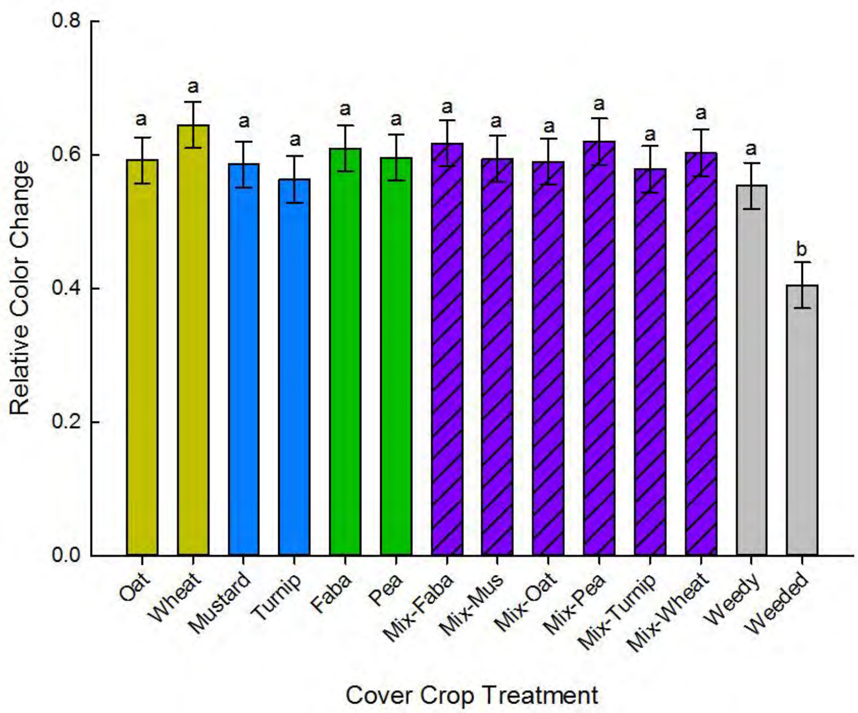


Figure 3: Relative absorbance (color change) in MicroResp colorimetric assay for determining glucose-induced microbial activity. A greater color change indicates greater microbial evolution of CO_2.

Publications Resulting from this Research Project

1. Holmes, A. A., A. A. Thompson, and S. E. Wortman. 2017. Species-specific contributions to community productivity and weed suppression in cover crop mixtures. Submitted to: *Agronomy Journal*. In revision.
2. Holmes, A. A., A. A. Thompson, A. C. Yannarell, S. T. Lovell, M. Villamil, and S. E. Wortman. 2017. Short-term effects of cover crop community composition on soil nitrogen cycling and microbial activity. In preparation for: *Nutrient Cycling in Agroecosystems.*
3. Wortman, S. E., C. Wortmann, A. L. Pine, C. Shapiro, A. Thompson, and R. Little. 2017. Nutrient Management for Organic Farming. University of Nebraska – Lincoln Extension NebGuide. In revision.

Outreach Activities

Outreach efforts in this project included a mix of presentations at on-farm field days, grower conferences and extension workshops, and academic meetings. Through our diverse outreach activities, we estimate that our research results were delivered to at least 300 individuals, including organic farmers, farmers interested in transitioning to organic, extension educators, NRCS conservationists, and organic researchers.

Source: Bloomington Pantagraph, Bloomington IL, September 2014

Collaborator Dr. Tony Yannarell explains his contribution to the cover crop study to attendees at the PrairiErth Field Day on September 8th, 2015.

Presentations to Disseminate Research Project Results

1. Bio-based weed management tools for specialty crops. Nebraska Sustainable Agriculture Research and Education (SARE) Webinar. July 2017. http://nesare.unl.edu/
2. Bio-based weed management tools for specialty crops. Small Scale Farming Workshop. Nebraska Extension. Nebraska City, NE. April 2017.
3. Blasting, biomulch, and cover crops: Non-chemical weed control for vegetable crops. Great Plains Growers Conference. St. Joseph's, MO. January 2017.
4. Blasting, biomulch, and cover crops: Multifunctional weed management tools for vegetable crops. Nebraska Sustainable Agriculture Society, Healthy Farms Conference. Columbus, NE. January 2017.
5. Holmes, A., A. Yannarell, and S. E. Wortman. 2016. Do benefits from cover crops vary by species or mixture composition? Midwest Organic and Sustainable Education Service Organic Farming Conference, La Crosse, WI.
6. Summer Cover Crops and Soil Health. PrairiErth Farms Field Day. Atlanta, IL. September 2015.
7. Holmes, A., A. Yannarell, and S. E. Wortman. 2015. Do soil health benefits from cover crops vary by species or mixture composition? Midwest Organic and Sustainable Education Service Organic Farming Conference, La Crosse, WI.
8. Wortman, S. E. and J. Dawson. 2014. Does the capacity for nitrogen fixation in cowpea (*Vigna unguiculata* L. Walp) increase when planted in diverse cover crop mixtures? ASA-CSSA-SSSA Annual Meeting, Long Beach, CA. https://scisoc.confex.com/crops/2014am/webprogram/Paper84973.html
9. Which cover crops contribute most to soil health? PrairiErth Farms Field Day. Atlanta, IL. September 2014.
10. Weed Blasting and Cover Crops in Vegetables. Kankakee Fruit and Vegetable Growers Symposium. Kankakee, IL. February 2014.