MONITORING SOIL NITRATE TO ESTIMATE COVER CROP NITROGEN CONTRIBUTION IN ORGANIC VEGETABLE PRODUCTION FIELDS

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ABSTRACT
Organic vegetable growers rely on legume cover crops as an economical source of plant-available N. This research evaluated N contributions to summer vegetable crops by cover crops (CC) residues by monitoring soil nitrate (NO_3-N) concentrations during the summer crop growing season. Replicated field plots were established with three CC mixes: solo common vetch (V), phacelia + V (PV), and cereal rye + V (RV), plus a winter fallow (F) control in grower fields in the north Willamette Valley OR. Soil textures were silt loam (7 sites) and sandy loam (2 sites). Cover crops were seeded in a randomized complete block design in mid-October and killed in April (vegetative) or in early May (just prior to flowering). Cover crop biomass was incorporated by tillage 1-3 wk. after CC kill. Soil samples (0-12 in depth, 4 in beside the row) were collected on 2-4 wk. intervals, beginning at summer crop planting (Year 1 sites) and at cover crop kill (Year 2 sites). Net soil NO_3-N contribution from CC in the field was estimated by difference in soil test nitrate concentrations (CC treatment minus winter fallow control). Summer crops monitored included winter squash (3 sites), lettuce (2 sites), and table beet, snap bean, kale and popcorn (1 site each). All sites received overhead sprinkler irrigation. Phacelia did not establish reliably as a winter cover crop. It emerged in fall, but did not survive the winter at most sites. At time of cover crop kill in spring, phacelia biomass exceeded 25% of total CC biomass (phacelia + V) at only 2 of 7 sites where it was seeded. Maximum net soil NO_3-N contribution was observed near time of crop planting for lettuce, kale, snap bean and table beet, and just prior to the first heavy irrigation for corn and winter squash. Across 9 sites, median net soil NO_3-N contribution (treatment minus control) was 28 lb/acre (range = 3 to 95) for RV and 46 lb/acre for V (range = 9 to 130). Soil nitrate monitoring had the most practical value for adjustment of organic fertilizer input rates for crops that receive limited early season irrigation (corn and winter squash), or for short season crops (lettuce and kale) planted in July. Median net soil nitrate contribution in the field was 50 to 80% of that measured in 10-wk laboratory incubation at 22°C. This suggests that N credits based on measuring soil nitrate (0-12 inches) following a cover crop will usually underestimate actual plant-available N supplied by a cover crop.

INTRODUCTION
Legume cover crops provide plant-available N for the succeeding crop. Predicting the amount and timing of plant-available N provided from a winter cover crop is critical to choosing appropriate rates of supplemental organic fertilizers. The present research was conducted to evaluate three cover crop seed mixtures for the timing and amount of plant-available N released in vegetable cropping systems in western Oregon. In this paper, we primarily address the measurement of soil nitrate in the field as an indicator of soil N status following cover crop kill. To provide additional context for the field soil nitrate data, we also briefly discuss the relationship

between soil nitrate concentrations measured in the field vs. those measured for the same cover crop residues incubated in soil at constant temperature and soil moisture in the laboratory.

Timing and depth of soil nitrate sampling is important for test interpretation. Extension guidance for irrigated vegetable crop in western states that soil nitrate concentrations (0-12 inch depth) exceeding 20 mg/kg at seeding, or 30 mg/kg at 4-6 wk. after seeding are considered adequate for many vegetable crops Oregon (OSU Extension EM 9221).

Interpretations of preplant or midseason soil nitrate tests (0-12 inches) are imperfect because they do not 1) account for plant-available NH_4-N, 2) forecast N mineralization that happens after the soil nitrate sample is collected, 3) assess crop root distribution and crop N uptake capacity below 12 inch depth, or 4) forecast the timing and amount of nitrate loss via leaching.

Table 1. Field site descriptions and date of maximum soil nitrate contribution from cover crop treatments. Willamette Valley, OR on-farm cover crop trials.

Summer crop yr	Farm	Soil mapping unit (NRCS) [a]	Cover crop kill	Summer crop	Summer crop planted	CC kill to planting (days)	Date of maximum net soil NO_3-N[b]
2009	MF	Canderly sal	9-Apr	table beet	10-May	31	18-May
	MSF	Amity sil	20-Apr	winter squash	28-May	38	10-Jun
	PMF	Aloha sil	30-Apr	winter squash	25-May	25	1-Jul
	SSF	Chehalis sil	21-Apr	lettuce	6-Jul	76	2-Jul
	WUG	Aloha sil	24-Apr	winter squash	30-May	36	30-Jun
2010	MF	Canderly sal	19-Apr	snap bean	18-May	29	25-May
	MSF	Amity sil	14-Apr	lettuce	5-May	21	25-May
	SSF	Chehalis sil	19-Apr	kale	25-Jun	67	8-Jul
	NWREC	Willamette sil	12-May	popcorn	22-Jun	41	9-Jul

[a] sal = sandy loam, sil = silt loam soil texture.

[b] Date listed for maximum net NO_3-N within each site-yr is based on soil NO_3-N data presented in Figure 1. At specified date, maximum net soil NO_3-N = [(soil NO3-N for CC treatment) - (soil NO_3-N for control winter fallow treatment)]. Table 3 estimates maximum net soil NO_3-N contribution in units of lb/acre.

MATERIALS AND METHODS

Field experiments were conducted over 9 site-yr (Table 1). Field sites were located in the north Willamette Valley (WV) of Oregon near Canby (MF and PMF), St. Paul (MSF), Clackamas (SSF), North Plains (WUG) and Aurora (NWREC). Commercial farms in the study grew a wide range of fresh market vegetables in rotation, with some historical use of cover crops. At NWREC, conventional wheat was grown for several years before the study and the field was being transitioned to organic management. Summer crops (Table 1) were direct seeded except for lettuce and kale. Weeds and insects were controlled by organically approved methods except at WUG and

MF. Overhead sprinkler irrigation as supplied via solid set irrigation systems and handlines, with 100% overlap at operating pressure. Irrigation timing and amount was determined by growers. All farms except WUG and MF used certified organic production methods; WUG used synthetic fertilizers in combination with yard debris compost. Preplant soil test values (0-12 in) indicated sufficiency for pH (6.1-6.6; 1:2 soil:water), P (69-160 ppm; Bray P1) and other nutrients, relative to OSU Extension guidance.

Cover crop species included common vetch (*Vicia sativa*), cereal rye (*Secale cereale*) and phacelia (*Phacelia tanacetifolia*). Cover crop trials were seeded by OSU personnel in small plots within larger grower-managed fields. Previous crop residues were mowed and incorporated by discing. Common vetch was seeded at 60 lb/acre in both solo and mixed species treatments. Vetch seed was treated with inoculum just prior to seeding (*Rhizobium leguminosarum* inoculant group C for peas and vetch). In mixed species treatments, cereal rye was seeded at 30 lb/acre and phacelia was seeded at 10 lb/acre. Experimental design within each field site was a randomized complete block with 4 replications. Cover crop subplots were 20-25 ft wide and 70-80 ft long within each replication. Cover crops were seeded in early to mid-October using a Gandy drop spreader, incorporated with a ring roller, then irrigated once or twice with overhead sprinklers on hand lines (if needed) before the onset of fall rain. Cover crop stands were good to excellent at all sites in November.

Just prior to cover crop kill in the spring, above-ground cover crop biomass and species composition were determined by harvesting four 4ft^2 quadrats within each plot (16 ft^2 per plot; method in PNW Extension publication 636, p. 6). After biomass determination, cover crops were killed by mowing (if needed) and then incorporated with a disc or moldboard plow. In the field, soil samples were collected 4 inches beside center rows to a depth of 12 inches using a 0.75 inch diameter push probe. Five to 10 cores were collected per composite sample. Soil samples were refrigerated (5 ^oC) on day of collection, and were oven-dried within 48 h of sampling.

Laboratory incubation. Cover crop biomass was incubated aerobically in moist soil to determine net CC contribution to soil nitrate after 4 and 10 wk. at constant temperature (22^oC). Between the date of field cover crop harvest and the start date for laboratory incubation, cover crop biomass samples were held in a kitchen freezer (-18^oC). Prior to mixing with soil, cover crop samples were defrosted, chopped into small pieces (1 to 2 inch length), then immediately added to soil at a rate of 25 g moist biomass per 500 g of moist soil, for an approximate incorporation rate of 1% w/w on a dry weight basis. To determine actual N added, CC dry matter was determined at 60 ^oC and soil dry matter at 100^oC. During the incubation, gravimetric soil moisture was monitored and maintained at 20 to 25% (200-250g H_2O/kg dry soil).

Analyses of C and N in cover crop biomass was performed by the Oregon State University Central Analytical Laboratory (CAL) using a combustion analyzer equipped with an infrared detector. Nitrate in 2M KCl soil extracts was determined by an automated cadmium reduction method at CAL. Soil NO_3-N (lb/acre) was estimated as soil nitrate-N (mg/kg) x 3.5. This conversion factor assumes a soil bulk density of 1.3 g/cm^3 in soils at all sites.

Table 2. Cover crop species composition, nitrogen and carbon analyses, biomass and above-ground N uptake[a].

Year	Farm	Cover Crop (CC)	Legume	Phacelia or cereal rye	Total N		C:N ratio		CC biomass		CC N uptake	
			% of CC dry wt.		% of CC dry wt.		lb/acre					
2009	MF	PV	90	1	3.6	(0.2)	11	(0.1)	2670	(390)	94	(12)
		RV	44	56	2.7	(0.2)	15	(0.8)	4950	(570)	135	(23)
		V	95	0	3.7	(0.1)	11	(0.4)	4450	(470)	164	(20)
	MSF	PV	62	7	2.9	(0.3)	14	(1.3)	3660	(480)	111	(24)
		RV	40	46	2.3	(0.2)	19	(1.8)	5560	(360)	128	(18)
		V	59	0	2.9	(0.1)	14	(0.6)	3880	(380)	114	(12)
	PMF	PV	32	34	2.4	(0.1)	16	(0.6)	5100	(410)	125	(11)
		RV	36	33	2.3	(0.1)	18	(0.7)	5230	(500)	124	(17)
		V	61	0	2.9	(0.2)	15	(0.7)	4660	(380)	137	(16)
	SSF	PV	12	2	2.0	(0.2)	20	(2.8)	2520	(350)	53	(13)
		RV	11	66	2.3	(0.1)	18	(0.7)	5860	(290)	137	(7)
		V	62	0	3.4	(0.1)	12	(0.5)	4000	(310)	137	(13)
	WUG	RV	5	90	2.0	(0.0)	21	(0.3)	8330	(490)	164	(9)
		V	56	0	3.7	(0.1)	11	(0.3)	3570	(150)	132	(10)
2010	MF	PV	56	27	3.0	(0.1)	13	(0.3)	3470	(270)	104	(10)
		RV	44	34	2.9	(0.2)	14	(1.0)	2660	(220)	76	(5)
		V	69	0	3.1	(0.1)	13	(0.6)	2650	(110)	82	(3)
	MSF	PV	62	13	2.6	(0.1)	15	(0.7)	2600	(340)	67	(6)
		RV	50	31	2.1	(0.0)	19	(0.4)	3060	(280)	64	(5)
		V	52	0	2.4	(0.3)	16	(1.4)	2170	(160)	53	(10)
	NWREC	RV	26	67	1.9	(0.1)	22	(1.3)	8490	(610)	163	(22)
		V	75	0	3.8	(0.2)	11	(0.7)	5750	(300)	221	(24)
	SSF	PV	69	0	3.0	(0.1)	13	(0.3)	2700	(100)	82	(4)
		RV	20	61	2.1	(0.1)	19	(0.5)	6700	(200)	141	(4)
		V	66	0	3.1	(0.1)	13	(0.3)	3320	(380)	101	(12)
	Median	PV	62	2	2.9		14		2700		94	
		RV	36	56	2.3		19		5560		135	
		V	62	0	3.1		13		3880		132	

[a] Values in parenthesis are standard error of the mean (n=4). Weed dry matter (%) = 100-CC dry matter (%).

RESULTS AND DISCUSSION

Median values for RV and V biomass and above-ground crop N uptake (Table 2) were in a typical range for our region, based on monitoring data from other farms and years. The median C:N for RV (19) was slightly above the “breakeven” value listed in literature for zero N mineralization/immobilization (15), suggesting a brief period of N immobilization for RV in soil. At a few sites (WUG in 2009; NWREC and SSF in 2010), values for RV biomass were very high (8330, 8490, 6700 lb/acre, respectively), because rye dominated cover crop biomass, and cover crop was allowed to grow until late April or May. Phacelia did not establish reliably as a winter cover crop. It emerged in fall, but did not survive the winter at most sites. At time of cover crop kill in spring, phacelia biomass exceeded 25% of total CC biomass (phacelia + V) at only 2 of 7 sites.

Soil NO_3-N concentrations following cover crop incorporation in the field (Figure 1;Table 3) were affected by: 1) amount and quality of cover crop biomass, 2) soil temperature and rainfall, 3) N uptake by the summer crop, and 4) leaching by rainfall + irrigation. Examples: In 2010, declines in soil nitrate were observed at most sites in early June (MF, MSF SSF), associated with unusually cool, wet weather. The seasonal peak in soil nitrate occurred just prior to the period rapid crop N uptake for corn (NWREC in 2010) and for winter squash (MSF and PMF in 2009), suggesting that a combination of crop N uptake and nitrate leaching may have been responsible for declining soil NO_3-N concentrations in July. Cover crop NO_3-N contribution was < 10 lb/acre for a lettuce crop seeded at MSF on 5-May 2010, associated with limited CC biomass and cool soil temperatures after CC incorporation.

Maximum net soil NO_3-N contribution was observed near time of crop planting for lettuce, kale, snap bean and table beet, and just prior to the first heavy irrigation (3-5 wk. after planting) for corn and winter squash (Table 3). Across 9 field sites, median net soil nitrate contribution (treatment minus control) was 28 lb/acre (range = 3 to 95) for RV and 46 lb/acre for V (range = 9 to 130). At all sites, the timing of net soil nitrate contribution was similar for RV and V.

Maximum net soil nitrate contribution (0-12 inches) in the field was generally lower than that measured in laboratory incubations (Table 3). Median net soil nitrate contribution in the field was 50 to 80% of that measured in 10-wk laboratory incubations at 22^oC. This suggests that N credits based on measuring soil nitrate (0-12 in) following a cover crop will usually underestimate actual plant-available N supplied by a cover crop.

We conclude that soil nitrate monitoring has the most practical value for adjustment of organic fertilizer input rates for crops that receive limited early season irrigation (e.g. corn and winter squash), or for short season crops (e.g. lettuce and kale) planted in July following an extended fallow period.

Table 3. Net soil nitrate contribution as estimated by laboratory incubation of cover crop residue (4 and 10 wk. at 22^oC) and maximum net soil nitrate contribution in field soil samples (0-12 inches)[a].

Year	Farm	Lab Incubation (4 wk. @ 22^oC)			Lab Incubation (10 wk.)			Field				Ratio: Field/(10-wk incubation)		
		PV	RV	V	PV	RV	V	Date of max NO_3-N contribution	PV	RV	V	PV	RV	V
		------------Net soil nitrate contribution from cover crop residue (lb NO_3-N/acre)-----------------												
2009	MF	44	48	74	54	71	87	18-May	16	13	26	0.3	0.2	0.3
	MSF	37	29	31	59	49	47	10-Jun	48	28	46	0.8	0.6	1.0
	PMF	28	35	46	40	53	74	1-Jul	34	21	25	0.9	0.4	0.3
	SSF	14	46	67	15	61	81	2-Jul	29	66	124	1.9	1.1	1.5
	WUG		20	49		37	42	30-Jun		95	130		2.6	3.1
2010	MF	36	28	36	55	45	51	25-May	28	24	23	0.5	0.5	0.5
	MSF	25	20	12	43	33	23	25-May	4	3	9	0.1	0.1	0.4
	NWREC		25	62		83	106	8-Jul		52	85		0.6	0.8
	SSF	18	26	32	38	82	69	9-Jul	30	40	48	0.8	0.5	0.7
Median		28	28	46	43	53	69		29	28	46	0.8	0.5	0.7

[a] Soil nitrate-N conversion from ppm to lb/acre based on a soil bulk density of 1.3 g/cm^3 for all sites and incubations.
PV treatment was omitted from experiment at WUG in 2009 and at NWREC in 2010.
In the field, net NO_3-N contribution was estimated at listed sample date within each field site-yr where maximum CC treatment response (CC treatment minus winter fallow treatment,“F”) was observed. Figure 1 shows soil NO_3-N concentrations across time.

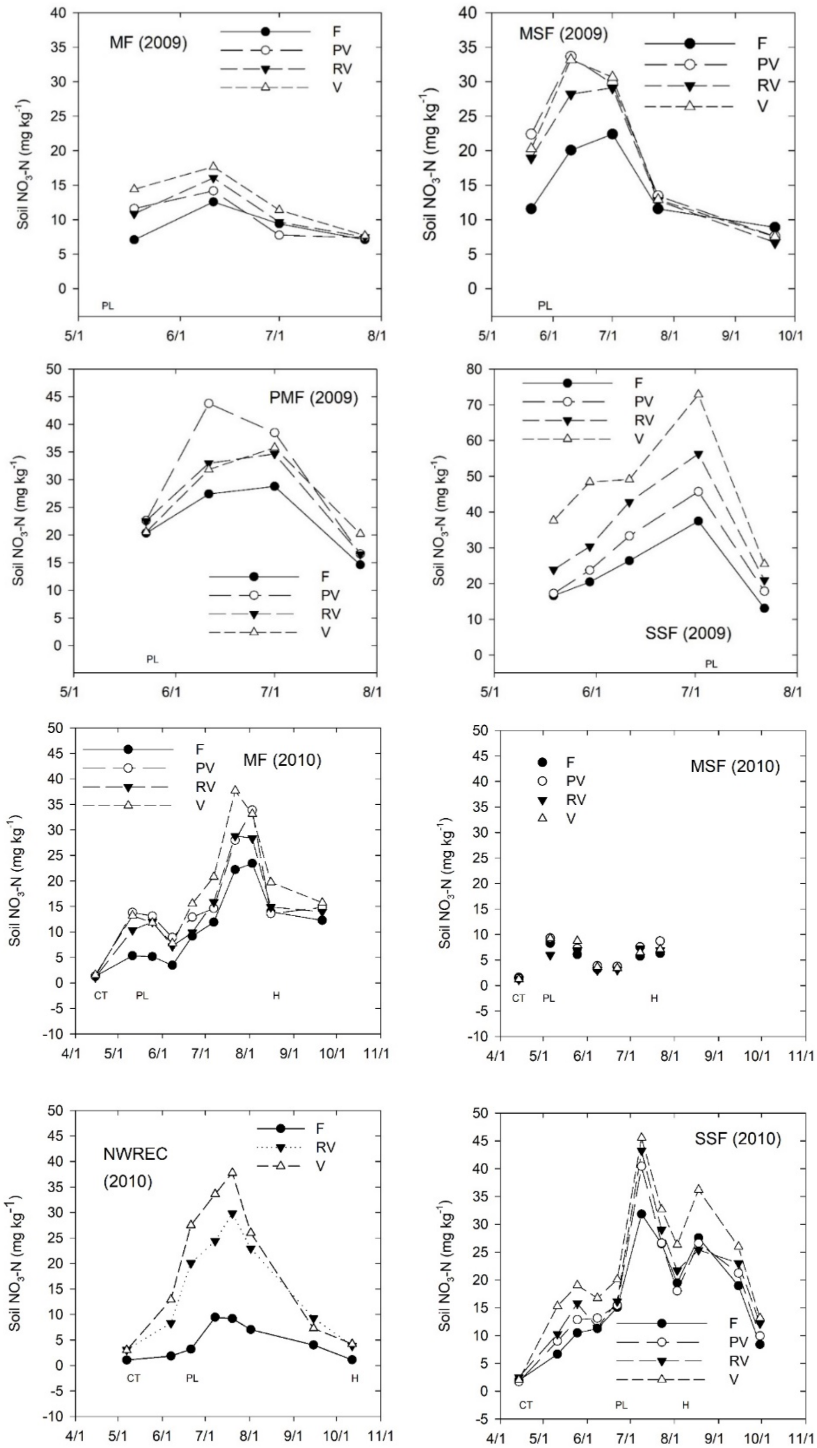

Figure 1. Effect of winter cover crop on soil nitrate-N (0-12 inches). Crop management events: CT = cover crop termination, PL = planting of summer crop, H = crop harvest. Zero cover crop control treatment = F (winter fallow). Summer crops present at each field site are listed in Table 1.