A Final Report Submitted to the
Oregon Processed Vegetable Commission

Reducing Energy Inputs in Oregon Vegetable Production to Enhance Economic and Environmental Sustainability

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Introduction

During the spring and summer of 2008, rapid escalating oil and natural gas prices produced associated increases in the price of fuel and fertilizer. Crude oil prices reached the astronomical $147 a barrel in July, with gasoline peaking at $ 4.11 per gallon the same month. Since nitrogen fertilizer is one of the most energetically costly agrichemicals to produce, distribute, and apply (Magdoff, 2007), urea fertilizer, manufactured from natural gas, also spiked, peaking at 900/ton. Then, amid the growing alarm among growers of increasing fuel, fertilizer and input costs, the prime mortgage industry crashed, banks and financial institutions collapsed, and the economy spun into a deepening recession. By December 2008, crude oil prices plummeted to below $49 a barrel, with gas prices dropping below $1.65 per gallon. Urea fertilizer was selling for less than $400/ton. In the past year crude oil prices have dropped, but appear to be on an upward trend again (Fig. 1), ending at $77 a barrel in December 2009. Nitrogen fertilizer prices (urea) started the year at nearly $550 per ton, but declined steadily over to year, ending a $395 per ton (Fig. 2) (Wilco Farm Supply, Mt. Angel).

Although there has been a brief respite from last year's high fuel and fertilizer prices, there is widespread recognition that world energy prices will continue to be volatile, and most likely increase again with resurgent world economies. Energy-intensive inputs, such as nitrogen fertilizer, will likely track world natural gas prices. However, availability and local prices may likely be influenced by other factors, including world demand and regional supplies.

Two well-documented approaches to reducing agricultural energy inputs and increasing net profit are conservation tillage and legume cover cropping. Conservation tillage practices, such as no-till, strip-till and ridge-till, have been widely adopted for agronomic crop production, yet most vegetable growers continue to use conventional or reduced tillage systems for seedbed preparation (Hoyt et al., 1994). Reducing the number of tillage operations required to prepare an adequate seedbed clearly has a direct effect on reducing diesel fuel consumption, labor and machinery costs. Conservation tillage practices are also strongly linked to increased crop yield and

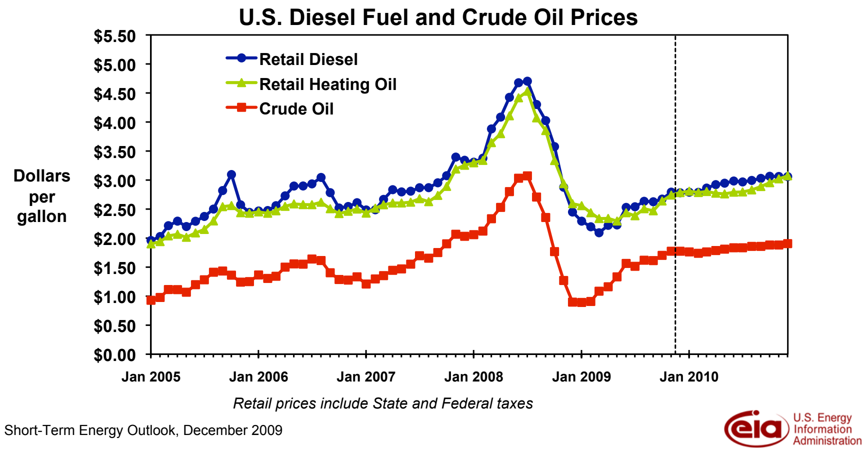


Fig. 1. Recent fluctuations in U.S. diesel fuel and crude oil prices.

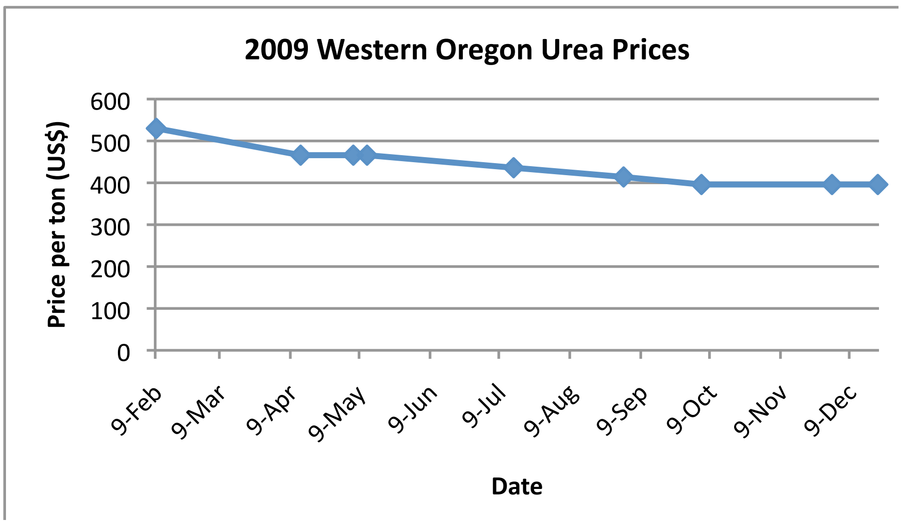


Fig. 2. Prices of urea fertilizer in Western Oregon during 2009. (Source: Wilco Farm Supply, Mt. Angel, OR.)

improvements in soil structure, water holding capacity, and organic matter, with reductions in soil erosion and nutrient loss.

Strip-till vegetable research in Western Oregon

From 1993 to 2000, a series of research station and on-farm trials were conducted to evaluate the feasibility of strip tillage for sweet corn production in the Willamette Valley. Strip-till, rather than no-till, was selected since it had been widely used in the Southeastern US, and offered potential to overcome some of the challenges of no-till. In 1998 a group of ten Oregon farmers formed *The Willamette Farm Improvement Association* to pool financial resources and collaboratively build a new strip-tillage machine called the "Transtiller." In a 4-year study, (1997 -2000) twenty on-farm trials were conducted comparing strip-tillage systems with conventional tillage systems for sweet corn production. Six-row strip tillage equipment was hauled from farm to farm, with trials typically 4 to 10 acres. Across an array of soils and crop residue situations, strip-tillage and conventional tillage systems produced *equivalent* sweet corn yields. However, machinery and labor costs were *reduced by nearly 50%* by strip-tillage (Luna and Staben 2002).

Problems with strip tillage. Slugs damaged corn in several strip tillage fields requiring the use of slug bait to prevent economic damage. There was no increase or decrease in insect pest damage associated with strip tillage in the 20 paired tillage system comparisons reported in this. However, in two paired trials in 2001, outbreaks of the garden symphylan (*Scutigerella immaculata*) damaged sweet corn in the strip tillage blocks. The winter and spring of 2001 were exceptionally dry, which may have allowed greater symphylan survival and population growth. Also, tillage has historically been used as a cultural method to suppress symphylan populations (Umble et al., 2001

Energy Analysis of Farming Practices

Estimating the energy costs of farming practices includes the more obvious energy value of fuels and electricity, but also includes estimates of total embedded production and transportation energy costs to the end user. A common approach used is to calculate "Energy Coefficients" which are presented as "megajoules (MJ) of energy (1 MJ = 1 million joules). A joule is the derived unit of energy in the International System of Units and is equal to the amount of work required to continuously produce one watt of power for one second, or one watt second. For energy comparison purposes, one kilowatt hour of electricity equals 3.6 MJ. Another way of looking at the energy in a MJ is that it approximates the kinetic energy of a one-ton vehicle moving at 100 mph. Or, in terms of diesel fuel, one gallon of diesel fuel equals 165 MJ and 1 lb N fertilizer equals 35 MJ (Table 1). Or, one gallon of diesel fuel is energetically equivalent to 5 lbs N fertilizer. The high energetic cost of nitrogen fertilizer comes from the energy-intensive process of manufacturing synthetic nitrogen fertilizer. Estimates are presented for average fertilizer and diesel fuel use on a per-acre-basis to show the relationship between fertilizer and tillage energy costs.

Table 1. Energy coefficients for fertilizer and diesel fuel, and average energy inputs into Willamette Valley sweet corn production.

Input	Unit	MJ per unit	MJ per acre[1]
Fertilizer (Urea-46-0-0)	Lb N	35	5,250
Diesel fuel	gallon	165	1,320

[1] Estimates based on an average of 150 lbs N per acre, and 8 tillage passes averaging 1 gal diesel per acre per tillage pass. Actual energy use per acre will depend in specific N-fertilizer rates, equipment size and number of passes

Energy input comparisons between tillage systems

In 2009, tillage equipment use data were collected by Pearmine Farms, Gervais OR. Using GPS guided tractors, time and fuel usage per acre were recorded for both conventional and strip tillage systems. There is no single description of conventional tillage, since it represents an array of tillage practices which vary among farms and crops, and between fields and soil types. One grower may use 8 to 10 tillage practices with moldboard plowing and ripping to prepare a seedbed; other may use 4-5 passes, however both would be considered "conventional" tillage. Minimum tillage has been used describe fewer passes over the field, but again there's no hard definition. At Pearmine Farms, the "conventional" tillage system used for sweet corn is shown in Table

The strip-till system involved a single pass of a 6-row Transtiller (set on 30" row spacing), followed by 1 to 2 passes of the Hendricks Farms 2nd pass strip-till finishing cultivator (see Luna and Staben (2003) for pictures and description of equipment). The 2nd pass machine was fabricated at Pearmine Farms based on the Hendricks Farms design.

At Pearmine Farms, 80 acres of sweet corn were grown using conventional tillage, and 125 acres were grown using strip-tillage. In addition, Pearmine Farms did custom strip tillage on an additional 130 acres of sweet corn land for three neighboring farms. There were no side-by-side comparisons of conventional and strip tillage, as had been done in the earlier work reported in Luna and Staben (2002), with field being split into two blocks. Rather, whole fields were tilled with one or the other method. Therefore corn yields will not be reported, since they were from an array of soil types, planting dates and varieties. It would be inappropriate to compare treatments since the treatments were not replicated.

RESULTS: Pearmine Farms reported that both conventional and strip tillage systems produced similar yields. The three neighboring farms which used the custom strip till service also reported good corn yields with strip tillage. All neighboring farms using strip till expressed a desire to continue strip tillage in 2010.

Although corn yields cannot be compared between tillage systems in this trial, the average tractor time and diesel fuel energy can be compared between the systems. Strip tillage dramatically reduced the number of equipment passes (2.7), diesel use (1.7 gallons), and energy use (195 MJ) per acre compared to conventional tillage, 5 equipment passes, 5.2 gallons diesel, and 858 MJ of energy equivalents (Table 2). This represents approximately a 50% reduction in equipment passes (which includes labor and equipment cost), a 2/3 reduction of fuel consumption, and a 75% reduction in energy equivalents consumed.

As in the earlier work in evaluating strip-till systems, occassional problems emerged with slugs, requiring additional control measures. Parts of one field were damaged by symphylans. Clearly strip tillage isn't as effective in reducing slug populations as conventional tillage, and fields with know symphylan problems should be avoided for strip tillage.

One of the largest constraints to the expansion of strip-tillage is the cost of equipment, since two specialized machines are required. Many growers say the economics just don't pencil out if the machines are only used for sweet corn. But the model of custom farming, in which one farm owns the equipment and contracts to strip till other growers' fields has excellent potential.

Reducing N fertilizer inputs using legumes

Crews and Peoples (2004) suggest that the energetic basis of legume N_2 fixation (solar energy) is more sustainable than fertilizer N sources, which require significant amounts of non-renewable fossil fuels or other commercial energy sources to produce.

The ability of legume cover crops to provide up to 150 lbs of biologically-fixed N to the next crop is well known (Dabney et al., 2001;

Table 2. Comparison of fuel costs for strip tillage and reduced conventional tillage at Pearmine Farms, Willamette Valley, OR 2009. Calculations of energy equivalents are based on 165 MJ per gallon diesel fuel.

Strip-Till (Tractor - JD 7830 160 hp)								
	Implement width (ft)	tractor speed (mph)	acres/ hour	diesel per hour (gal)	diesel per acre (gal)	passes per acre	total fuel per acre (gal)	Energy equivalents (MJ)
Transtiller	15	5	8	4	0.5	1	0.5	83
2nd pass roller disk	15	6.5	10	4	0.4	1.7	0.7	112
					total per acre	**2.7**	**1.2**	**195**
Conventional Till (Tractor - JD 7140 200 hp)								
Offset disk	30	6	16	16	1	2	2.0	330
Vibra-shank cultivator	30	6	16	16	1	2	2.0	330
Perfecta finish cultivator	25	6	13.3	16	1.2	1.0	1.2	198
					total per acre	**5**	**5.2**	**858**

Sullivan et al., 1991; Wyland et al., 1996). There is a widespread reported synergistic effect on crop yield between N fertilizer and legume-based cover crops. Optimum economic yields are usually obtained by using both legume cover crops and a moderate amount of N fertilizer

To evaluate the value of legumes as part of a cover crop mixture used in strip-till sweet corn production, a series of on-farm trials were conducted in 2003- 2005. Since the ability of strip tillage to produce similar yields to conventional tillage has already been shown (Luna and Staben 2002), only strip tillage was used in these trials. To evaluate the nitrogen contribution of legume cover crops to broccoli production, a two-year experiment was conducted at the Oregon State University Lewis Brown Farm.

Fig. 3. Legume-enhanced cover crops, such as the phacelia-legume mixture (left) and the oat-legume mixture (right) can improve crop yields and water

On-Farm Trials, 2003 – 2005

Alternative cover crop species and mixtures were evaluated on several farms in the Willamette Valley. Cover crop treatments were identical on all farms and included (1) Oats ('Monida') (2) an oat-vetch mixture (oats plus common vetch (*Vicia sativa*), (3) a phacelia (*Phacelia tanacetifolia*)-vetch mixture, and (4) no cover crop (naturally occurring weeds) (Fig. 3). Cover crops were planted in six on-farm trials from early September through late October. Individual treatment blocks varied from 2-4 acres to permit the use of commercial harvesting equipment to obtain realistic assessment of crop yield. Each field represented a single replication in a randomized complete block experimental design.

Fig. 4 On-farm research plots were harvested using growers' equipment and quality parameters determined at the food-processing plant.

Cover crop biomass was estimated (see below) in the spring within a week of the cooperating grower's decision to kill the cover crop with Roundup® (glyphosate). Cover crop sampling occurred from April 3 through April 27, depending on the grower and the year. In all fields a strip tillage system was used to prepare a seedbed. Sweet corn was planted in May and June each year using the growers' planting equipment, and standard fertilizer and weed management practices were used to grow the crops.

Data Collection. Cover crop biomass was estimated by randomly selecting 4-6 locations within each cover crop block by tossing a 0.25m^2 aluminum quadrat. The quadrat was worked through the cover crop foliage to the soil surface and the foliage clipped within the quadrat. Individual cover crop species within the mixtures were separated into paper bags and returned to laboratory for drying and weighing. Samples were taken to the OSU Central Analytical Laboratory for analysis of percent carbon and nitrogen.

Corn yield was determined using the participating growers' commercial harvesting equipment (Fig. 4). Corn was hauled to the Norpac processing facility where harvest weights and quality grades were determined. Harvested plot areas in the field were measured to calculate crop yields. Cover crop seed costs were obtained from the seed suppliers for the economic analysis.

Results

Corn yield response to cover crop treatments

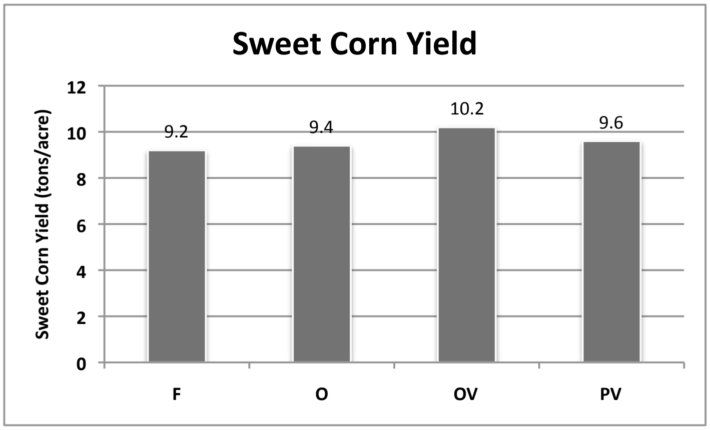


Fig. 5. Effect of cover crops on graded yield of sweet corn in strip-till systems (n=6).

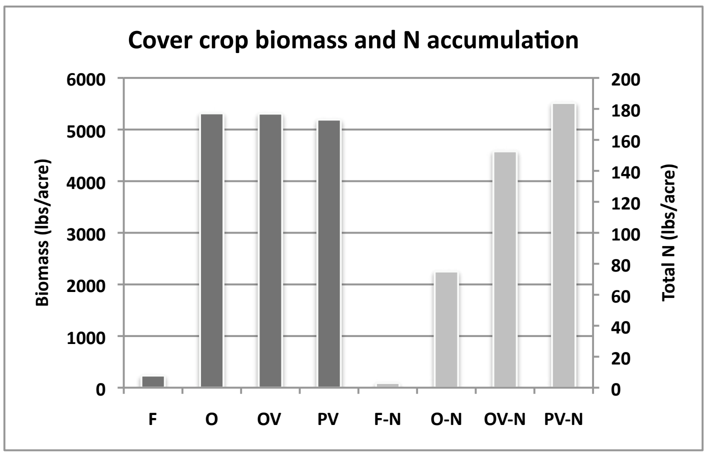


Fig. 6. Cover crop biomass and accumulated above-ground nitrogen per acre, averaged across 6 fields in three years.

varied across the farms, however when averaged across the six fields, sweet corn yields were 1.0 tons higher in the oat-legume cover crop plots compared to fallow treatment, an 11% increase ($p = .12$) (Fig. 5). There were no yield differences among the cover crop treatments.

Averaged across the six fields, all cover crops produced similar biomass, approximately 5,000 lbs per acre (Fig. 6). Total N content was highest in the phacelia-vetch (185 lbs N/acre), with N content in the oat-vetch mixture of 153 lbs N/acre double of the N content of the oats (75 lbs N/acre) (Fig. 6). Cover crop performance and N content varied considerably among the farms and years (Table 3, Fig. 7)

Carbon-to-nitrogen ratios have been used to indicate the relative percent nitrogen in cover crops, since the percent carbon of most plant tissues remains relatively constant. Percent nitrogen content of plant tissue varies considerably, not only between species, but also within various growth stages of a given species. For example, an immature cereal crop has a higher nitrogen content (and hence lower C: N ratio) than a mature cereal crop. The C: N ratio is commonly used as a relative indicator to predict how rapidly the plant tissue will degrade after it is killed, either in the soil or on the soil surface as a mulch. Plant tissue with high C: N ratios (>30) will be degraded more slowly than tissue with low C: N ratios such as <15.

In these trials, the C: N ratios (and percent nitrogen) of the cover crops, as well as the increased quantity of cover crop nitrogen, may be a key factor in the increase of corn yields in the oat-vetch cover crop mixture. The oats grown in the mixture with vetch had a higher nitrogen content (1.9%) and lower C:N ratios (25) compared to the fallow plots with 1.5% nitrogen content and a C:N ratio of 36 (Table 4). Apparently, the legumes in the mixtures are releasing nitrogen in the soil, which is taken up by the oats, reducing the C: N ratio of the oat tissue. A combination of increased N fixation associated with the legumes, as well as more rapid mineralization of the higher N containing oats in the oat-vetch mixtures likely contributed to the increased plant available nitrogen during the growing season and the increased sweet corn yields. However, legumes are also known to improve a variety of soil quality parameters, including enzyme activity.

The lack of increase in corn yields in the strip-till fields by oat cover crops alone compared to the no-cover crop plots, may be due to several factors, including immobilization of soil nitrogen by soil bacteria engaged in degrading high C: N ratio plant material. Oats may contain allelopathic compounds that could retard corn growth as well.

Economic analysis of cover crop treatments

Cover crop establishment costs depend on seed costs, seeding rates, planting equipment, and labor costs. Seed costs per acre for the cover crop treatments were oats, \$9.00; oat-legume, \$17.40; and phacelia-legume, \$23.40 (Table 5). Planting equipment and labor costs are based OSU Extension cost estimates for two disk passes to prepare a seedbed, followed seeding with a grain drill (\$33.00/a). Estimated benefits from the cover crop treatments can be calculated by subtracting cover crop costs from the net return (graded yield x corn price).

field	year	date	cvcrp	cmponet	acre wt	cper	nper	c:n ratio	N -lbs/a
Sweeney	2003	14-Apr	Oats	oat	**6,940**	44	1.2	37	**85**
			Oat-vetch	oat	3,780	43	1.5	29	55
				vetch	2,090	44	3.1	14	65
				total mix	**5,870**				**120**
			Phacelia-vetch	phacelia	4,320	44	4.3	10	185
				vetch	1,690	44	4.2	10	71
				total mix	**6,010**				**256**
			Fallow	weeds	**580**	45	0.9	48	**5**
Sweeney	2004	8-Apr	Oats	oat	**2,000**	43	1.3	34	**25**
			Oat-vetch	oat	980	43	2.0	22	20
				vetch	2,130	43	4.1	10	88
				total mix	**3,110**				**108**
			Phacelia-vetch	phacelia	1,130	40	1.6	25	20
				vetch	1,620	43	4.3	10	70
				total mix	**2,750**				**90**
			Fallow	weeds	**590**	43	1.9	22	**10**
Hendricks	2004	23-Apr	Oats	oat	**6,300**	42	0.7	65	**40**
			Oat-vetch	oat	930	43	1.3	34	10
				vetch	3,240	43	3.7	12	118
				total mix	**4,170**				**128**
			Phacelia-vetch	phacelia	1,770	42	1.1	38	20
				vetch	3,460	43	4.6	9	160
				total mix	**5,230**				**180**
Hendricks	2004	23-Apr	Fallow	weeds	**0**				0
Sweeney	2005	27-Apr	Oats	Oat	**5,390**	**44**	**2.1**	**21**	**114**
			Oat-vetch	Oat	4,620	46	2.1	22	98
				Vetch	2430	46	3.9	12	95
				total mix	**7,050**				**193**
			Phacelia-vetch	Phacelia	6,000	41	2.3	18	140
				Vetch	1,800	45	3.4	11	61
				total mix	**7,800**				**201**
			Fallow	weeds	**0**				0
Hendricks	2005	19-Apr	Oats	Oat	**5,940**	**43**	**1.8**	**24**	**107**
			Oat-vetch	Oat	3,420	43	2.5	17	85
				Vetch	2,920	44	4.3	10	125
				total mix	**6,340**				**210**
			Phacelia-vetch	Phacelia	1,860	39	3.2	12	60
				Vetch	2,310	44	4.7	10	108
				total mix	**4,170**				**168**
			Fallow	weeds	**0**				**0**

Table 3. Cover crop components for on-farm research trials, 2003-2005. Note: data are not included for Hendricks 2003 because of missing laboratory analysis of N and C content.

The oat-legume treatment produced a net increase of about $50/acre in net profit compared to the fallow. Obviously, the high corn yield from this treatment produced the high economic returns.

field	year	date	cvcrp	cmponet	% C	%N	C:N ratio
Sweeney	2003	14-Apr	Oats	oat	44	1.2	37
Sweeney	2004	8-Apr	Oats	oat	43	1.3	34
Hendricks	2004	23-Apr	Oats	oat	42	0.7	65
Sweeney	2005	27-Apr	Oats	oat	44	2.1	21
Hendricks	2005	19-Apr	Oats	oat	43	1.8	24
				average	**43**	**1.4**	**36**
Sweeney	2003	14-Apr	Oat-vetch	oat	43	1.5	29
Sweeney	2004	8-Apr	Oat-vetch	oat	43	2.0	22
Hendricks	2004	23-Apr	Oat-vetch	oat	43	1.3	34
Sweeney	2005	27-Apr	Oat-vetch	oat	46	2.1	22
Hendricks	2005	19-Apr	Oat-vetch	oat	43	2.5	17
				average	**43**	**1.9**	**25**

Table 4. Cover crop components for on-farm research trials, 2003-2005. Note: data are not included for Hendricks 2003 because of missing laboratory analysis of N and C content.

Cover crop	Cover Crop component	Seeding Rate (lbs/a)	Seed Cost $/lb	Total Seed Cost ($/a)	Tillage and planting costs ($/acre)	Total Cover Crop Planting Cost ($/acre)
Oats	oat	60	0.15	9.00	$33.00	**42.00**
Oat-vetch	Oat	20	0.15	3.00		
	Vetch	40	0.36	14.40		
			Total Mix	17.40	33.00	**50.40**
Phacelia-Vetch	Phacelia	2.0	4.50	9.00		
	Vetch	40	0.36	14.40		
			Total Mix	23.40	33.00	**56.40**

Table 5 Cover crop components for on-farm research trials, 2003-2005. Note: data are not included for Hendricks 2003 because of missing laboratory analysis of N and C content.

Objective 3. To evaluate the nitrogen contribution of legume-based cover crops to organic vegetable production

Materials and Methods

Year 1. An experiment was initiated in October 2006, at the OSU Horticulture Farm near Corvallis, OR. The soil is a Chehalis silt loam. The field was planted in blackberries from 2001 until 2003 and was fallowed for two years before the cover crop trials were planted during the first week of October 2006. Although the land had not been certified "organic" by a certification organization, based on the time from prior chemical applications, the land would have been eligible for certification.

In preparation for planting, the field was disked and rolled with a cultipacker. Experimental treatments consisted of five cover crop treatments and a no cover crop control (Table 6). A randomized complete block design with four replications was used. Cover crop treatment plots were 4.6 m x 36.6 m. To ensure accurate and uniform seeding rates, cover crop plots were subdivided into 4.6 m x 6.1 m subplots, and strings were stretched to define the subplot boundaries. Cover crop seed was weighed separately for each subplot and the seed distributed by hand. The vetch in all treatments was inoculated with *Rhizobium leguminosarum* at approximately 4g/kg of seed. A few drops of water were added to the seed before mixing in the *Rhizobium*. Because of the small size of the phacelia seed, a "seed shaker" was made using a 0.5 L mason fruit jar with 0.2 cm diameter holes drilled in the lid. After seeding, strings were removed and a tine-harrow drag was pulled longitudinally down the length of the plots to cover the seed. After planting, irrigation was applied with overhead sprinklers several times to assure germination and establishment during a very dry October.

Cover crop biomass, carbon and nitrogen content. Two biomass samples were taken on May 11, 2007 in each cover crop treatment by mowing across

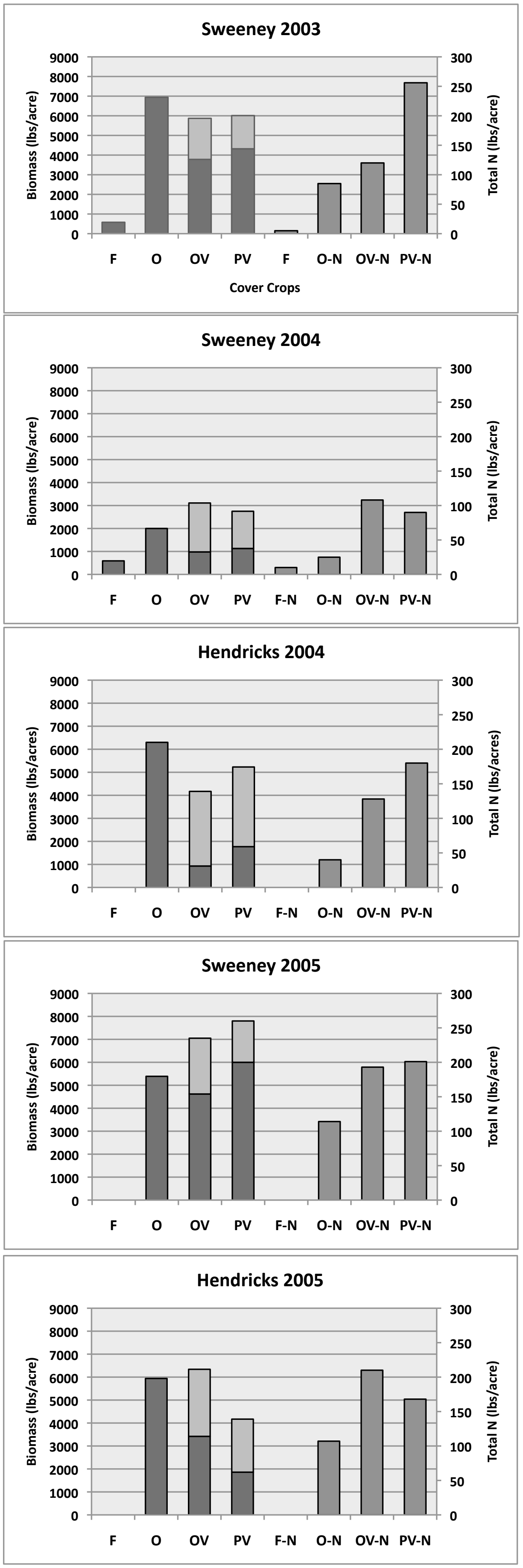


Fig. 7. Cover crop biomass (bars on left side of figure) and total nitrogent content (bars on right side).

Fig. 8. A sickle-bar mower was used to mow 75 sq.ft swaths across each cover crop block. Cover crops were raked and weighed, and subsamples taken to the lab for separation by cover crop species. Percent moisture, carbaon and nitrogen were determined.

Fig. 9. Cover crops were flail mowed, then incorporated into the soil using a Tortella powered spader. Two more passes with a Lely Roterra with a sprocket roller were used to prepare a seedbed for transplanting broccoli.

each replication using a 0.76 m-wide powered sickle bar mower (Fig. 8). Cover crops were raked within a 4.6 m long section and weighed using a hanging scale. A sub-sample was then pulled from the pile and the legumes, weeds and grasses were separated and placed in paper bags. The samples were oven dried at 65°C for 72 hours and then weighed to determine percent dry matter. Sub-samples were analyzed for percent C and N by the OSU Central Analytical Laboratory using a LECO CNS-2000®.

Effects of cover crops on N availability and yield of broccoli

A Tortella power spader and Lely Roterra ®

were used to incorporate the above-ground cover crop biomass and prepare a seed bed in mid-May (Fig. 9). A split-plot randomized block design was then established. Each cover crop plot was split into four sub-plots with different N fertilizer rates (0, 100, 200, and 300 kg N/ha), which was randomized within each cover crop treatment plot. Feather meal, an organically approved source of N, was selected for this experiment because it has an N-P-K analysis of 12-0-0. Each cover crop plot was 4.6 m x 36.6 m and the N fertilizer sub-plots were 4.6 m x 9.2 m. Feather meal was weighed and hand applied in an approximate 15 cm-wide band over the row and incorporated to a depth of 5 to 8 cm using a tine harrow.

Transplant production. 'Arcadia' broccoli seeds were planted in the greenhouse on in 200-cell trays using an organically approved potting mix. Seedlings were transplanted on May 30 through June 1, 2007 using a mechanical trans-planter and irrigated immediately afterward. Broccoli rows were on 90 cm centers, with plants spaced at 46 cm apart within the rows.

Pest management. Tractor-mounted sweep cultivators and hand hoeing were used for weed control. Insect population abundance was sampled weekly by visually examining broccoli leaves. Pyganic® was applied to control cabbage aphid on June 21 and July 3, 2007 with a power spray-boom. To control flea beetles and cabbage aphids, Safer's BioNeem (0.09% azadirachtin) was applied on July 20 using a Solo® backpack sprayer. To control cabbage loopers and imported cabbage worm, Entrust® (80% spinosad); was applied on August 6 using a Solo® backpack sprayer.

Soil Sampling. A soil sample was taken at the end of April 2007 to test pH, P and K, so that amendments could be made prior to transplanting broccoli. Lime was the only amendment needed, so prilled lime was applied at a rate of 1.2 tons/acre on May 23, 2007. Prior to planting, lime was incorporated using a Lely Roterra.

Broccoli Yield. Fifteen broccoli plants were harvested from each treatment. The broccoli plants selected for harvesting had plants on both sides and preference was given to the interior two rows of each treatment. Heads larger than 10 cm in diameter were harvested upon maturity (Fig. 10). Broccoli was harvested on 3 to 6 day intervals, from August 14 through August 30, 2007, for a total of five cuttings. The number, weight and diameter of the broccoli heads was recorded.

Following each broccoli cutting for yield data, surrounding mature broccoli was harvested, and the crop boxed and sold through several local natural and organic food stores, including a regional organic foods wholesaler. The average price received for the crop through all markets was $2.20/kg ($1. 00/lb.)

Table 6. Cover crops and seeding rates (lbs per acre) used to evaluate cover crop impacts on organic broccoli production.

Cover crops	Code	Species	Seeding rate	Seeding rate
			(Year 1)	(Year 2)
'Monida' oats	O	*Avena sativa*	80	80
Common vetch	V	*Vicia sativa*	40	40
Phacelia	P	*Phacelia tanacetifolia*	3	4
'Monida' oats plus vetch	OV	*A. sativa.*	20 / 40	20 / 40
Phacelia plus vetch	PV	*P. tanacetifolia*	2 / 40	3 / 40
No cover crop	NCC	-	-	-

Soil Nitrate Sampling. Five soil cores 6" deep were taken from the 0 N treatments in all cover crop treatments on 4 dates throughout the growing season. Soil cores were taken outside of the broccoli root zone, in the center of the rows and submitted to CAL for nitrate analysis.

Data Analysis. PROC MIXED (SAS 2007) was used to analyze the split-plot design, testing hypotheses that cover crops and N-rate affect broccoli yield, and examining the interaction between the two variables. A least squares mean test was used to calculate matrices of p-values comparing individual cover crop and N-rate treatments. P values are the SAS-calculated probability values use to examine the "statistical significance" of comparing treatment means. P-values range from 1.0 (no significance) to a very low number. The lower the number, the greater the probability that the treatment means are truly different.

Year 2. The experiment was relocated in October 2007 to an adjacent plot at the Horticulture Farm. The field had been planted in grasses from 2003 through 2004, assorted vegetables in 2005, summer buckwheat in 2006 and fallowed in 2007 before the cover crop trials were planted. In preparation for planting, the field was disked and rolled with a cultipacker, and prilled lime was applied on September 24, 2007 at a rate of 1 ton/acre and incorporated with a tine-harrow drag. Experimental treatments consisted of the same five cover crop treatments and a no cover crop control, and the same N rates.

The same experimental design as 2007 was again used, however the shape and size of the plots were reduced to make more efficient use of land and water resources. Cover crop treatment plots are 4.1 m x 24.4 m. To ensure accurate and uniform seeding rates, cover crop plots were subdivided into 4.1 m x 6.1 m subplots, and the cover crop seed weighed and hand sown. Inadvertently, the vetch treatments were not inoculated with *Rhizobium leguminosarum* at as they were last year. After seeding, a tine-harrow drag was pulled longitudinally down the length of the plots to cover the seed. After planting, irrigation was not needed due to plentiful rains in October. Cover crop biomass and N-content was sampled in early May, and analyzed as in the previous year. Cover crops were flail mowed and incorporated as in Year 1, however a modified rotary strip cultivator was modified to till 15 cm (6 in) wide bands in the plant row. Feather meal was distributed within the N rate plots by hand, and the strip cultivator was used to incorporate the feather meal and prepare a seedbed. Broccoli transplants were produced in the greenhouse, as in the previous year and hand transplanted to the field on July 10. Between row spacing was reduced to 76 cm (30 in) and in-row spacing was reduced to 35 cm (14 in). Soil nitrate sampling was conducted as in Year 1. Weed and insect control procedures were also similar to Year 1. Broccoli was harvested over five dates in late August to early September to estimate yield.

Results

Cover Crop Biomass and Nitrogen Contribution.

Year 1. The phacelia-vetch mixture produced the highest above ground, dry matter biomass (9,380 lbs/acre) and the highest amount of nitrogen (185 lbs/acre), followed by the oat-vetch mixture at 8,210 lbs of biomass per acre and 165 lbs N (Fig. 11, A & B). In both of these mixtures, the vetch component produced higher biomass than the non-legume component, and with the higher percent N of the vetch (2.5% compared to 1% for oats and 0.8% for oats, the vetch contributed the greatest proportion of nitrogen to the mixture (Table 6). In both of the mixtures, the non-legume component contained a higher percent N than the same crop grown as a sole crop, showing the increased uptake of N from the associated legume. The high C: N ratio of the oat (68:1) and the phacelia (66:1) were likely responsible for nitrogen immobilization and subsequent reduction of broccoli yield described above.

Fig. 10. Broccoli heads were harvested, trimmed and weighed for yield estimation. Individual broccoli head diameters were also measured. Harvest occured on 3-6 day intervals from Aug. 14 to Aug. 30, 2007; Aug. 26 to Sept. 12, 2008.

Year 2. Cover crops established very poorly in the fall of 2007 as result of unusually onset of cold, rainy weather. Cold wet weather throughout the fall and winter produced rather weak cover crop stands in the spring of 2008, as shown in Fig. 11, C & D. Legume nitrogen in the vetch and vetch mixtures was about a third of that produced in 2007.

Broccoli Yield.

Year 1. SAS analysis revealed a highly significant interaction between cover crops and N-rates (p = .02), therefore cover crop treatment effects were examined for each N-rate separately. Cover crops affected broccoli yields for both the zero and 100 kg N/ha rates (p = .01, and .02 respectively), whereas the cover crop effects were lost at the higher N rates of 200 and 300 kg N/ha (p = .32 and .75 respectively). Therefore, most of the following discussion of cover crop effects will focus on the zero and 100 kg/ha N rates, with p-values comparing individual treatment means are shown in the p-value table (Table 7). At the zero N-rate, oat sole crops reduced broccoli yield by 67% compared to the no-cover crop fallow (p = .01), and the phacelia sole crop reduced broccoli yield by 33% (p = .12) (Fig. 12). At the 100 kg N rate, oats continued to reduce yield compared to the fallow treatment (p = .10), however there was no yield loss in the phacelia blocks (p = .77) These yield reductions were likely caused by nitrogen immobilization by soil microorganisms. Many other cover crop studies have shown crop yield loss following relatively high C: N ratios of the cover crop residue at time of incorporation.

The addition of legumes in the oat-vetch (OV) and phacelia-vetch (PV) mixtures compensated for the yield-suppressive effects of the oats and phacelia, with broccoli yields exceeding the fallow treatment in the PV blocks at zero nitrogen (p= .06), and OV mixtures increasing yields in the 100 kg N rate treatment (p = .03) (Fig. 12). The OV mixtures produced nearly three times greater broccoli yields than the oats alone at both zero and 100 kg N/ha (p = .02, .01). The PV mixture increased broccoli yields over phacelia alone at the zero N rate (p=. 01), however increases were not significant at the 100 kg N rate (p = .18).

Vetch as a sole crop failed to increase yields over the fallow in the 100 kg N rate (p = .73), and although average broccoli yields were increased over the fallow by one ton per acre in the zero N rate treatment, the effect was not likely different (p = .20). Although there as no overall cover crop treatment effect in the 200 kg N rate treatment, the PV treatment increased yields over the fallow, oat, and OV treatments (p = .08, .05, and .06).

Year 2. SAS analysis revealed no interaction between cover crops and N rate, with all treatment yields increasing linearly with increasing fertilizer rate. Both the oat and phacelia cover crops (without legumes) reduced broccoli yields across all N rates. Although the total N accumulation in the oat-legume

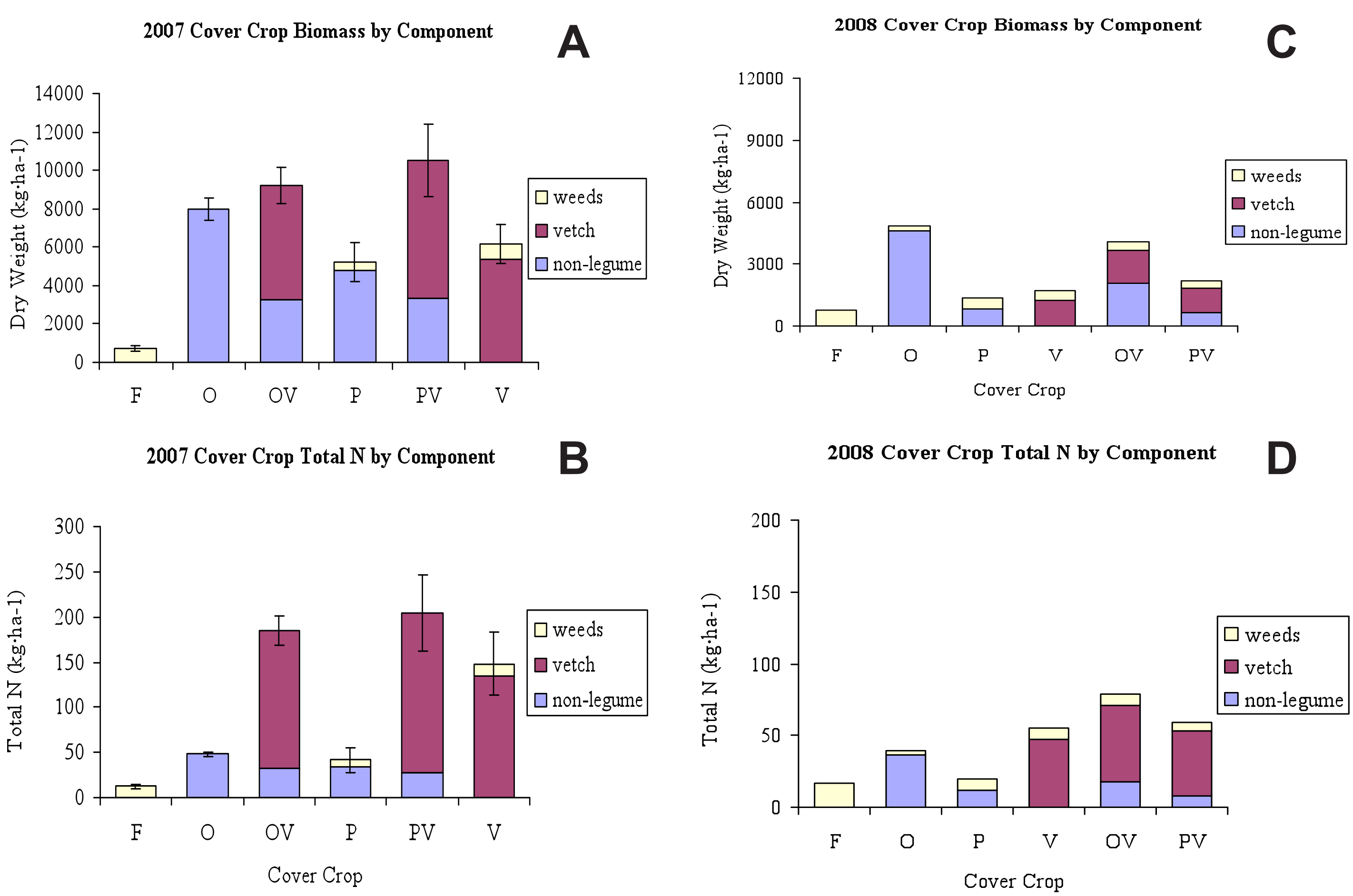


Fig. 11.Cover crop component biomass (A = 2007; C = 2008) and nitrogen content (B = 2007; C = 2008). Cover crop biomass sampled May 12, 2007 and May 14, 2008..

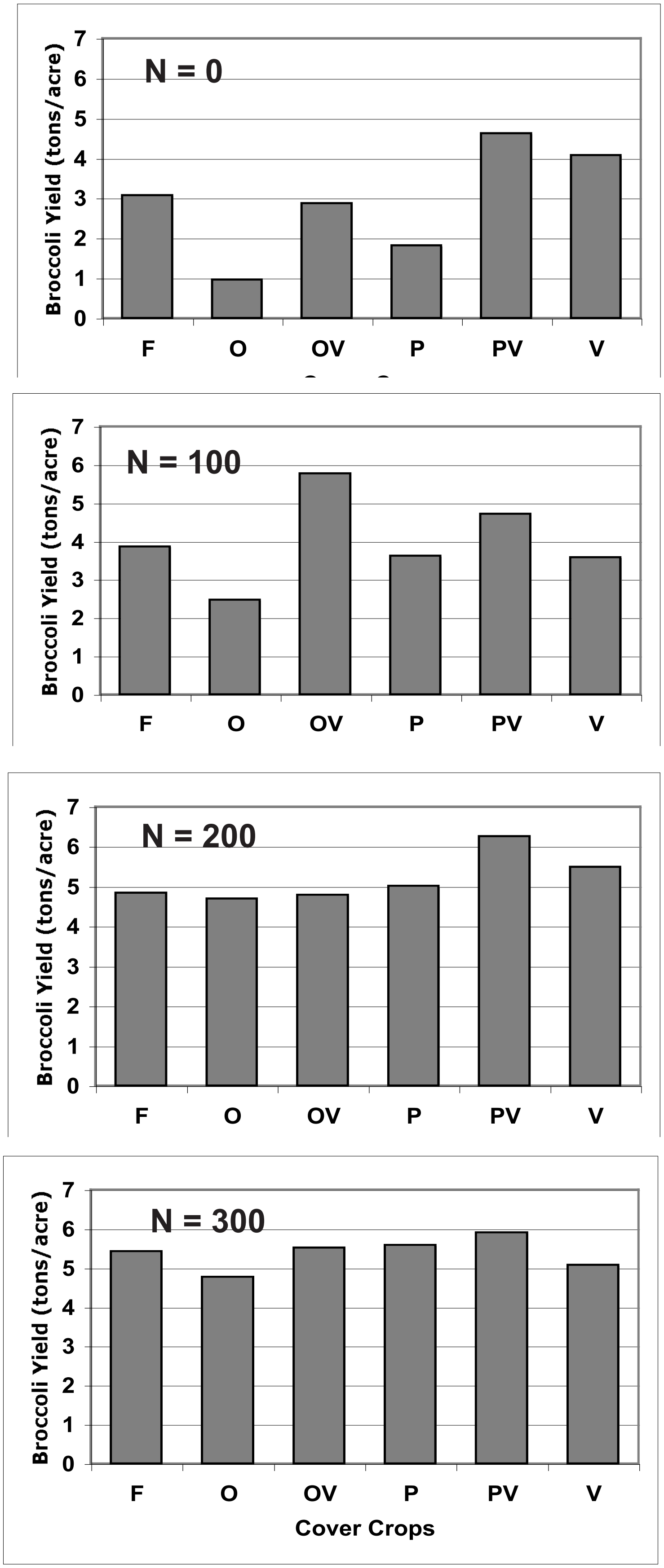


Fig.12. Effects of cover crops on broccoli yield, 2007, Corvallis, Oregon. Cover crop abbreviations: F = fallow, O = 'Monida' oats, OV = oats + common vetch, P= phacelia, PV= phacelia + vetch. N = 4.

N = 0

F	O	OV	P	PV	V	
	.01	.79	.12	.06	.20	F
		.02	.27	>.01	>.01	O
			.18	.03	.13	OV
				>.01	>.01	P
					.48	PV
						V

N = 100

F	O	OV	P	PV	V	
	.10	.03	.77	.29	.73	F
		>.01	.16	.01	.17	O
			.02	.20	.01	OV
				.18	.96	P
					.17	PV
						V

***Table 7.** P-values associated with comparing individual cover crop treatment affects on broccoli yield in the zero and 100 lbs N/acre fertilizer rate. P-values range from zero to one, with low values representing high probability of treatment means being different; high values indicate low probability of being different (F = fallow; O = oats; OV = oat-vetch mixture; P = phacelia; PV = phacelia-vetch mixture, and V = vetch only.)*

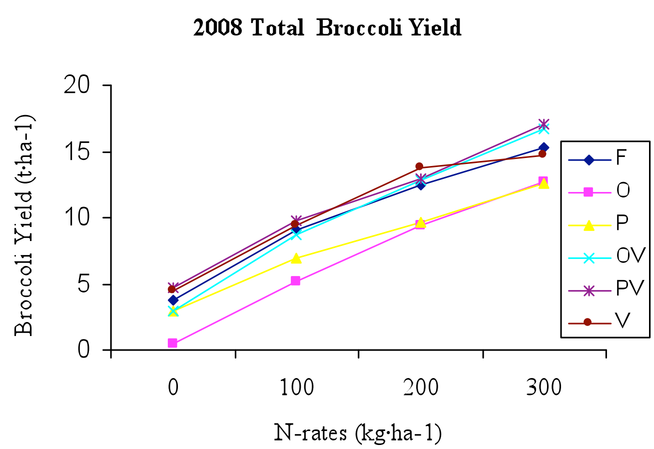


Fig. 13. Broccoli yields in 2008, the second year of the study. Vetch and vetch mixture cover crops increased yields over no cover crop control. The straight oat and phacelia cover crops reduced yields.

or phacelia-legume mixtures was considerably less than in Year 1, this was enough to overcome the apparent N immobilization occurring with the oats and phacelia (Fig. 13).

Soil Nitrate. Soil nitrate values through the season for both years followed the pattern of broccoli yield, with the highest soil nitrate found in the vetch and vetch mixtures and the lowest soil nitrate found in the oat and phacelia sole crops. Soil nitrate in the fallow plots was intermediate between the vetch mixtures and the sole crops. These data clearly reveal the nitrogen immobilization effects of high C:N ratio cover crops, and how the addition of legumes to the mixture can alleviate this effect.

Economic Analysis

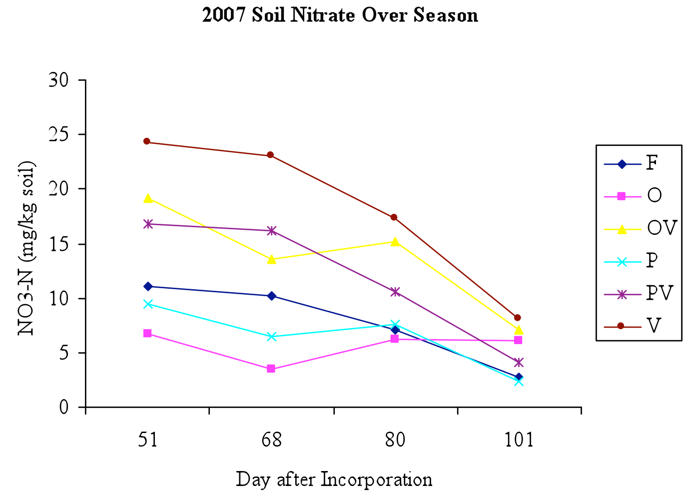
The advantages of legume-based cover crop mixtures over sole crops are apparent in this study, both for increasing broccoli yield, but also for increasing soil organic matter. In year 1, broccoli yield was severely reduced by oat cover crops at the zero and 100 kg N rate, requiring up to 200 kg N/ha of supplemental fertilizer to overcome the yield loss. The phacelia-vetch mixture, however, *increased* broccoli yield compared to the fallow treatment by an average of 1.3 tons per acre (1.5, 0.8, and 1.5 tons broccoli/acre at zero, 100 and 200 kg N). The oat-vetch cover crop mixture also increased broccoli yield, but only at the 100 kg N rate. Broccoli yields were virtually identical at the other three N rates (see Fig. 12). At the 100 kg N rate, however, the oat-vetch treatment produced the highest broccoli yield, 5.8 tons/acre, which was 1.9 tons higher than the no cover crop fallow plots.

Both the oat-vetch and the phacelia-vetch mixtures at 100 lbs fertilizer N per acre produced similar yields to the fallow treatment at 200 kg N/ha, suggesting a 100 kg of "N fertilizer equivalency" or fertilizer replacement value.

Cover crop seeding costs were higher in the phacelia-vetch mixture ($42/acre) compared to $21/acre for the oat-vetch mixture, due to the higher cost of the phacelia seed ($7/lb). However, because the cover crop was broadcast seeded in this experiment, a higher seeding rate of phacelia (3.5 lb/acre) was used than rates (2 lbs/acre) used previously in other trials where the cover crop was planted with a grain drill.

No estimates were made of the economic contribution of the cover crops to short and long-term soil quality. However the cover crop mixtures contributed 4 to 5 tons of dry matter biomass per acre to the soil. Averaging 41% percent carbon, this represents a carbon contribution of 1.6 to 2 tons C per acre. Increasing soil organic matter is critically linked to short and long term soil productivity and sustainability.

The yield impacts reported in this study are relevant to crops typically planted in mid to late May or early June, across the maritime Pacific Northwest. Because



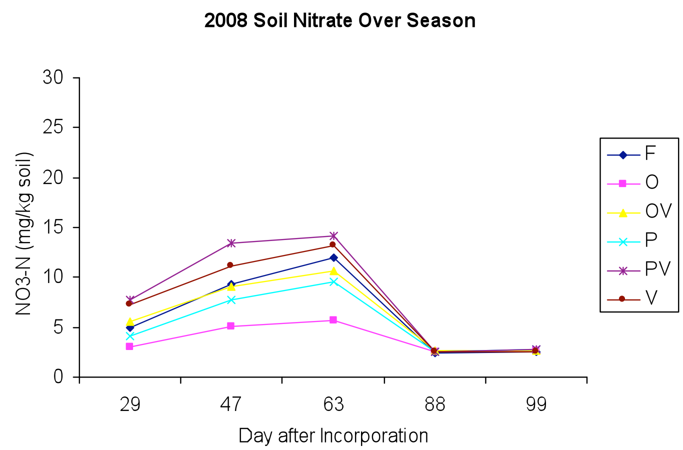


Fig. 14. Soil nitrate sampled between the crop rows in the zero N treatments, 2007 and 2008.

yield impacts are likely related to total mineralizable N accumulated by the cover crops, killing the cover crops and planting vegetable crops earlier in the spring will not likely produce the same level of response. Cover crops killed earlier will likely have less legume nitrogen, since vetch is growing rapidly in the spring. At the same time, sole crops of cereals, such as oats in this study, will also not be as mature and will have a higher percent N in the tissue. This would likely produce less N immobilization and yield loss as was seen in this experiment.

This research applies to sweet corn production in the Willamette Valley, since corn is also a high N user like broccoli. With more than 2/3 of the processed sweet corn acreage planted after June 1 (M. Silvera, personal communication), there is ample opportunity to grow an significant quantity of legume biomass before having to kill it and prepare fields for planting.

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