Renewable Agriculture and Food Systems: 34(1); 41–49 doi:10.1017/S1742170517000321

Rotating alfalfa with dry bean as an alternative to corn-soybean rotations in organic systems in the Upper Midwest

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Accepted 7 May 2017; First published online 6 June 2017 **Research Paper**

Abstract

Dry bean (*Phaseolus vulgaris*) can be grown as a local food source and as an alternative to soybean (*Glycine max*) to diversify organic crop rotations. To understand the benefits of diversification of organic cropping systems, the effects of preceding alfalfa (*Medicago sativa*) and corn (*Zea mays*) crops on yields of five dry bean types and one soybean type, and the effect of bean type on following spring wheat (*Triticum aestivum*) yields, were tested at four Minnesota locations. Dry bean and soybean yields following alfalfa were 25% greater than yields following corn at two of four locations, though bean yields following corn were greater at one location. A preceding alfalfa crop benefited bean yields at locations where hog manure or no manure was applied to corn, whereas bean yields following corn fertilized with cow manure were similar to or greater than bean yields following alfalfa. Among dry bean types, black bean yielded similarly to soybean at three of four locations, but dark red kidney bean consistently yielded 25–65% lower than soybean. Navy, pinto and heirloom dry bean types yielded similarly to soybean at two of four locations. Across locations, weed biomass was 3–15 times greater in dry bean than in soybean and dry bean yield response to weed competition varied among bean types. However, dry bean, regardless of the preceding crop, demonstrated the potential to produce yields comparable with soybean in organic systems and the substitution of dry bean for soybean did not affect subsequent wheat yields. More studies are needed to identify nitrogen fertility dynamics in organic systems as they relate to dry bean yield.

Key words: alfalfa, crop rotation, dry bean, nitrate, organic, weeds

Introduction

Dry beans (*Phaseolus vulgaris*), also known as common beans, edible beans and field beans, have well-documented human health benefits (Mitchell et al., 2009; Hayat et al., 2014; Messina, 2014), which has resulted in an increase in production to meet demands from national programs (USDA-FNS, 2012). Consumers are also demanding local, organic foods; thus US sales of organic dry beans increased from US$8.4 million in 2008 to US$29.9 million in 2014 (USDA-ERS, 2016). Organic dry beans were harvested from about 300 ha in Minnesota in 2014, which accounted for 3% of total US organic dry bean cropland (USDA-NASS, 2014). By contrast, organic soybeans were harvested from 4830 ha in Minnesota in the same year (USDA-NASS, 2014). Growers in the region are more accustomed to producing soybeans than dry beans given historical commodity crop trends in the region, and a large market exists for organic soybeans (McBride and Greene, 2009).

Despite the strong interest and relatively large production of soybean in Minnesota, there has been a fourfold increase in organic dry bean production in the state since 2008, with the majority of growth occurring in the dark red kidney, navy and pinto bean types. Given rising demand, prices for organic food grade dry beans are generally two to three times greater than for conventionally produced dry beans (USDA-AMS, 2016). Organic growers in the Upper Midwest could improve revenues from the pulse phase of their rotation by substituting dry bean for soybean (*Glycine max*), while producing food-grade grains for local food systems. Furthermore, the incorporation of alfalfa and dry bean into organic rotations could contribute to greater landscape diversity in the Midwestern USA, where 2-year corn-soybean rotations predominate. The dominance of corn-soybean rotations has been criticized for contributing to losses of landscape-scale biodiversity (Karlen et al., 2006; Meehan et al., 2011), whereas introducing dry bean and forage crops into rotations can increase biodiversity. With greater diversity comes the potential for enhanced biocontrol of crop pests (Gardiner et al., 2009), increased soil quality (Karlen et al., 2006), lower nitrogen (N) leaching (Coiner et al., 2001) and decreased weed soil seedbanks (Teasdale et al., 2004).

Dry beans fit well into existing crop rotations in Minnesota, but they are relatively inefficient at biologically fixing atmospheric nitrogen (N_2) compared with other pulses (Isoi and Yoshida, 1991; Peoples et al., 2009). Unlike soybean, dry beans benefit from supplemental N, especially if soils are low in organic matter, or if nodulation is poor due to insufficient inoculation by *Rhizobium* (Kaiser et al., 2011; Farid and Navabi, 2015). Only 50% of pulse crops' N requirement is generally derived from biological N_2 fixation (compared with >80% in forage legumes) and much of this fixed N is removed through grain harvest (Watson et al., 2002). In organic systems, legume crops are widely used in crop rotations to build soil fertility and increase subsequent crop yields due to their N fixing ability (Blackshaw et al., 2007; Heilig and Kelly, 2012). However, typically little long-term soil N benefit is derived from adding pulse crops to a rotation, as large proportions of fixed N are removed via grain harvest (Kumar and Goh, 2000). When grown in rotation with wheat and other N-responsive crops, dry beans have been found to contribute only 5–12 kg N ha^{-1} to soils for subsequent crop production (Miller et al., 2002; Kaiser et al., 2011). Alternatively, organic growers could incorporate perennial forage legumes like alfalfa (*Medicago sativa*) into rotations to reduce the need for additional N inputs. In Minnesota, alfalfa N credits for bean production range from 25 to 80 kg N ha^{-1}, depending on the stand density of the terminated alfalfa (Kaiser et al., 2011). Christenson et al. (1995) observed 10% greater yields for dry bean when grown following alfalfa in a rotation, compared with following corn.

Along with soil fertility considerations, organic growers must design crop rotations with weed management in mind. Weed prevention and suppression is important in organic systems, particularly in dry bean, as yield reductions of up to 99% have been reported if weeds are not controlled throughout the growing season (Amador-Ramirez et al., 2001). Integrating alfalfa into a crop rotation can influence weed dynamics, as alfalfa has a different growth habit, harvest regime and life cycle than annual row crops, potentially reducing the need for mechanical weeding operations that disturb the soil and stimulate weed seed germination (Teasdale et al., 2004; Tautges et al., 2017). Seed production of both grass and broadleaf weeds has been observed to be lowest in alfalfa, compared with corn (*Zea mays*) and soybean where weeds were controlled with tillage (Clay and Aguilar, 1998; Kegode et al., 1999). Weed seedling emergence has been observed to decrease by 90% over the life of a 3-year alfalfa stand (Anderson, 2010), and residual suppressive effects of alfalfa on weeds have been observed in subsequent crops in a rotation (Tautges et al., 2017).

Table 1. Locations of four organically managed field sites in Minnesota, with stand age of alfalfa and nitrogen (N) fertilization rates of corn crops, preceding planting of six bean types.

Location	Coordinates	Alfalfa Stand Age year	N Applied to corn kg N ha^{-1}
Becker	45.23°N, 93.52°W	1	125[1]
Lamberton	44.23°N, 95.27°W	3	214[1]
Madison	45.01°N, 96.20°W	3	208[2]
Rosemount	44.72°N, 93.10°W	3	0

[1] Composted cow manure.
[2] Composted hog manure.

Although dry bean production has been studied in conventional cropping systems in Minnesota (Burnside et al., 1994; de Jensen et al., 2004), there is a lack of information on production of dry beans in organic crop rotations. As both environment and dry bean genotype variation influence N_2 fixation, grain yields and subsequent N contribution (Farid and Navabi, 2015), there is a need to evaluate dry bean productivity in common Midwestern crop rotations, productivity among bean types and subsequent rotational effects of dry bean in diverse environments and soils. Therefore, our objectives were to (1) determine the effect of preceding corn and alfalfa crops on yields of five dry bean types compared with food grade soybean; (2) evaluate the effect of preceding alfalfa and corn crops on weed biomass and residual soil nitrate in dry bean and soybean, and (3) evaluate the effects of dry bean compared with soybean, on following wheat yields.

Methods

Location description

The field trials were conducted at four locations (referred to throughout as 'Lamberton', 'Madison', 'Becker' and 'Rosemount'; Table 1) in Minnesota from 2010 to 2015. The trials at the University of Minnesota's Southwest Research and Outreach Center near Lamberton, Minnesota and an on-farm site near Madison, Minnesota were established on certified organic land on a Webster clay loam (fine-loamy, mixed, superactive, mesic Typic

Endoaquolls). The two field trials at the University of Minnesota UMore Park near Rosemount, Minnesota and the Sand Plains Research Farm near Becker, Minnesota were not established on certified organic land, but were managed organically with no synthetic chemical fertilizer or pesticide inputs for 3 years prior to the trial's establishment. The trials at Rosemount and Becker were on a Tallula silt loam (coarse-silty, mixed, superactive, mesic Typic Hapludolls) and a Hubbard loamy sand (sandy, mixed, frigid Entic Hapludolls), respectively.

Experimental design and crop management

Five dry bean types and soybean were planted following corn and alfalfa in a randomized complete split plot design with four replicates, with preceding crops alfalfa and corn as the whole-plot treatment and bean type as the split-plot treatment. The trial was established in 2011 at the Rosemount location and in 2013 at the Becker, Lamberton and Madison locations. The locations were selected to reflect a range of fertility scenarios, to enable examination of the effects of preceding crops alfalfa and corn on bean yields in a range of organic fertility management programs. Alfalfa varied in stand age but received no N fertilizer at any of the locations, whereas fertility management of corn varied by location (Table 1). Following the final cutting of alfalfa and corn grain harvest, residues were disked and incorporated in the fall by chisel plowing.

In the spring following alfalfa termination and corn harvest, the seedbed was prepared with a field cultivator and bean crops were planted in early June after being inoculated with the proper *Rhizobium* strain. A food grade soybean (cv. MN 1505SP), and five dry bean types: black (cv. Eclipse), heirloom (cv. Peregion), dark red kidney (cv. Red Hawk at Rosemount; cv. Montcalm at Becker, Lamberton, and Madison), navy (cv. OAC Rex) and pinto (cv. Lariat) were grown. Seeding rates were 370,658 seeds ha^{-1} for soybean, 222,395 seeds ha^{-1} for small-seeded black, heirloom, and navy beans, and 172,974 seeds ha^{-1} for large-seeded kidney and pinto. Soybean and dry beans were seeded in four rows to split plots of 3×6 m^2 in early June. Beans were rotary hoed and inter-row cultivated twice to control weeds when soil moisture conditions permitted. Organic crop rotations in the region typically follow a pulse crop with a small grain; therefore, the effects of preceding bean types on subsequent wheat yields were assessed. Following the bean crop treatments, the seedbed was prepared with a field cultivator and spring wheat (cv. RB07 or Prosper) was drilled across all plots at a rate of 135 kg ha^{-1} in the beginning of May the following year.

Data collection

Bean yields were determined by hand-harvesting a 3.75-m^2 area in the center of each split plot in the second or third week of September following physiological maturity. Grain was threshed and dried at 35 °C, and yields were calculated based on a 13% moisture level. Wheat was hand-harvested from a 1-m^2 area from the center of each plot, threshed and dried at 35 °C. Yields were adjusted to 12% moisture content. Weed biomass was measured by clipping weeds from a 1-m^2 area within each plot at both bean and wheat harvests, though weed sampling in wheat did not occur at Rosemount. Weeds were dried at 35 °C and yields reported on a dry matter basis. At the beginning of the experiment and before planting bean and wheat, soil samples were collected to 15 cm depth and analyzed for pH, P and K, which indicated adequate levels for beans and wheat based on University of Minnesota Guidelines (Kaiser et al., 2011). Also, in the spring before planting beans and wheat, soil samples were collected from each plot to a depth of 61 cm and samples were extracted for nitrate-N with potassium chloride and analyzed using the cadmium reduction method (Dorich and Nelson, 1984).

Statistical analysis

As the four locations differed greatly in soil type and fertility, locations were analyzed separately. The effects of preceding crops alfalfa and corn and bean type on bean yield and weed biomass were analyzed with analysis of variance (ANOVA), using the 'nlme' package (Pinheiro et al., 2017) in R version 3.2.2 (R Core Team, 2015). The main effects of 'preceding crop' and 'bean type,' and interactions between main effects, were treated as fixed effects and 'block' was treated as a random effect. All data were verified visually for normality and constant variance of residuals using QQ and residuals versus fitted values plots. ANOVA was performed to compare soil nitrate-N levels following alfalfa and corn, prior to bean planting, with 'preceding crop' as a fixed effect and 'block' as a random effect. Analysis of covariance was performed to analyze the effect of weed biomass and dry bean type on bean yield. Pearson's correlation coefficients were calculated for bean yield, bean weed biomass and bean pre-plant soil nitrate-N; and for wheat yield, wheat weed biomass and wheat pre-plant soil nitrate-N, across all four locations. The effect of preceding bean type on following wheat yield and weed biomass was analyzed with ANOVA, where 'bean type' was treated as a fixed effect and 'block' as a random effect.

Results and Discussion

Effects of alfalfa and corn on bean yields and soil nitrate

Preceding crop (alfalfa versus corn) and bean type main effects on bean yields were significant at all four locations, though there was no interaction between preceding crop and bean type. Bean yields were greater following

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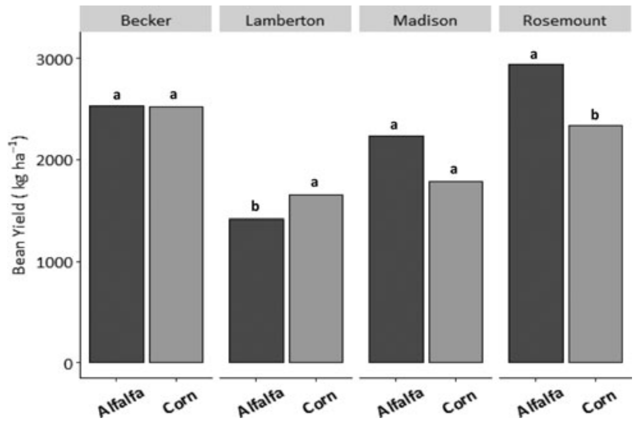

Figure 1. Bean yields, averaged across six bean types, following alfalfa and corn at four locations in Minnesota. Within a site, means followed by the same letter are not significantly different at α = 0.05, as determined by Tukey's HSD.

Table 2. Spring total soil nitrate-N measured at combined depths of 0–61 cm in April prior to planting six bean types and measured prior to spring wheat planting the following year, at four Minnesota locations.

Preceding crop	**Becker**	**Lamberton**	**Madison**	**Rosemount**
	kg N ha^{-1}			
Pre-plant bean				
Alfalfa	28 b[1]	161 a	168 a	198 a
Corn	69 a	93 b	198 a	126 b
Pre-plant wheat				
Black bean	72[2]	159[2]	147[2]	55[2]
Dark red kidney bean	70	156	171	55
Heirloom bean	84	118	141	50
Navy bean	74	136	129	42
Pinto bean	84	128	153	44
Soybean	68	104	153	44
Location average	*75*	*133*	*149*	*48*

Location averages are depicted for wheat pre-plant soil nitrate-N levels, as soil nitrate-N was similar following the six bean types.
[1] Within rotation years and locations, means followed by the same letter are not significantly different at α = 0.05, as determined by Tukey's HSD.
[2] Not significantly different at α = 0.05, within a location.

alfalfa compared with corn at Madison ($P < 0.001$) and Rosemount ($P < 0.001$), but were similar following alfalfa and corn at Becker ($P = 0.894$) and were greater following corn compared with alfalfa at Lamberton ($P = 0.009$; Fig. 1). Bean yields were not correlated with soil nitrate-N measured at bean planting ($r = -0.09$; $P = 0.220$). The lack of correlation between soil nitrate-N and bean yields was not consistent with the findings of several studies, where bean yields were observed to increase with N fertilization (Edje et al., 1975; Liebman et al., 1995). Pre-plant soil nitrate tests have been used as a diagnostic tool for adaptive N management on some soils (Yost et al., 2014), but may not be a good predictor of soil N status on all soils or as an indicator of crop performance (van Kessel and Hartley, 2000; Farid and Navabi, 2015). There is some evidence that dry bean yield response is greater for post-emergence N applications than for soil N status at planting (Da Silva et al., 1993). Differences in bean yield response to previous crop and fertilization regimes may be a function of differences in soil N release.

Greater bean yields following alfalfa at Rosemount was likely due to the beans benefiting from residual soil N, as alfalfa can contribute residual soil fertility to following crops in a rotation (Yost et al., 2014). Soil nitrate-N levels measured prior to bean planting suggest N fertility was high following alfalfa at Rosemount, where soil nitrate-N was greater following alfalfa, compared with following unfertilized corn (Table 2). At Madison, despite alfalfa's benefit to subsequent bean yields, no differences in soil nitrate-N were observed following alfalfa and manure-fertilized corn (Table 2). It is possible that alfalfa was contributing to soil N fertility but that the additional soil N was not captured in the soil nitrate measurements, as soil nitrate is highly spatially and temporally variable (Bruckler et al., 1997). Additionally, mineralization rates of alfalfa residues may have been low as a result of low spring temperatures prior to soil sampling, but accelerated later in the season as soil temperatures increased, leading to increased nitrate availability for bean uptake. At Madison, bean yields were greater following alfalfa compared with corn despite the 208 kg N ha^{-1} in liquid hog manure applied to corn. Residual fertility effects from the hog manure may have been limited in the following bean crop due to the high liability of nutrients in hog manure, which generally has a C:N ratio of <10 (Malley et al., 2002). In contrast, the C:N ratio of 3-year-old alfalfa root residues ranges from 19 to 27 (Louarn et al., 2015), which results in net immobilization of N (Wedin and Tilman, 1990).

In contrast, no difference in bean yields was observed following alfalfa versus corn ($P = 0.894$; Fig. 1) at Becker. Bean yields following alfalfa may have been similar to yields following corn because the alfalfa stand was terminated after only 1 year of growth at Becker. As alfalfa contributes little N to the soil in the year of establishment (Kelner et al., 1997), there was likely little residual soil N remaining to meet bean N requirements. Contrary to Rosemount and Madison, a lack of fertility benefits from alfalfa resulting in low bean yields at Becker is supported by low soil nitrate-N levels observed following alfalfa, compared with corn (Table 2).

Bean yields were greater following corn compared with alfalfa at Lamberton (Fig. 1). The high levels of composted cattle manure (4–5 t ha^{-1}) applied to corn at Lamberton likely led to carryover fertility effects in the bean crop, though those effects were not detected in the soil nitrate-

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Table 3. Total weed biomass in six bean types collected at dry bean and soybean harvest following preceding alfalfa and corn crops, and weed biomass in spring wheat following six bean types, at four locations in Minnesota.

Preceding crop	Becker	Lamberton	Madison	Rosemount
		Weeds in bean kg ha^{-1}		
Alfalfa	983 a[1]	1901 a	902 a	143 a
Corn	261 b	2196 a	1294 a	289 a
		Weeds in wheat kg ha^{-1}		
Navy	1244 a	2992 a	1616 a	229 ab
Pinto	839 ab	2250 a	577 ab	102 ab
Black	742 ab	2237 a	1107 a	278 ab
Heirloom	525 ab	1746 a	1278 a	245 ab
Dark red kidney	339 b	2396 a	1796 a	441 a
Soybean	85 c	670 b	217 b	0 b

[1] Within main effects and locations, means followed by the same letter are not significantly different at $\alpha = 0.05$, as determined by Tukey's HSD.

N measurements following corn. When comparing nitrate leaching among several organic fertilizers applied at high rates, Beckwith et al. (1998) found the lowest soil nitrate values following application of solid cattle manure, which may explain why low nitrate was observed at Lamberton after a high rate of cattle manure was applied. Solid cattle manure applied at high rates can also increase yields by contributing to crop phosphorus and potassium demands (Evans et al., 1977), which could explain the bean yield increase despite similarities in soil nitrate values following the corn and alfalfa crops. Phosphorus is an important factor for N_2 fixation in dry bean (Ssali and Keya, 1983) and greater phosphorus availability to dry bean following corn compared with alfalfa at Lamberton may have increased symbiotic N fixation and plant N availability, which resulted in greater yields. Although bean yields were similar following alfalfa and corn, nitrate-N levels were greater following alfalfa than the manured corn (Table 2), indicating a difference in N input between the two preceding crops.

Effects of alfalfa and corn on weed biomass in bean

No differences in weed biomass were observed following alfalfa and corn at Lamberton, Madison and Rosemount (Table 3). The similarity in weed biomass following both alfalfa and corn suggests that the soil weed seed bank was similar following both corn and alfalfa (Clay and Aguilar, 1998; Kegode et al., 1999; Anderson 2010), or that neither corn nor alfalfa provided a greater benefit to the bean crop in terms of competitiveness with weeds. Weed biomass was greater following alfalfa compared with corn at Becker (Table 3), where alfalfa was only grown for 1 year.

There was no correlation between weed biomass in bean and soil nitrate-N at bean planting ($P = 0.539$), so differences in weed biomass in bean were likely driven by other factors, such as the weed seedbank, bean competitiveness, or other soil factors. Weed biomass is often high in alfalfa at establishment (Hall et al., 1995), but declines appreciably over 3 years of production (Anderson, 2010). At Becker, high weed biomass in establishing alfalfa likely led to weed seedbank buildup, which can contribute to weed infestation in the subsequent crop (Tørreson et al., 2003). Three-year alfalfa at Lamberton, Madison and Rosemount did not decrease weed biomass the following year compared with the annual corn crop, which contrasts with reports that alfalfa is effective in reducing weed populations relative to annual crops (Moncada and Sheaffer, 2010; Tautges et al., 2017). However, while beans are generally highly susceptible to yield loss when competing with weeds (Blackshaw et al., 2000), it was notable that greater weed pressure following alfalfa at Becker did not result in bean yield differences between preceding crops (Table 4). Apart from the effects of preceding crops, weed biomass in bean may also have been affected by other soil nutrient levels that were not measured in this study.

Bean types: yield and competitiveness

Soybean was among the highest-yielding bean types at all locations, but black bean yields were consistently high and were similar to soybean at three of the four locations (Table 4). Navy, pinto and heirloom bean yields were similar to soybean at Madison and Rosemount, but lower at Becker and Lamberton (Table 4). Dark red kidney bean was the lowest-yielding type at three of the four locations. These results agree with previous organic research demonstrating that black and pinto are often the highest yielding dry bean types, while dark red kidney is among the lowest in conventional and organic systems (Heilig and Kelly, 2012; Michaels, 2016). Given these results, black bean is likely to produce the greatest yields in Minnesota. However, navy, pinto and heirloom bean varieties also demonstrated the ability to produce high yields at some locations, relative to soybean and could be financially viable for an organic grower depending on market demand for those bean types. The similarity among yields of soybean and those of several dry bean types across locations indicates that dry beans are a viable alternative to soybeans in organic systems in Minnesota.

Weed biomass was lower in soybean than the five dry bean types at all locations (Table 3). There was no difference in weed biomass among dry bean types at Lamberton, Madison and Rosemount, and weed biomass differed between only navy and dark red kidney bean types at Becker (Table 3). While few differences were observed in weed biomass among dry bean types, the relationship of weed biomass to bean yield differed among the five dry bean types ($P = 0.0454$). Soybean yield was not correlated

Table 4. Grain yields of six bean types following preceding crops of alfalfa and corn, at four Minnesota locations.

Bean type	Becker	Lamberton	Madison	Rosemount
		kg ha^{-1}		
Soybean	3212 a[1]	2513 a	2125 a	2655 a
Black	2845 ab	1402 bc	1988 a	2546 ab
Dark red kidney	2616 abc	886 c	1257 b	1945 b
Navy	2223 bc	1321 bc	2052 a	3039 a
Pinto	2215 bc	1650 b	2557 a	3083 a
Heirloom	2049 c	1430 bc	2083 a	2564 ab

[1] Within a column, means followed by the same letter are not significantly different at $\alpha = 0.05$, as determined by Tukey's HSD.

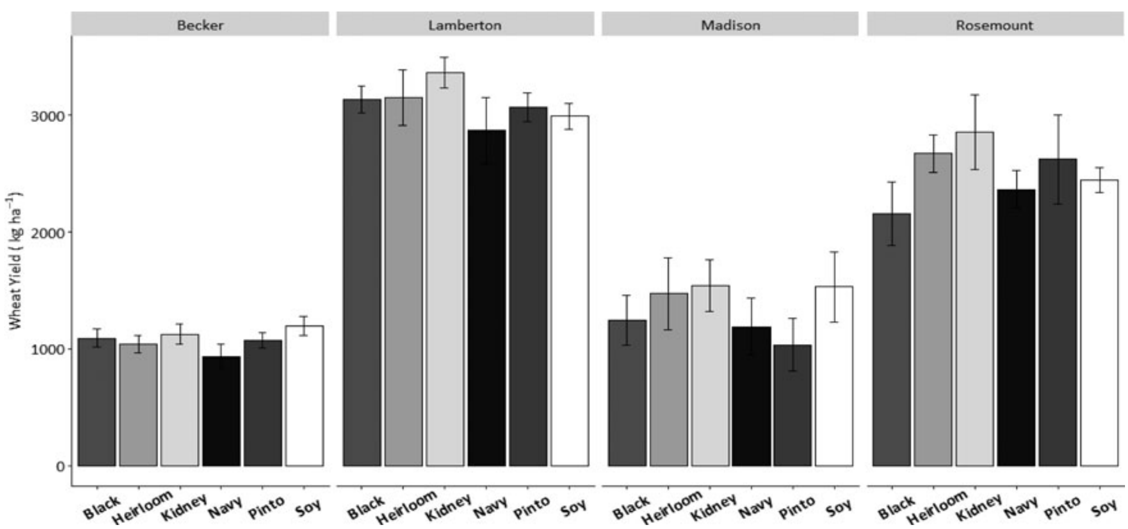

Figure 2. Spring wheat yields following six bean types ('Black' = black bean; 'Heirloom' = heirloom bean; 'Kidney' = dark red kidney bean; 'Navy' = navy bean; 'Pinto' = pinto bean; 'Soy' = soybean) at four locations in Minnesota. Error bars depict the standard error of the mean.

with weed biomass ($r = -0.36$; $P = 0.0934$), but dark red kidney bean yield was strongly correlated with weed biomass ($r = -0.74$; $P < 0.001$). Weed biomass was consistently high in navy bean across locations, though the correlation between navy bean yield and weed biomass ($r = -0.65$; $P = 0.001$) was lower than for dark red kidney bean. Moderate correlations between weed biomass and pinto bean yield ($r = -0.59$; $P = 0.002$), black bean yield ($r = -0.58$; $P = 0.003$) and heirloom bean yield ($r = -0.49$; $P = 0.016$) were observed.

Variability in yield response to weed pressure among bean types may have been related to morphological differences among bean types. The indeterminate semi-climbing or vining (Type III) growth habit has been identified as a bean morphology that confers greater yield stability and competitiveness with weeds, whereas the determinate 'bush' type growth habits (Types I and II) generally result in lower competitiveness (Kelly et al., 1987; Singh, 1989; Wortmann, 1993). The heirloom dry bean type with a Type III growth habit displayed lower yield response to weed biomass, whereas the navy (Type II) and kidney (Type I) bean types displayed greater yield response to weed biomass. Organic growers should select bean varieties with indeterminate semi-climbing or vining growth habits if they desire maximum competitiveness with weeds.

Bean type effect on spring wheat

Bean type did not affect spring wheat yields the following year ($P = 0.115$; Fig. 2). Other researchers, such as Przednowek et al. (2004) and Miller et al. (2002), reported no consistent effect of dry bean and soybean on subsequent wheat yields. Most of the N within the bean biomass was likely removed in the form of grain at harvest and any N left in the residue decomposed slowly or became immobilized by the decomposing microflora (Lupwayi and Kennedy, 2007); consequently, differences in the effect of bean type on soil nitrate-N might be expected to be small. Further, masking of apparent N benefits from legumes by high soil N status has been observed by others (Przednowek et al., 2004), which could explain why little effect of bean type on wheat yields was detected.

https://doi.org/10.1017/S1742170517000321 Published online by Cambridge University Press

Soil nitrate-N levels prior to wheat planting were similar following all bean types ($P = 0.203$; Table 2). Wheat yields were positively correlated with soil nitrate-N at planting ($r = 0.14$; $P = 0.048$) and negatively correlated with weed biomass ($r = -0.50$; $P < 0.001$). Weed biomass in wheat was not affected by bean type grown the previous year ($P = 0.869$), but weed biomass in wheat was positively correlated with soil nitrate-N at wheat planting ($r = 0.18$; $P = 0.029$). Soil nitrate-N levels were relatively stable between pre-plant bean and pre-plant wheat samplings 1 year later at Becker, Lamberton and Madison (Table 2). However, soil nitrate-N decreased from pre-plant bean to pre-plant wheat samplings by 70% at Rosemount (Table 2). Mineralization of N from manures applied at Becker, Lamberton and Madison may have contributed to soil nitrate-N stability from bean to wheat growing years, whereas soil nitrate-N decreased during the bean phase at Rosemount, where no additional N was applied to corn.

As supported by the results of this study, wheat yield is highly responsive to soil N at planting (Justes et al., 1994) and weed growth is favored by high soil N availability (Blackshaw et al., 2003). These relationships create a paradox for organic growers, because soil N fertility must be built to levels great enough to support high wheat yields; however, maintaining high soil N increases weed pressure, which decreases wheat yields. Maximizing crop competitiveness, which can be increased by soil fertility and steady release of N, is essential for weed management in organic systems (Liebman and Davis, 2000). The results of this study suggest that management of soil N by incorporating legumes like alfalfa into organic rotations, rather than high rates of manure application, can support high-yielding pulse and wheat crops while limiting weed biomass. Future studies should identify methods for determining alfalfa N credits to pulses, as well as investigating other non-N-related fertility benefits of alfalfa to subsequent pulse crops. Based on our results, we recommend that either alfalfa or corn prior to dry bean production is acceptable in rotations if soil fertility is adequate. However, if soil N is limited, growing alfalfa prior to dry beans will likely increase yields compared with growing beans after corn.

Some dry bean types demonstrated the potential to produce yields similar to soybean. Specifically, black, navy and pinto beans consistently demonstrated the ability to yield similarly to soybean across locations, supporting the idea that dry beans can be a viable alternative to soybeans in organic rotations in Minnesota. However, greater weed biomass in several dry bean types, relative to soybean, suggests that more weed control efforts will likely be required in dry bean on the part of organic growers. More long-term studies on rotations should be conducted to expand understanding of legume rotational effects, particularly N and weed seedbank dynamics, as well as the benefits of diversifying cropping systems with perennial forages and pulses.

Acknowledgements. This research was supported by the National Institute of Food and Agriculture, US Department of Agriculture, under grant number 2011-51300-30743. Partial funding for this research was provided by Ceres Trust, NCR-SARE, and the Minnesota Agricultural Experiment Station.

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