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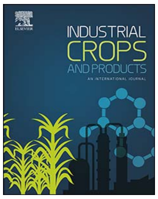

Integrating winter camelina into maize and soybean cropping systems

Marisol Berti[a,*], Dulan Samarappuli[a], Burton L. Johnson[a], Russ W. Gesch[b]

[a] North Dakota State University, Fargo, ND, USA
[b] USDA-ARS-NCSCRL, 803 Iowa Ave, Morris, MN 56267, USA

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ABSTRACT

Camelina [*Camelina sativa* (L.) Crantz.] is an industrial oilseed crop in the Brassicaceae family with multiple uses. Currently, camelina is not used as a cover crop, but it has the potential to be used as such in maize (*Zea mays* L.)-soybean [*Glycine max* (L.) Merr.] cropping systems. The objective of this study was to determine the agronomic performance of winter camelina intersown as a cover crop into standing soybean or maize prior to their harvest. Experiments were conducted in Fargo, ND in 2014, Prosper, ND, in 2015, and in Morris, MN in 2014 and 2015. The experimental design was a randomized complete block design with a split-plot arrangement with three replicates. The main plot was row spacing (61 and 76 cm in maize, 31 and 61 cm in soybean) while the sub-plot was maize or soybean growth stage at relay-sowing of camelina. Winter camelina was sown on four different dates: Date 1 (SD1), at the same sowing date as maize and soybean, Date 2 (SD2) at V4-V5 of maize and V3-V4 of soybean growth stages, Date 3 (SD3) at 'silking' of maize and R1-R2 stage of soybean, and Date 4 (SD4) after maize and soybean harvest. Camelina establishment into standing maize and soybean largely depended on rainfall after sowing. Camelina intersown on SD1 resulted in lower maize and soybean grain and biomass yield of 14 and 10%, respectively, whereas intersowing after SD2 had no significant effect on yield.. Camelina N accumulation varied between 24 and 59 kg N ha^{-1} and P accumulation ranged between 4.3 and 9.2 kg P ha^{-1} in the spring when sown after maize and between 14 and 57 kg N ha^{-1} and 1.5 and 6.9 kg P ha^{-1} after soybean. Results indicate that camelina intersown after V4-V5 of maize or V3-V4 of soybean stages will likely avoid competition with the primary cash crop. Camelina establishment and winter survival was best when sown after maize and soybean harvest, and tended to be greater in soybean. However, there are many unanswered questions on camelina intersowing management. New research will allow optimization of intersowing management to increase yields of both crops while enhancing ecosystem services.

1. Introduction

Camelina [*Camelina sativa* (L.) Crantz.] seed meal and oil have multiple uses and applications as feedstock for biofuel, animal feed, human food, and many more (Berti et al., 2016). Camelina has been grown since 4000 BCE, although it is not a well-known or widely produced crop. In the last 10 years, abundant new research in camelina uses, genetics, and agronomic management have been published indicating great interest and potential of this crop due to product end-use diversity (Berti et al., 2016).

One new potential use of camelina is as a cover crop in maize-soybean rotations in the Midwest USA. Winter camelina can be direct-sown following the harvest of short-season cereals such as wheat (*Triticum aestivum* L.) (Gesch and Archer, 2013; Berti et al., 2015) and it has the potential to be established by broadcasting into longer season standing crops such as maize and soybean.

Integrating winter camelina into maize-soybean cropping system will likely increase biodiversity, and reduce: i) soil erosion, ii) nitrate leaching, iii) phosphorus run-off, and iv) production input costs, while maintaining or improving the yield of the primary cash crop.

Generally, broadleaf cover crops do not survive most winters in the northern Great Plains (NGP) region of the USA, even when drilled in later summer to early autumn. Therefore, identifying new winter-hardy broadleaf cover crops is necessary for incorporation into the NGP cropping systems.

Winter camelina is very winter hardy and has been demonstrated to be successfully double- and relay-cropped with soybean and forage sorghum [*Sorghum bicolor* (L.) Moench] (Gesch et al., 2014; Berti et al., 2015). In the NGP, winter camelina can be sown during fall (between early-September to mid-October) after a cereal crop harvest. It germinates even when soil temperatures are as low as 1°C (Gesch and Cermak, 2011). Plants established in the autumn remain in the rosette stage over winter and resume growth the following spring after which they bolt, flower, set seed, and mature in early summer (Grady and

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* Corresponding author.
E-mail address: marisol.berti@ndsu.edu (M. Berti).

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Nleya, 2010).

Planting a cover crop in conventional maize-soybean production systems in the northern regions of the USA is challenging due to the narrow establishment window, short growth period, and limited soil water availability (Bich et al., 2014). In areas with longer season, cover crops can be sown by drilling or aerial broadcasting after harvesting the primary cash crop (Wilson et al., 2014). Unfortunately, when cover crops are broadcast, establishment depends largely on rainfall shortly after sowing and if not received, the probability of failed stand establishment increases (Fisher et al., 2011).

In order to improve establishment of cover crops, many researchers have started investigating the establishment of cover crops by intersowing at early growth stages of maize (V4-V8). Intersowing of cover crops or legumes in winter wheat has been evaluated in Europe (Bergkvist et al., 2011). Most studies report no penalties on grain yield of wheat or oat (*Avena sativa* L.) when cover crops are intercropped into the cereal crop (Bergkvist et al., 2011; Amossé et al., 2013; Neugschwandtner and Kaul, 2014). In maize-soybean systems, most research on intersowing has been done in organic production systems in an effort to reduce weed pressure without decreasing grain yield (Baributsa et al., 2008; Belfry and Van Eerd, 2016).

Intersowing camelina into standing cash crops is not common. However, mixed cropping of camelina, with pea (*Pisum sativum* L.), lupin (*Lupinus angustifolius* L.), or wheat was evaluated in an organic cropping system by Paulsen (2007) in Germany. Both crops were grown and harvested together and sorted by seed size screening post-harvest. Overall, yields of mixed cropping with camelina were similar or lower than the sole crop with good legume plant stand. In years with poor legume stand, camelina was able to fill gaps on grain legume establishment for a higher total yield of both crops as compared with the total yield of sole legumes (Paulsen, 2007). Winter camelina was intercropped with barley (*Hordeum vulgare* L.) in Lithuania in an organic system to reduce weed pressure. After drilling camelina in strips between the rows of barley, weed density decreased by 1.79 times (Raslavicius and Povilaitis, 2013). Additionally, camelina can be grown in mixtures with flax (*Linum usitatissimum* L.), or rape (*Brassica napus* L.), to produce on-farm-biodiesel (Paulsen, 2008, 2011; Paulsen et al., 2011).

Intersowing of winter camelina into standing maize and soybean as a cover crop in the establishment season has not been previously studied. The objective of this study was to determine the overall agronomic performance of intersowing winter camelina as cover crop into a standing soybean and maize to provide soil cover in late fall and early spring, recycle nutrients, and provide secondary grain production in the season after establishment.

2. Materials and methods

2.1. Field description and management

Experiments were conducted at two North Dakota State University research (NDSU) sites at Fargo, ND (46° 89′ N, −96° 82′ W, 274 m elevation) in 2014, and Prosper, ND (46°58′ N, −97° 3′W, elevation 284 m) in 2015, and at the Swan Lake Research Farm, Morris, MN (45° 35′N, −95° 54′W, elevation 344 m) in 2014 and 2015. The soil type in Fargo was a Fargo silty clay soil (fine, montmorillonitic, frigid, Vertic Haplaquoll, with a leached and degraded nitric horizon), while the soil in Prosper was a Kindred-Bearden silty-clay loam (Perella: fine-silty, mixed, superactive Typic Endoaquoll; Bearden: fine-silty, mixed, superactive, frigid Aeric Calciaquoll). The soil type at Morris was a Barnes loam soil (fine-loamy, mixed, superactive, frigid Calcic Hapludoll). The previous crop at all three locations was either oat (*Avena sativa* L.) or soybean and the experimental plots were not tilled.

Daily temperature and rainfall were recorded by the North Dakota Agriculture Weather Network (NDAWN) system at Fargo and Prosper and by an automated weather station at the Swan Lake Research Farm. Soil samples were taken at all locations for analysis at the beginning of each experiment in 2014 and 2015, at both locations before the crops were sown. Soil samples were taken at a 0- to 15-cm depth and tested for pH, organic matter, Olsen P (Olsen et al., 1954), and K, while the NO_3—N analysis was done from the soil samples taken at 0- to 15-cm and 15- to 60-cm depth with Vendrell and Zupancic (1990) method.

2.2. Experiment description

The experimental design was a randomized complete block design with a split-plot arrangement and three replicates. The main plot was the row spacing (61-cm and 76-cm in maize and 31- and 61-cm in soybean) and the sub-plot was the maize or soybean growth stage at the time camelina was intersown into the standing crop. Check plots of maize and soybean were not intersown with camelina. Maize and soybean were analyzed as separate experiments. Experimental units were 7.6 m long and all had four rows of either maize or soybean regardless the row spacing.

The maize hybrid used was 75K85 GEN VT2PRO (85 d maturity, Roundup Ready™). The soybean variety was 13R08N GEN RR2Y (maturity group 0.8 Roundup Ready™). Sowing rates were calculated based on the percentage of pure live seed (PLS), taking purity and germination percentage into account. Soybean seeds were not inoculated before sowing. Targeted plant density was 86,450 and 432,250 plants ha^{-1} for maize and soybean, respectively.

Maize was sown on 22 April, and 29 April 2014 at Morris and Fargo, respectively, and on 22 May and 27 May 2015 at Morris and Prosper, respectively. Maize was sown at a depth of 50 mm (on minimum-till soil) with a 4-cone plot seeder (Wintersteiger Plotseed XL, Salt Lake City, UT) for the 61-cm row spacing and with a 4-row seeder (John Deere MaxEmerge 1730, Ankeny, IA) for the 76-cm row spacing.

Winter camelina was intersown between maize rows on four different dates: Date 1 (SD1), at the same sowing date as maize, Date 2 (SD2) at V4-V5 maize growth stage, Date 3 (SD3) at ‘silking’ maize growth stage, and Date 4 (SD4) after maize harvest. In Morris, SD2 was sown on 23 June 2014 and 22 June 2015; SD3 on 29 July 2014 and 28 July 2015, and SD4, on 1 October 2014 and 21 October 2015. In Fargo, SD2, SD3, and SD 4 were sown on 2 July, 8 August, and 8 October 2014, respectively. In Prosper, SD2, SD3, and SD4 were sown on 30 June, 9 August, and 21 October 2015, respectively.

For SD1 treatment, camelina was sown with an 8-row cone drill (Wintersteiger Plotseed XL, Salt Lake city, UT), at 15-cm row spacing right after the maize and soybean seeding and off-set by 7.5 cm from the primary crop rows. For the SD2, SD3, and SD4 in maize and soybean, camelina seed was hand-broadcasted without incorporation between the primary crop rows. Having the SD1 drilled and the other sowing dates broadcasted, could have confounded some of the results. This was done, since it is possible to sow at the same time as the main crop, but it is not possible to sow over the crop once is emerged. Nowadays, new sowing equipment is available to allow intersowing in V6-V8 of maize. The camelina seeding rate in both maize and soybean was 10 kg ha^{-1} PLS for all sowing dates. For SD1, seeds were sown to a depth of approximately 1.3 cm.

Soybean was sown on the same dates as maize at Morris in 2014 and 2015 and at Prosper in 2015, using the same equipment as used for sowing maize. The soybean at 31-cm spacing was sown with the same planter as for 61-cm row spacing. Winter camelina was sown on four different dates in soybean: Date 1 (SD1), at the same sowing date as soybean, Date 2 (SD2) at V3-V4 soybean growth stage, Date 3 (SD3) at R1-R2 soybean growth stage, and Date 4 (SD4) after soybean harvest. In Morris, SD2 was on 23 June 2014 and 22 June 2015; SD3 on 29 July 2014 and 28 July 2015; SD4 1 October 2014 and 21 October 2015. In Prosper, SD2, SD3, and SD 4 were sown on 30 June, 9 August, and 22 October 2015, respectively.

Approximately four weeks after sowing the primary crop all plots were fertilized. In 2014, all maize plots in both locations were fertilized by hand broadcasting with 180 kg N ha^{-1}, and 30 kg P_2O_5 ha^{-1}, and with 180 kg N ha^{-1}, 40 kg P_2O_5 ha^{-1}, and 30 kg K_2O ha^{-1}, in 2015. Soybean plots only received P and K at rates that were the same as for maize in both years.

During the study, as needed, glyphosate [N-(phosphonomethyl) glycine] was applied at 1.1 kg a.i ha^{-1} to the plots on the same day or prior to the camelina sowing to control weeds. However, glyphosate was not applied on SD4 due to very low weed pressure. No herbicides were used on plots with camelina.

When maize reached physiological maturity (R6) cobs were harvested by hand from 1 m of each of the 2-center rows of each plot and threshed. This was done on 1 October and 8 October in 2014 at Morris and Fargo, respectively, and on 21 October 2015 at Prosper. However, in 2015, a plot combine harvester (Massey Ferguson Kincaid 8XP, Haven, KS) was used to harvest maize seed by harvesting the 2-center rows at Morris on 22 October. Maize biomass was hand-harvested in 1 m of each of the 2-center rows of each plot, before harvesting the seed, leaving a stubble height of 10-cm.

Soybean seed was harvested with a plot combine harvester (Hedge 160, Wintersteiger, Salt Lake City, UT) by taking the 2-center rows of each plot in the 61-cm row spaced plots, while all four rows were harvested in the 31-cm plots. Soybean was harvested on 1 October 2014 at Morris, and on 29 September and 20 October 2015 at Morris and Prosper, respectively.

Harvested maize biomass samples were dried (70˚C for seven days), and tissue samples were then ground in a mill with a 1-mm size mesh screen. Maize ground samples were analyzed for crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), in vitro dry matter digestibility (IVDMD), and total digestible nutrients (TDN) content using near infrared reflectance spectroscopy (NIRS) (Foss-Sweden Model 6500, Minneapolis, MN) following the method described by Abrams et al. (1987). Soybean seed samples were analyzed for crude protein and oil content using NIRS (Perten DA7250, Perten Instruments in Springfield, Illinois) at the Northern Crops Institute (Fargo, ND).

The percent area of a plot covered with camelina plants both in maize and soybean was recorded after harvesting, following visual inspection of each plot in the fall. Spring coverage evaluation and camelina biomass was planned but only was taken at one location in two years Morris 2015 and 2016. The other two locations were accidentally tilled before evaluations of camelina survival could be taken.

Camelina spring biomass samples of 1 m^2 were taken on 9 May 2015 and from 0.09 m^2 on 25 April 2016 in Morris. Because of the high number of plots with no camelina plants or not enough biomass for analysis, only plots with plants were analyzed to compare sowing dates. Crude protein, NDF, and N and P content were analyzed. Biomass samples were dried (70˚C for seven days), and tissue samples were then ground in a mill with a 1-mm size mesh. Camelina biomass samples were analyzed by wet chemistry. The total N content was measured with the Kjeldahl method, percentage of ash with AOAC Method 942.05, and CP and P with AOAC Method 2001.11.

The N and P total accumulation in all crops was determined by multiplying N and P content (g kg^{-1}) of the biomass by the biomass dry matter yield (kg ha^{-1}). Total nitrogen was calculated applying the equation CP = total N x 6.25. Nitrogen accumulation (kg N ha^{-1}) was calculated arithmetically multiplying the biomass yield by the N content (g kg^{-1}).

2.3. Statistical analysis

Statistical analysis was conducted using standard procedures for a randomized complete-block design with a split-plot arrangement. Each location-year combination was defined as an "environment" and considered a random effect in the statistical analysis. The different cropping systems were considered fixed effects. Analysis of variance and mean comparisons were conducted using the Mixed Procedure of SAS (SAS Institute, 2014). Trait error mean squares were compared for

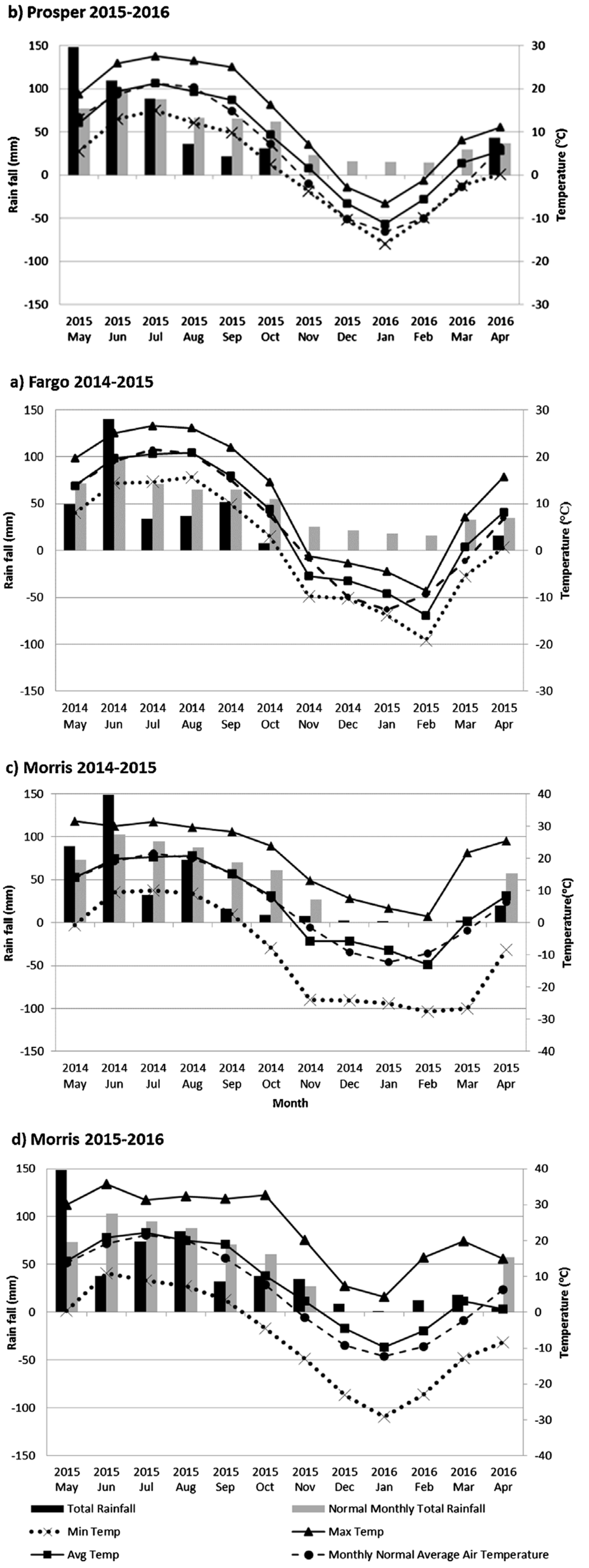

Fig. 1. Rainfall, 30-yr normal monthly total rainfall, maximum minimum and average temperature, and monthly 30-yr normal average air temperature; a) Fargo, ND 2014–2015, b) Prosper, ND 2015–2016, c) Morris, MN 2014–2015, d) Morris, MN 2015–2016.

homogeneity among environments according to the folded *F*-test and if homogeneous, then a combined ANOVA was performed across environments. Treatment means separation was determined by *F*-protected LSD comparisons at the $P \leq 0.05$ probability level.

3. Results and discussion

3.1. Climatic and soil characteristics

The 2014–2015 seasonal temperatures were very close to normal from May 2014 to April 2015 for Fargo and Morris and May 2015 to April 2016 for Prosper and Morris (Fig. 1a–d). Rainfall deficit in Fargo, in 2014, was 52 and 43% of the monthly 100-year normal for July and August, respectively. Also, the snow and rainfall deficit from November 2014 to March 2015 was 100%. The lack of snow cover during the 2014–2015 increased winter-kill of overwintering crops. In Prosper, during 2015, rainfall deficit was 47, 67, and 50% for the months of August, September, and October, respectively. Lack of snow fall from November 2015 through March 2016 was also observed at this location. In Morris, a rainfall deficit was observed in July, September, and October of 2014 and June, September, and October of 2015.

Soil tests indicated that the Morris and Prosper sites had similar NO_3—N while the Fargo site was much higher in NO_3—N. Phosphorus levels in Morris were much lower than in the Prosper site (Table 1).

3.2. Maize grain and biomass yield

The analysis of variance was significant for sowing date and the interaction of row spacing and sowing date for maize grain yield. Maize grain yield was reduced significantly ($P \leq 0.05$) only when camelina was intersown at the same date as maize in the 61-cm row spacing (Fig. 2). Although other treatments might seem different from each other, no other comparison was statistically significant. Seed yield reduction was 13.5% averaged across both row spacings and 25.7% for the 61-cm row spacing. Grain yield was greater when sown at 61-cm for all sowing dates than at the 76-cm row spacing.

These results indicate camelina apparently does not significantly compete with maize when sown after V4-V5 stage at both row spacings. Biomass yield also was reduced only when camelina was sown at the same time as maize, but no interaction with row spacing was observed (Table 2).

Studies on competition between weeds and maize indicate that the critical period for weed control in maize ranges from V1 to V12 stages to prevent yield losses of more than 5% (Tursun et al., 2016) or V4 to V10 to prevent economic losses (Keller et al., 2014). However, maize plants detect the presence of another growing plant nearby at very early growth stages which prompts them to modify their shoot/root ratio, cell wall composition, growth, and development (Liu et al., 2009, 2016). Maize seedlings can respond to the presence of weeds within 24 h after emergence of the weeds resulting in reduced seedling growth and development (Page et al., 2009). This early detection of the presence of a foreign plant by maize, might be of importance for managing the intersowing of cover crops such as winter camelina into maize-soybean cropping systems.

Table 1
Soil test results from the experimental sites at Fargo, Prosper, ND, and Morris, MN, in 2014 and 2015.

Environment	N– NO_3 (0–15 cm-depth)	N—NO_3 (15–60 cm-depth)	P	K	OM	pH
	kg ha^{-1}		mg kg^{-1}		g kg^{-1}	
Fargo 2014	36.6	70.0	10.1	406	75.0	7.9
Morris 2014	10.3	39.1	4.7	128	47.0	8.1
Morris 2015	14.0	51.0	9.3	165	45.0	8.1
Prosper 2015	12.7	30.3	42	345	38.7	6.7

OM = Organic matter.

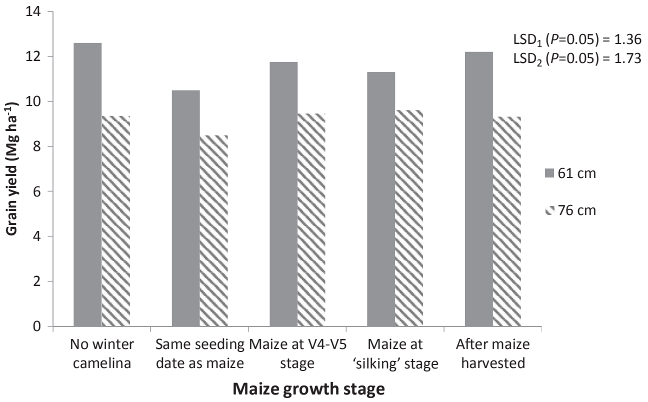

Fig. 2. Mean maize seed yield on plots intersown with winter camelina at different maize growth stages, in two row spacings (76 cm and 61 cm) and averaged across four environments at Fargo in 2014, Prosper in 2015 and Morris, MN in 2014 and 2015. LSD_1: To compare the means of different seeding date treatments within a row spacing treatment; LSD_2: To compare the means of the different seeding date treatments across different row spacing.

3.3. Camelina soil cover in maize

Camelina soil cover in the fall and spring was low in all treatments (Table 2). Most camelina seeds sown the same date as maize emerged, but this was only a visual observation, unfortunately stand counts were not taken at emergence. Apparently, many plants died after emergence likely by competition or soil water deficit (not measured). Camelina growth was probably suppressed by maize shade, thus surviving plants were very small after maize harvest providing little soil cover. The highest soil cover in the fall averaged across four environments was when camelina was sown at silking stage of maize, although not significant from the other treatments due to the high variability among treatments (Table 2). All surviving camelina plants stayed in rosette stage, none of them bolted until next spring.

In the spring, highest camelina cover and survival was for those sown after maize harvest (Table 2). Camelina was broadcasted on SD2-SD4 which limited the emergence on dates with rainfall deficit in the weeks after sowing. The rainfall deficit observed in July and September of 2014 and June of 2015 in Morris was likely the main factor of poor establishment of camelina in SD2 and SD3, but without stand counts at emergence, this could not be confirmed. Seeds were broadcasted 23 June and 29 July in 2014 and 22 June and 28 July in 2015 in Morris. Rain deficit was observed in the months following SD2 and SD4, but not in the months following SD3. Lack of snow cover from November to March could have also reduced camelina stands. Camelina plants from seed sown after maize harvest were very small going into the winter to record significant coverage, but were able to survive providing coverage early in the spring.

3.4. Maize biomass composition

Interestingly, although there was no maize yield reduction observed when sowing camelina after the V4-V5 stage, there were differences detected in NDF, ADF, IVDMD, and TDN of maize biomass among some of the intercropped sowing dates compared with the check plants (Table 2). Both NDF and ADF were significantly higher in maize plants where camelina was sown at the V4-V5 stage.

Fiber components characterize the cell wall composition, while NDF includes all the components in the cell wall, ADF includes lignocellulose, silica, cutin, and waxes. Higher NDF and ADF values are an indication of stronger cell walls. These change in maize cell wall

Table 2
Mean maize biomass yield, camelina fall and spring soil cover, ADF, NDF, IVDMD, TDN and N accumulation of maize at harvest, for four sowing dates averaged across two row spacing treatments and four environments at Fargo in 2014, Prosper in 2015, and Morris, MN in 2014 and 2015.

Camelina sowing date	Maize	Camelina		Maize biomass				
	Biomass yield	Fall cover[a]	Spring cover[a]	ADF[b]	NDF	IVDMD	TDN	N accumulation
	Mg ha^{-1}	%	%	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	kg N ha^{-1}
Check	25.1	–	–	177	354	866	752	268
Same sowing date as maize	20.1	10	7	188	366	866	745	204
Maize at V4-V5 stage	23.4	9	10	207	392	848	732	236
Maize at 'silking' stage	24.9	17	9	181	359	870	750	255
After maize harvested	24.3	14	13	206	392	844	733	249
LSD (P = 0.05)	4.7	NS	NS	21	30	20	14	34
n	120	47	21	120	120	120	120	120

[a] Spring and fall cover analysis was conducted only with plots with camelina plants. Fall cover means were averaged from samples from Fargo and Morris in 2014 and Prosper and Morris in 2015 n = 47. Sampling dates for camelina fall cover: 22 October 2014 in Fargo, 20 October 2014 in Morris, 20 October 2015 in Prosper and 29 September 2015 in Morris. Spring cover means include samples from Morris in 2015 and 2016, sampling dates 5 May 2015 and 25 April 2016 (n = 21). Cover data presented comes from a very small number of samples, interpretation of these results must be done cautiously.

[b] Quality parameters: total digestible nutrients (TDN), acid detergent fiber (ADF), neutral detergent fiber (NDF), and in vitro dry matter digestibility (IVDMD).

composition could have been a response to the presence of camelina in the inter-row, although SD4 which did not have intersown camelina also had higher ADF and NDF than the check. Evidence for cell wall composition changes in plants with and without competition has been reported by Liu et al. (2009, 2016) and Page et al. (2009). Higher NDF and ADF usually results in lower TDN and IVDMD and this was the response observed between check plants and those with camelina intersown at the V4-V5 stage. In maize harvested for grain, a change in the biomass composition is not of significance, however in silage corn a reduction in forage quality would impact animal performance and could also impact utilization of maize stover as bioenergy feedstock.

3.5. *Maize nitrogen accumulation*

Nitrogen accumulation in maize plants was significantly reduced only when camelina was sown at the same time as maize following the same response as for biomass yield (Table 2). Although camelina has been classified as of low competitive ability (Davis et al., 2013), the results suggest camelina competed for soil NO_3—N with maize early in the season. This was expected because other researchers have reported that most of the N accumulation in maize occurs early in the season before 1000 growing degree days (Ciampitti et al., 2013). Maize plants deplete soil NO_3—N mainly between V3 and V15 growth stage whether weeds are present or not and with N fertilization rates between 0–120 kg N ha^{-1} (Jalali et al., 2012).

3.6. *Soybean seed and biomass yield*

Similar to maize, soybean seed yield averaged across row spacings and environments was reduced only when camelina was sown at the same time as soybean (Fig. 3). The row spacing main effect and the interaction between row spacing and sowing date were not significant. Yield reduction was 9.5% of the soybean check treatment without relayed camelina. The low competitive ability of camelina was probably the reason that even when camelina was sown at the same time as soybean, yield loss was less than 10%. This indicates that camelina's low competitiveness gives it good potential as a cover crop for intersowing into standing soybean. Alternatively, it is also possible that soybean has a better competitive ability than corn in intercropping with camelina. A similar response was observed by Berti et al. (2015), in relay cropping of maize and soybean into standing camelina. Also, winter camelina stayed in the rosette stage under the soybean canopy thus limiting the risk of foreign green material at harvest that might stain seed or decrease lifespan of harvest machinery such as self-propelled combines. This is important since commercial soybean harvesting equipment cuts the soybean stem close to the soil surface.

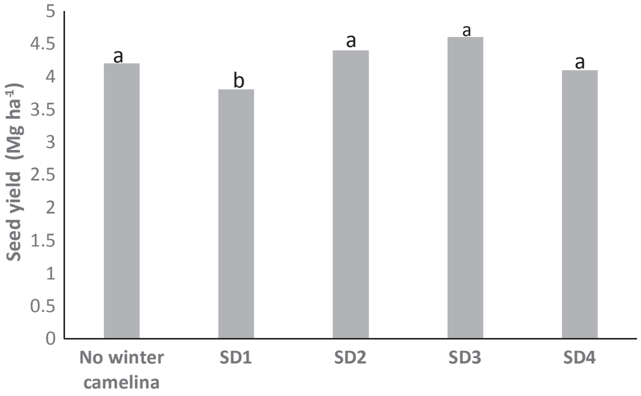

Fig. 3. Mean soybean seed averaged across three environments at Prosper in 2015 and Morris, MN in 2014 and 2015 on plots intersown with winter camelina. Date 1 (SD1), at the same sowing date as soybean, Date 2 (SD2) at V3-V4 soybean growth stage, Date 3 (SD3) at R1-R2 soybean stage, and Date 4 (SD4) after soybean harvest. Small case letters indicate significant differences among sowing dates and the check (no winter camelina), Mean separation test LSD, P = 0.05.

Yield losses reported in other crops intercropped with camelina vary from 0 to 25%. Dry pea seed yield in mixture with camelina was not significantly different than dry pea as a sole crop (Saucke and Ackermann, 2006). Ghaouti et al. (2015) reported 25% yield loss in faba bean (*Vicia faba* L.) intercropped with camelina. Other authors have reported 27–38% reduction in soybean seed yield in maize-soybean intercropping when both crops were sown and harvested at the same time (Liu et al., 2017).

3.7. *Camelina spring biomass yield, composition, and N and P accumulation*

In the maize experiment, camelina biomass yield, NDF, ADF and N and P accumulation in spring regrowth were similar for all sowing dates ($P \geq 0.05$) (Table 3). This was due likely to the high variability among plots. As indicated before, these values come from a very small number of plots, thus data interpretation must be taken cautiously. Biomass yield fluctuated between 966 and 2240 kg ha^{-1} of aboveground biomass n = 21. Nitrogen accumulation varied between 24 and 59 kg N ha^{-1} and P accumulation ranged between 4.3 and 9.8 kg P ha^{-1}. These values are potential nutrient accumulation values, given you have a high and uniform soil coverage. Camelina scavenging ability for soil nutrients falls within the range observed for other Brassicaceae cover crops (Dean and Weil, 2009; Sapkota et al., 2012; Liu et al., 2014, 2015). Brassica cover crops have been studied extensively with the goal

Table 3
Mean camelina biomass yield, ADF, NDF, N and P accumulation of camelina sown at four maize growth stages in Morris in 2015 and 2016.

Sowing growth stage	Biomass yield[a]	ADF	NDF	N accumulation	P accumulation
	kg ha^{-1}	g kg^{-1}	g kg^{-1}	kg N ha^{-1}	kg P ha^{-1}
Same sowing date	1112	230	283	24	4.3
Maize at V4-V5 stage	966	309	386	26	4.9
Maize at 'silking' stage	2204	276	336	59	9.8
After maize harvested	2240	264	320	55	9.2
LSD (P = 0.05)	NS	NS	NS	NS	NS
n	21	11	11	21	21

[a] Biomass yield, N accumulation, and P accumulation include samples from Morris in 2015 and 2016, sampling dates 9 May 2015 and 25 April 2016 (n = 21). ADF and NDF are from Morris 2015 (n = 11). Data presented comes from a very small number of samples, interpretation of these results must be done cautiously.

to reduce nutrient losses from agriculture to surface or groundwater (Weil and Kremen, 2007). Nitrogen accumulation in the fall by brassica cover crops has been reported to fluctuate between 36–171 kg N ha^{-1} which is similar to or greater than rye (42–112 kg N ha^{-1}) (Dean and Weil, 2009). Although most brassica cover crops do not survive the winter, Dean and Weil (2009) reported a rapeseed spring N accumulation of 41–118 kg N ha^{-1}. Winter canola can accumulate up to 30 kg N ha^{-1} in fall aboveground biomass but leaves can then die back due to winterkill and the N in leaves is lost. Plants can then regrow in the spring from crown buds, but N in frost- or winterkilled leaves is no longer present in these plants

In terms of P accumulation, oilseed radish (*Raphanus sativus* var. *oleiformis* L.), white radish (*R. sativus* var. *longipinnatus* L.), and white mustard (*Sinapis alba* L.) have been found to range between 2.0 and 8.0 kg P ha^{-1} in studies conducted in Sweden (Liu et al., 2014, 2015), similar to those in this study. Similarly as observed in maize, the highest values of ADF and NDF in camelina were for plants sown at V4-V5 stage although not significant from the other treatments.

In the soybean experiment, camelina soil cover in the fall averaged across three environments was significant for sowing date (P = 0.05, n = 25) (Table 4). Camelina sown after soybean harvest had the highest percentage of soil cover at 50%. This indicates that similar to maize the intersown treatments of camelina were shaded by the soybean crop, resulting in competition that led to reduced area coverage following soybean harvest. Also, SD2 and SD3 stands were likely decreased by the lack of rainfall in the months of July and August. Soil cover in the spring averaged across two environments was significantly higher for camelina sown after soybean (P = 0.05, n = 29), following the same trend observed in the fall.

Establishment of broadcasted camelina into standing soybean is influenced by timely rainfall. In this study, the best soil coverage in the fall and spring was provided by camelina sown following soybean harvest. This was probably a combination of both timely rainfall and lack of competition with soybean. It is clear that surface broadcasting is risky for establishing winter camelina in a standing crop. Fisher et al. (2011) reported that the establishment of rye by aerial broadcasting depended largely on rainfall after sowing.

Drilling camelina in the inter-row plot area at the V6 to R4 stages in soybean might be a means to improve its establishment and provide soil protection in the fall after soybean harvest when erosion potential increases. However, additional research on sowing dates and methods to enhance camelina survival prior to soybean harvested is needed.

The camelina spring regrowth averaged across two environments was similar in biomass yield, and N and P accumulation among sowing dates (P = 0.05, n = 29) (Table 4). Camelina biomass yield, N and P accumulation in the spring varied between 360 and 2097 kg ha^{-1}, 14 and 57 kg N ha^{-1}, and 1.5 and 6.9 kg P ha^{-1}, respectively. Spring N and P accumulation of camelina after soybean were similar to those observed in camelina after maize, indicating the main crop does not affect the ability of camelina to accumulate soil nutrients in the spring. Nutrient accumulation values are within the ranges reported by other researchers (Dean and Weil, 2009; Liu et al., 2014). The nutrient scavenging ability of winter camelina in the spring is likely greater than in the fall, because plant growth and biomass accumulation is greater in the spring due to higher nutrient requirements for life cycle completion associated with transitioning from vegetative to reproductive development. Fall N and P accumulation was not evaluated in this study. A winter-hardy crop like camelina has potential to decrease NO_3—N leaching and P run-off and thus improve water quality (Ott et al., 2015).

Crude protein, NDF, and ADF in camelina biomass sampled in the spring, average of two environments, were different among sowing dates. Crude protein concentration was highest in camelina intersown at V3-V4 stage, and ADF and NDF were highest in camelina sown following soybean harvest (Table 4). Higher NDF and ADF was observed in the treatments with highest average camelina biomass yield. Larger plants usually have lower CP concentration and higher ADF and NDF. A negative correlation (r = −0.93) was observed between biomass yield and CP concentration. This is likely due to a dilution effect or as a result

Table 4
Mean camelina fall cover, spring biomass yield, N accumulation, P accumulation CP, ND, and ADF sown at different growth stages of soybean in two environments, Morris in 2015 and 2016.

Sowing date	Fall cover[a]	Spring cover[a]	Biomass yield spring	N accumulation	P accumulation	CP	ADF	NDF
	%	%	kg ha^{-1}	kg N ha^{-1}	kg P ha^{-1}	g kg^{-1}		
Same as soybean	24	22	1607	49	6.9	192	329	392
Soybean at V3-V4 stage	5	8	360	14	1.5	236	285	381
Soybean at R1-R2 stage	20	12	1687	57	6.0	210	338	433
After soybean harvested	50	61	2097	56	6.0	168	413	480
LSD (P = 0.05)	24	22	NS	NS	NS	19	44	26
n	25	29	29	29	29	15	15	15

[a] Spring and fall cover analysis was conducted only with plots with camelina plants. Fall cover includes samples from Morris in 2014 and Prosper and Morris in 2015, n = 29. Sampling dates for camelina fall cover: 20 October 2014 in Morris, 20 October 2015 in Prosper, and 29 September 2015 in Morris. Spring cover, biomass yield, N accumulation and P accumulation include samples from Morris in 2015 and 2016, sampling dates 9 May 2015 and 25 April 2016 (n = 29). CP, ADF, and NDF are from Morris 2016 sampling n = 15. Data presented comes from a limited number of samples, interpretation of these results must be done cautiously.

of N deficiency in the soils at the sites used. Conversely, both ADF and NDF had a positive correlation with biomass yield $r = 0.99$ and $r = 0.95$, respectively.

3.8. Soybean oil and protein content

Soybean seed oil and protein content were not significantly different for row spacing, sowing date, or their interaction. This indicates that even a significant effect on seed yield was observed when camelina was sown at the same time with soybean, it did not affect the seed composition (data not shown).

4. Conclusions

Broadcast establishment of winter camelina into standing maize and soybean greatly depended on rainfall after sowing. Camelina sown on the same date as maize or soybean resulted in lower grain and biomass yield of both crops indicating that camelina intersowing should be done after V3-V5 stages to avoid competition. Camelina establishment and survival in the fall and following spring was better when sown after maize and soybean harvest. Camelina establishment, survival and soil cover was much higher in soybean than in maize, which was likely due to soybean being a less aggressive competitor for light and moisture than corn.

In general, winter camelina scavenging ability is within the range reported in other cover crops. Although in the present study, camelina did not provide much soil cover in the fall, when intersown into standing maize or soybean, its ability to survive the winter and scavenge nutrients in the fall and spring gives this crop good potential to be integrated as a cover crop in maize-soybean systems in the US Midwest.

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