Oilseed Cover Crops Relay Planted With Soybean: Yields, Economics, and Nutrient Uptake Across Minnesota

Matthew A. Ott[1], Carrie A. Eberle[2], Matt D. Thom[1], Frank Forcella[3], Russell W. Gesch[3], Donald L. Wyse[1], James J. Eklund[3] and Dean H. Peterson[3],
(1)Agronomy and Plant Genetics, University of Minnesota, St. Paul, MN, (2)Plant Sciences, University of Wyoming, Lingle, WY, (3)USDA-ARS, Morris, MN

Abstract

Many agricultural watersheds in Minnesota have excessive phosphorus and nitrogen, much of which originate in agricultural fields that are fallowed from October through May. Autumn-sown winter cover crops can be used to retain these nutrients. Soil NO_3-N and PO_4^{-3} -P levels and quantities of N and P sequestered by winter rye (*Secale cereale*), forage radish (*Raphanus sativus*), and the oilseed crops, winter camelina (*Camelina sativa*), and pennycress (*Thlaspi arvense*) were evaluated in a relayed cover crop/soybean production system at three sites spanning the north-south climatic gradient of Minnesota. Forage radish sequestered the most N in autumn, but winter-killed and had high soil NO_3-N levels in spring. Winter rye was terminated chemically by early May at each site, whereas the oilseed crops were allowed to grow into June to full maturity and their seeds were harvested. In autumn through early May, winter camelina and pennycress sequestered about 25% less N than winter rye. However, they often sequestered ≥ 2.5 times more N and ≥ 2 times more P than winter rye when compared at maximum seasonal biomass (up to 130 and 20 kg ha^{-1}, respectively), with some of this N and P coming from a spring application. Oilseed sequestration efficiency of applied N and P ranged from 44-120% and 23-40%, respectively. Winter camelina yields ranged from 600 to 1100 kg ha^{-1}, while pennycress yields ranged from 900 kg ha^{-1} to 1550 kg ha^{-1}. When combined with yields of relay-cropped soybean, net income for relay-crop systems was generally equivalent to mono-cropped soybean.

Materials and Methods

- Study was conducted from August 2014 to October 2016, spanning two complete growing seasons.
- Conducted in: Waseca (southern MN), Morris (west central MN), and Roseau (northern MN).
- There were four autumn-planted cover crop treatments, a tilled winter fallow control, and a no-tilled fallow control with spring wheat stubble (referred to as stubble hereafter) placed in a randomized complete block experimental design that included four blocks for each site-year.
- The four cover crop treatments were winter rye, an improved forage radish variety called Tillage Radish® (hereafter, radish), winter camelina ('Joelle'), and pennycress ('Beecher Farms').
- Plots were 3 m by 9.1 m, in which 12 rows of cover crops and later 4 rows of soybean were planted. Cover crops were sown in 25 cm spaced rows in early autumn into spring wheat stubble with a no-till drill.
- Winter camelina and pennycress at all sites were fertilized by broadcasting 80-30-30 kg ha^{-1} N-P-K after the late April or early May soil sampling date.
- Appropriate maturity group soybeans were sown in 76 cm spaced rows into growing winter camelina and pennycress that were beginning to bolt, into standing winter rye that was killed with glyphosate (1.1 kg a.e. ha^{-1}), and into fallow plots for the other treatments.

Table 1 Summary of Crop Operations and Specifications

Crop	Year	Seeding Rate	Planted Depth	Planting/Removal Date: Waseca	Morris	Roseau	Removal Method
Radish	2014/15	11 kg ha^{-1}	1.3 cm	5 Sep/NA	2 Sep/NA	28 Aug/NA	Winter Killed
	2015/16			22 Sep/NA	31 Aug/NA	3 Sep/NA	
Rye	2014/15	7.6 kg ha^{-1}	1.3 cm	5 Sept/27 Apr	2 Sep/1 May	28 Aug/4 Jun	Glyphosate Application
	2015/16			22 Sep/5 May	31 Aug/22 Apr, 16 May	3 Sep/17 May	
Camelina	2014/15	6.7 kg ha^{-1}	0.6 cm	5 Sep/18 Jun	2 Sep/2 Jul	28 Aug/2 Jul	Harvested
	2015/16			22 Sep/23 Jun	31 Aug/23 Jun	3 Sep/7 Jul	
Pennycress	2014/15	6.7 kg ha^{-1}	0.6 cm	5 Sep/18 Jun	2 Sep/23 Jun	28 Aug/1 Jul	Harvested
	2015/16			22 Sep/21 Jun	31 Aug/16 Jun	3 Sep/7 Jul	
Soybean	2015	444,800 seeds ha^{-1}	2.5 cm	24 Apr/2 Oct	30 Apr/15 Sep	5 May/6 Oct	Harvested
	2016			3 May/6 Oct†	22 Apr/19 Sep‡	17 May/3 Oct	

†For one block, soybean was harvested on 13 Oct for these treatments: Stubble, Tilled, Winter Rye, Radish
‡For all blocks, soybean was harvested on 29 Sep for the Pennycress and Winter Camelina treatments

Results

Oilseed and Soybean Yields

- Range in camelina yield: 600 kg ha^{-1} (Roseau 2015) to 1100 kg ha^{-1} (Waseca 2015).
- Range in pennycress yield: 900 kg ha^{-1} (Morris 2015) to 1550 kg ha^{-1} (Roseau 2015).
- Range in soybean yield: 443 kg ha^{-1} (Roseau 2015 relayed into pennycress) to 4596 kg ha^{-1} (Waseca 2016 relayed into camelina).
- Mono-cropped soybean averaged 1819, 3510, and 4180 kg ha^{-1} in Roseau, Morris, and Waseca, respectively, which matches the yield expectations for climates of these regions.
- Net income was generally not significantly different between aggregated oilseed and soybean treatments compared to soybean alone. The range was from $77 to $1483 ha^{-1} for pennycress plus soybean, -$130 to $1481 ha^{-1} for camelina plus soybean, and $88 to $1319 ha^{-1} for soybean alone in tilled treatments, all in Roseau and Waseca, respectively. Cost estimates used were from Gesch et al. 2014, adjusted for appropriate seed, fuel, and fertilizer prices.

Cover Crop Nitrogen and Phosphorus Sequestration

- Cover crop biomass samples were analyzed for dry weight, percent N/P, and N/P uptake per unit area.
- Radish produced more biomass (up to 2500 kg ha^{-1}) and sequestered more N (up to 100 kg N ha^{-1}) than other cover crops in autumn, but it winter-killed , and thus sequestered less N overall (Table 2).
- Winter rye occasionally produced more biomass (up to 1900 kg ha^{-1}) in spring and sequestered more N and P (up to 50 kg N and 8 kg P ha^{-1}), than the oilseed crops, but it was sprayed with glyphosate after spring biomass sampling, which prevented it from continuing to sequester N and P.
- Camelina and pennycress accumulated significantly more biomass in total than either radish or winter rye, since they overwinter and mature early, which permits them to be relay cropped with soybean . More total biomass production often allowed them to sequester ≥ 2.5 times more N and ≥ 2 times more P than winter rye when compared at their maximum seasonal biomass (up to 130 and 20 kg ha^{-1}, respectively), with some of this N and P coming from a spring application. Oilseed sequestration efficiency of applied N and P ranged from 44-120% and 23-40%, respectively. Frequently observed higher percentages of N in oilseed biomass also contributed to greater N sequestration than winter rye (data not shown here).

Acknowledgments

This project was funded by the Minnesota voters who passed the Clean Water, Land, and Legacy Amendment in 2008 to provide resources to improve Minnesota's environment, arts, and cultural heritage for 25 years.

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Figure 1. Yield comparison of soybean for four cover crop and two control treatments. For each pair of bars, left is 2015, right is 2016. WC=Winter Camelina, PC=Pennycress, RY=Winter Rye, RA=Forage Radish, ST=Stubble, TI=Till. Values are means ± SE, *n*=4.

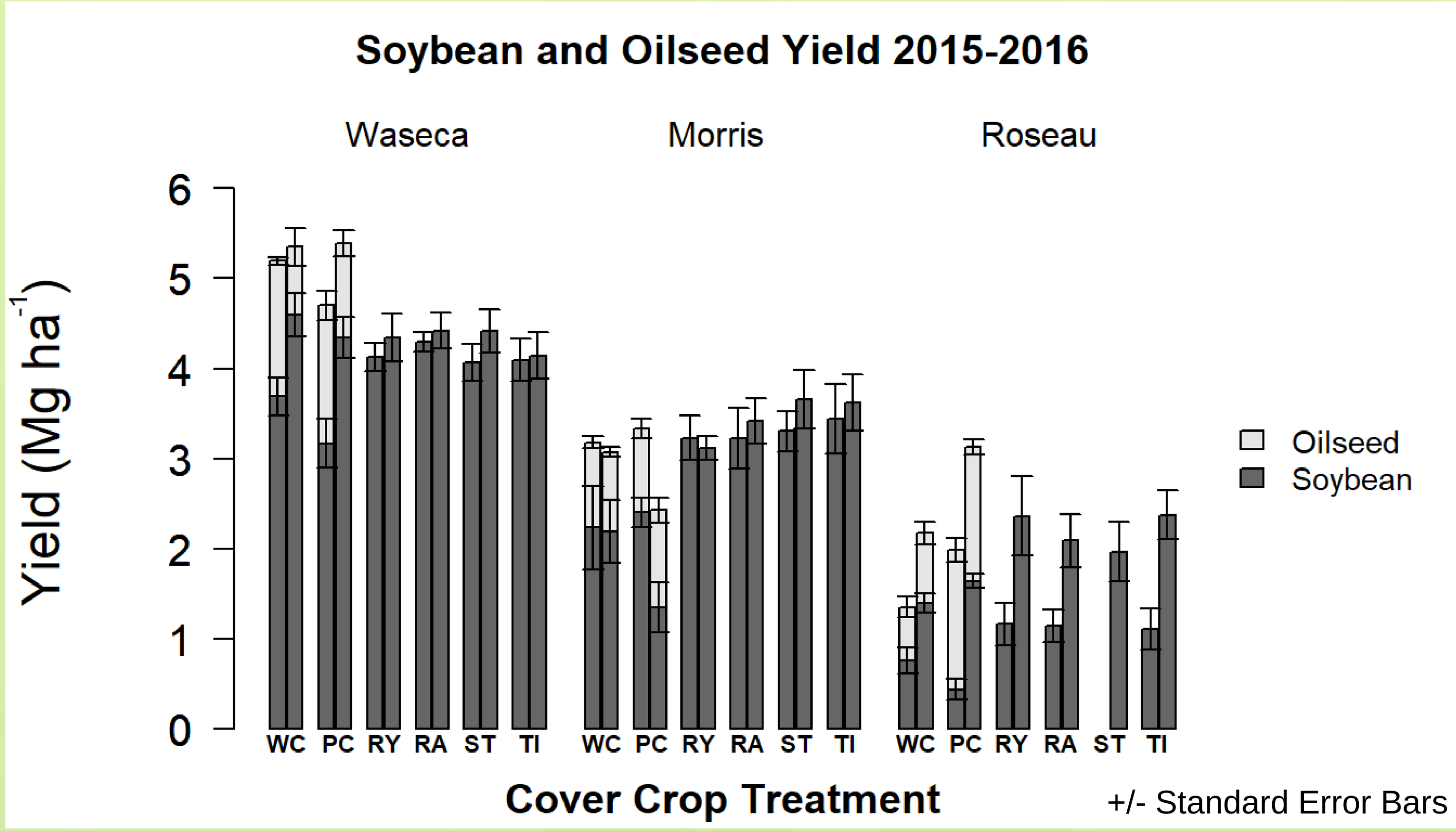

Figure 2. Soybean growing underneath a canopy of pennycress. Credit: Carrie Eberle

Table 2

Month/Year	Cover Crop Treatment	Waseca: Above Ground Biomass (kg ha^{-1})	Waseca: Sequest-ered N (kg ha^{-1})	Waseca: Sequest-ered P (kg ha^{-1})	Morris: Above Ground Biomass (kg ha^{-1})	Morris: Sequest-ered N (kg ha^{-1})	Morris: Sequest-ered P (kg ha^{-1})	Roseau: Above Ground Biomass (kg ha^{-1})	Roseau: Sequest-ered N (kg ha^{-1})	Roseau: Sequest-ered P (kg ha^{-1})
Sept./Oct. 2014	Radish	1579a	41a	NA	1032a	32a	NA	2529a	104a †	NA
	Rye	1413a	41a		829ab	26ab		1319b	57b	
	Camelina	1045ab	24b		488bc	16bc		1030bc	36c	
	Pennycress	631b	14b		237c	7c		684c	26c	
Apr. 2015	Rye	1083a	39a	3.5NS	770NS	26a ‡	2.4NS	1810a	50a ‡	8.3NS
	Camelina	669b	30ab	3.8	525	29a	2.5	1095a	41a	6.7
	Pennycress	492b	20b	2.1	1015	48a	4.4	1442a	62a	10
Apr. 2015 (max. biomass)	Rye	1083b	39b		770b	26b	2.4b	1810b	50b	8.3b
May/Jun. 2015 (max. biomass)	Camelina	4348a	129a		3260a	115a	13a	3501ab	123ab	15a
	Pennycress	3985a	94ab		3617a	104a	15a	3957a	131a	21a
Sept./Oct. 2015	Radish	105a	3.46a	NA	1396a	38a	NA	381a	12a†	NA
	Rye	63ab	2.3ab		673b	27ab		293ab	11ab	
	Camelina	40b	1.6b		302bc	14bc		121b	8b	
	Pennycress	27b	1.12b		123c	6c		270ab	5ab	
Apr. 2016	Rye	901a	27NS	4.7NS	1776NS	41NS	7.2NS	1909a	27NS	6.4NS
	Camelina	526b	24	3.9	1147	37	5	342b	17	2.2
	Pennycress	429b	20	3	1983	57	6.8	1045ab	35	5
Apr. 2016 (max. biomass)	Rye	890b †	27b †	4.7NS	1776b	41b	7.2b	1909NS	27b	6.4NS
May/Jun. 2016 (max. biomass)	Camelina	3407a	81ab	11	4422a	120a	17a	3393	67a	11
	Pennycress	2161a	55a	9	3906a	99a	14a	3112	83a	13

† indicates log transformation to meet assumptions of ANOVA
‡ indicates significance at the P<0.05 level

Discussion

If pennycress and/or camelina were planted on the 40 million fallow acres in the Midwest in autumn, 1-6 billion gallons of oil could be produced (Winchester et al. 2013), which would serve well as biodiesel or jet fuel (Jan et al. 2013, Shonnard et al. 2010, Moser 2010). A key finding in this study was that relay-cropping oilseeds and soybean with the current germplasm, at the given row spacing and planting dates, was correlated with decreased soybean yield compared to mono-cropped soybean. Our future agronomic research will investigate how soybean yield responds to skip-row planting of oilseeds – in which a seed box on the planter is not filled with oilseeds for every planned row soybean to be planted. Though net income from the oilseed cover crop-soybean system was never greater than in the mono-cropped soybean, income-neutrality with oilseed cover crops may actually be a better starting point for further development than with cover crops that cost a similar amount, but have yet to result in substantial direct income to growers. Since the earliest that winter rye matures in the Upper Midwest is not until the third week in July (Oelke et al. 1990), the only income it can provide in a double-cropping system with soybean is as a forage or cellulosic ethanol feedstock, which are less lucrative commodities compared to oilseeds.

Pennycress and camelina are still being domesticated, and there have been several recent advances in the pennycress germplasm (Dorn et al., 2015 and Folstad 2016), which suggests there is a great potential for improvement in pennycress and camelina. Since pennycress has a relatively high baseline yield across the Minnesota and camelina does so in the central and southern regions of the state, gains from domestication may make them the most eligible cover crops to change the Upper Midwestern landscape.

The extent of N sequestered by the two winter oilseed crops is notable, with ranges of 67 to 129 kg ha^{-1} for camelina and 55 to 131 kg ha^{-1} for pennycress (Table 2). These values represent appreciable levels of sequestration during a time of year when N is vulnerable to loss by erosion and leaching. Direct sequestration of P by the oilseed crops was not as notable (up to 21 kg ha^{-1}), but others have demonstrated that cover crops significantly reduce P movement by preventing erosion (Kovar et al. 2011). The rate of applied N and P in the spring has been shown to optimize oilseed yield in west central Minnesota (Johnson and Gesch, 2013). Further investigation into factors influencing the sequestration efficiencies of oilseed crops with regard to applied N and P under different conditions would be worthwhile. With over half of Minnesota's 81 watersheds polluted by P and over a fourth polluted by N, it is clear why improving Minnesota's water quality is a top priority garnishing some bipartisan support. As breeding for each of these crops continues at the University of Minnesota and elsewhere, further improvements in their capacity to produce carbon-neutral fuels as well as capture excess nutrients are expected.

Contact: ottxx142@umn.edu