Organic dry bean (*Phaseolus vulgaris* L.) response to crop rotation, row spacing, and weed management in Minnesota

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DEDICATION

To organic dry bean growers...

ABSTRACT

In the Upper Midwest, edible grain legumes like dry beans (*Phaseolus vulgaris* L.) provide an opportunity for year-round access to sustainably grown, nutritious local foods. While the demand for organic local foods is increasing, only 0.3% of total dry bean acreage in MN is organic. Research is needed to identify dry bean market classes, weed management tactics, and crop rotations suitable for organic production in this region. Our overall project objective was to develop agronomic strategies to promote efficient production and high yields of dry beans, while sustaining economic viability and soil quality.

A three-year rotation experiment: Phase 1) corn or alfalfa, Phase 2) six different market classes of beans, Phase 3) wheat, was conducted from 2010 to 2015 at four locations in southern Minnesota. Yield, weed competition, and soil nitrate contributions were studied pertaining to the effects of the previous crops being either corn or alfalfa in Phase 1 and beans in Phase 2. Bean yield averaged across bean types were highest following alfalfa at three of four locations. Soybean yielded the highest (2312 kg ha^{-1}), followed by pinto (2213 kg ha^{-1}), black (1950 kg ha^{-1}), navy (1818 kg ha^{-1}), heirloom (1720 kg ha^{-1}), and kidney (1398 kg ha^{-1}). Wheat yield was similar following all bean types. Phase 1 crop (corn or alfalfa) did not impact wheat yield despite differences in soil nitrate levels prior to production. Total weed biomass varied substantially by location. Economic analyses showed promising net returns for all dry bean classes, at least 150% higher than soybean.

To evaluate alternative tillage practices and row spacing effects on dry bean and soybean yield as well as weed control, another experiment was carried out from 2012 to 2014 at two certified locations in southwestern Minnesota. The objective was to determine the combined effects of tine weeding in 38 cm rows, tine weeding and cultivation in 76 cm rows, or cultivation in 76 cm rows on black, kidney, and soybean yield and weed biomass. Across years, excessive early season moisture led to high weed populations and reduced bean yield. Both dry bean and soybean yields were 25% less in the narrow row treatments. Correspondingly, weed biomass was higher in the narrow tine weeded treatments as compared to the two wide row cultivated treatments. Total weed biomass differed among classes, with the lowest in soybean treatments (2,360 kg ha^{-1}). While narrow rows have lead to dry bean and soybean yield increases in some conventional studies, our results demonstrate that wider rows that facilitate tillage operations may lead to better weed control and subsequently higher yields in organic systems.

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CHAPTER ONE

Rotation Effects of Dry Bean Market Classes (*Phaseolus vulgaris* L.): A 3-year Organically Managed Cropping Sequence in Minnesota

Summary

Organic dry bean (*Phaseolus vulgaris* L.) has the potential to be grown as a local food source and as an alternative to soybean (*Glycine max*) in organic crop rotations. To meet the demand for local organic dry beans and promote diversification of organic cropping systems with grain legumes, research is needed to identify dry bean market classes and crop rotations suitable for organic production and management. A three-year crop rotation study was conducted in 2010-2015 at four locations in Minnesota. The rotation included corn (*Zea mays*) or alfalfa (*Medicago sativa*) in Phase 1, edible dry bean and soybean market classes in Phase 2, and spring wheat (*Triticum* spp.) in Phase 3. Bean yield averaged across bean types were highest following alfalfa at three of four locations, averaging 1990 kg ha^{-1} following alfalfa compared to 1813 kg ha^{-1} following corn. There was no previous crop by bean type interaction effects on yield. Soybean yielded the highest (2312 kg ha^{-1}), followed by pinto (2213 kg ha^{-1}), black (1950 kg ha^{-1}), navy (1818 kg ha^{-1}), heirloom (1720 kg ha^{-1}), and kidney (1398 kg ha^{-1}). Wheat yield was similar following all bean types. Phase 1 crop (corn or alfalfa) did not impact wheat yield despite differences in soil nitrate levels prior to production. Total weed biomass varied substantially by location. Economic analyses showed promising net returns for all dry bean classes, at least 150% higher than soybean. More long-term studies on rotations

are needed to identify mechanisms underlying our results (e.g. nitrogen dynamics) and the potential ecological benefits in organic dry bean systems.

Introduction

In the Upper Midwest, edible legumes provide an opportunity for year-round access to sustainably grown, nutritious local foods for families and institutions. Dry beans (*Phaselous vulgaris* L.) also known as common beans, edible beans, and field beans, have been identified as a food for farm-to-school lunch programs (USDA-FNS, 2012), and recent surveys conducted by the Minnesota Regional Sustainable Development Partnerships (RSDP) suggest demand for organic beans in direct-to-consumer markets (unpublished, 2013). Dark red kidney, navy, and pinto are the top three dry beans produced in Minnesota; however, many organic dry beans for local use are supplied by imports from China (USDA-ERS, 2016).

The demand for organic foods is increasing; yet only 0.5% of total dry bean acreage in MN is organic (USDA-NASS, 2014). Organic dry beans were harvested from an estimated 296 hectares (732 ac) in Minnesota in 2014, which accounted for approximately 3% of total U.S. organic dry bean cropland (USDA-NASS, 2014). This is a four-fold increase in organic dry bean production in the state since 2008, worth close to $1 million dollars.

Challenges encountered in conventional dry bean production, such as pest and weed management, soil fertility, and maintaining crop yield and yield stability, also affect the production of dry bean in an organic system (Hill et al., 2016). However, organic growers are more restricted in their management alternatives based on National Organic

Program (NOP) guidelines, and rely heavily on crop rotation and crop diversity (USDA-NOP, 2010). The inclusion of legume cover crops, forage, and/or pulse crops is a key factor in these crop rotations, as they contribute to soil fertility by fixing N_2 (Blackshaw et al., 2007; Heilig and Kelly, 2012).

Dry bean is typically grown in rotation with small grains and other row crops. In Alberta, Canada, Blackshaw et al. (2007) found that dry bean establishment and yield was similar following a range of crops including wheat (*Triticum* spp.), barley (*Hordeum vulgare*) and barley silage, canola (*Brassica napus*), flax (*Linum usitatissimum*), oat (*Avena sativa*) and oat silage, and pea (*Pisum sativum*). Christenson et al. (1991) showed that, in Michigan, the oat-alfalfa (*Medicago sativa*)-dry bean-sugarbeet (*Beta vulgaris*) rotation gave the highest bean yield, followed by a corn-dry bean-sugarbeet rotation. These findings suggests that farmers have a high degree of flexibility when considering including dry bean in their crop rotations, particularly as a replacement for soybean.

Unlike soybean, however, dry bean yield typically benefit from supplemental N, especially if soils are low in organic matter, P, or if nodulation is poor due to inadequacy of the symbiosis with *Rhizobium* (Farid and Navabi, 2015). Low levels of soil N, have been reported to be the most important yield-limiting factor, with attributable yield losses of 30-60% (Fageria, 2002). In conventional systems, increases in grain yield and herbage dry matter yield of dry bean have been reported when fertilized at low levels (50 kg urea ha^{-1}) as compared to unfertilized soil (Daba and Haile, 2000). The current recommended N rate for conventional dry bean production in Minnesota is 45-78 kg N ha^{-1}, less soil test nitrate, with inoculated or non-inoculated seed, respectively (Kaiser, 2011).

Growing dry bean in rotation after a perennial forage legume like alfalfa may help supplement this N fertilizer requirement and reduce weed populations. Deep-rooted legume crops like alfalfa scavenge residual soil N and thus increase N availability to subsequent shallow-rooted crops, like dry bean (Mathers et al., 1975). Minnesota Extension recommendations are for N credits of 78 kg N ha^{-1} in the first year and 39 kg N ha^{-1} in the second year when following alfalfa (Kaiser et al., 2011). Yost et al. (2014) reported significant N contribution effects on corn from alfalfa in the first two years following alfalfa incorporation. Integrating alfalfa into a crop rotation can also influence weed dynamics, as it has a different growth habit and life cycle than typical row crops, potentially reducing the need for mechanical weed control. (Teasdale et al., 2004; Tautges et al., 2015). Weed suppression is advantageous in organic systems, particularly in dry bean where yield reductions of up to 99% have been reported if weeds are present throughout the growing season (Amador-Ramirez et al., 2001).

Only 50% of grain legume N requirement is typically derived from biological N_2 fixation (compared with >80% in forage legumes) and much of this fixed N is removed in the grain harvest (Watson, 2002). When grown in rotation with wheat and other N-responsive crops, dry beans can contribute as much as 11 kg N ha^{-1} to the following crops, according to UMN Extension guidelines (Kaiser et al., 2011). Miller et al. (2002) provide a more conservative estimate of 4 kg N ha^{-1} associated with dry bean crop stubble. Still, both environment and dry bean genotype variation significantly influence N_2 fixation and subsequent N contribution. For example, Farid and Navabi (2015) identified Middle American genotypes (navy and black) as better N_2-fixers compared to

Andean (kidney) genotypes.

Although dry bean has been studied in conventional systems, there is a lack of information on production of dry beans in organic crop rotations in diverse environments. Therefore, our objective is to determine the effect of preceding corn or alfalfa crops on yields of different market classes of dry bean and a food grade soybean, and their effects on a following wheat crop. Weed and soil N dynamics will also be evaluated as these factors are highly interactive in organic cropping systems.

Methods

Site Descriptions

Rotational cropping sequence experiments were conducted at four locations in Minnesota from 2010 to 2015. Two certified organic sites were the Elwell Agroecology Farm at University of Minnesota's Southwest Research and Outreach Center near Lamberton, MN (44.23°N, 95.27° W, elev. 348 m) (certifying agency: Minnesota Crop Improvement, St. Paul, MN), and on-farm in Madison, MN (45.01°N, 96.20° W, elev. 226 m) (certifying agency: International Certification Services, Inc.). The other two locations were University of Minnesota research sites including UMore Park in Rosemount, MN (44.72° N, 93.10° W, elev. 948 m) and Sand Plains Research Farm in Becker, MN (45.23° N, 93.52° W, elev. 296 m), both of which were not organically certified. The soil types were Webster clay loam at Lamberton and Madison, Tallula silt loam at Rosemount, and Hubbard Mosford Loamy Sand at Becker. Not all phases of the rotation were completed at each location within the same year. The three-year rotations were initiated in 2010 at Rosemount, 2011 at Lamberton, 2012 at Becker, Madison, Rosemount, and Lamberton, and 2013 at Becker and Lamberton.

Experimental Design and Procedures

The three-year crop rotation sequence consisted of the following, Phase 1: corn or alfalfa; Phase 2: five dry bean market classes and soybean; Phase 3: wheat. The experimental design was a randomized complete block with treatments in a split-plot arrangement. Main treatments were either corn or alfalfa in Phase 1, and the subplots were soybean and dry beans representing five market classes in Phase 2. In Phase 3, all plots were cropped to spring wheat. At each site, there were four replicates of each treatment.

In Phase 1, organic corn and alfalfa were grown. A Blue River Hybrids Organic Seed (Ames, IA) corn hybrid was grown and weeds were controlled with standard practices (Moncada and Sheaffer, 2010). Locally adapted alfalfa varieties were grown at each site and varied from 2 to 4 years old, except in Becker in 2013 where the stand was 1-year-old. Alfalfa plant populations in the fall of incorporation were at least 54 plants m^{-2}, which is considered a good stand by current guidelines from University of Minnesota Extension (Kaiser et al., 2011). Fall alfalfa yield averaged about 1000 kg ha^{-1}. Each site managed fertility at this stage differently; no fertilizer was applied to the corn at Rosemount since the previous crop was a 2-year-old alfalfa stand; corn at Becker received 125 kg N ha^{-1} through banding at planting; Lamberton applied 214 kg N ha^{-1} in the form of composted livestock manure; Madison applied 208 kg N ha^{-1} with liquid hog manure. Stands of alfalfa were terminated in the fall by tillage. Corn and alfalfa residues were incorporated in the fall by chisel plowing.

In Phase 2, a food grade soybean (‘MN 1412’ or ‘MN 1505SP’), and five market classes of dry bean including black (‘Eclipse’), heirloom (‘Peregion’), kidney (‘Red Hawk’ or ‘Montcalm’), navy (‘OAC Rex’), and pinto (‘Lariat’) were grown (MCIA, 1974; Kelly et al., 1997; Michaels et al., 2006; NDAES, 2004; Osorno et al., 2010). This selection of edible beans provided a range of contrasting growth habits and seedling vigor. Bean seeds were inoculated with complementary *Rhizbobium* bacteria prior to planting. Seeding rates were: 370,658 seeds ha^{-1} (150,000 seeds ac^{-1}) for soybean, 222,395 seeds ha^{-1} (90,000 seeds ac^{-1}) for small seeds of black, heirloom, and navy, and 172,974 seeds ha^{-1} (70,000 seeds ac^{-1}) for large seeds including kidney and pinto. Legumes were seeded in four row plots, 3 m wide and 6 m long, that had previously been corn or alfalfa.

The soil was field cultivated twice before planting beans, and rotary hoed and cultivated twice post-planting to control weeds based on standard practice (Moncada and Sheaffer, 2010). Bean stand counts from 4.65 m^2 were used to estimate populations. Soybean and dry bean yield was determined by hand-harvesting 3 m of the center two rows of each plot in the second or third week of September. Plants were threshed using a rasp bar type Alamaco Plot Thresher (LPT-RRB; Nevada, IA), then seeds were dried at 35°C, and yield was calculated based on 13% moisture level.

In Phase 3, spring wheat, either ‘RB07’ or ‘Prosper,’ was drilled at a rate of 135 kg ha^{-1} in the spring around 1 May each year, following the soybean and dry bean treatments. Wheat grain and straw yield were measured after physiological maturity by hand harvesting 1 m^2 area from each plot. Grain was threshed using a 'Wintersteiger LD350' (Salt Lake City, Utah).

Broadleaf and grass weed biomass was measured by sampling weeds from ½ m^2 of each plot at both bean and wheat harvests. Weeds were dried 35°C and reported on a dry matter basis. We did not determine the background weed seedbank population or density for this experiment, but rather considered it as a location effect.

Soil nutrient status was determined each year. At the beginning of the experiment, soil samples were taken from each replicate to 15 cm (6") and analyzed for organic matter, pH, P, and K. All levels were adequate for bean and wheat planting based on University of Minnesota Extension Guidelines. Prior to planting dry beans in Phase 2 of the rotation, soil samples were taken again from each replicate to a depth of 61 cm (24"), divided into two increments of 0-30.5 cm and 30.5- 61 cm, and analyzed for Nitrate-N. In early spring of Phase 3, prior to planting wheat, soil samples were taken again at these two depths in each plot to assess the effects of edible beans on soil nutrient status. Samples were analyzed by Agvise Laboratories (Benson, MN) using standard procedures.

Statistical Analysis

Data sets were analyzed in the R statistical programming environment using the 'car', 'stats', and 'nlme' packages (Fox and Weisberg, 2011; Pinheiro and Bates, 2013; R Development Core Team, 2015). All data were verified for normality and constant variance of residuals. Outliers, values more than 1.5 interquartile ranges (IQRs) below the first quartile or above the third quartile, were identified using the 'Boxplot function' in R and were removed. Initial analysis of variance detected many interactions ($P < 0.05$) among years, locations, and the main effects of previous crop and bean type. Because cropping sequences were initiated during different years, comparisons between years could not be made. Differences in locations, based on cropping history, soil profiles, weed and fertility management, and climatic conditions lead us to analyze locations separately. Therefore, within locations, responses of bean and wheat yield, soil nitrate, and weed biomass were analyzed separately using a linear mixed effects model. Bean type was nested in previous crop and treated as fixed effects, while year and replication were treated as random effects. Treatment means were separated using the Tukey's Honestly Significant Difference (HSD) at 5% level of significance. Pearson's correlation coefficients were used to assess correlations among bean yield and total weed biomass using the 'cor.test' function in R. A non-linear regression model was also applied to these measures to quantify the effect of weed biomass on bean yield.

Economic Analysis

We estimated costs for organic dry bean market classes and soybean production based on both indirect and direct equipment and labor costs, similar to organic soybean production costs as calculated by Chase and Delate (2014). Seed and inoculant costs are based on the rates used in this experiment and derived from personal communication with regional commercial distributors. We included the cost of liquid manure fertilizer for dry bean production based on a recommended rate of 45 kg N ha^{-1} (Kaiser, 2011) and prices based on personal communication with local organic farmers.

Dry bean and soybean gross revenue were calculated from current market prices and averaged experimental yield; a 40% premium was added to conventional dry bean prices as recommended by regional grain buyers (personal communication; USDA-AMS, 2015). Grower price for heirloom dry beans was not available at a commodity market scale, and thus were not included in the analysis. We used estimated production expenses and prices of dry bean and soybean to calculate break-even yield, or the yield level at which the value of the crop produced is equal to the cost of production as demonstrated by Fernandez et al. (2012).

Results and Discussion

Environmental Conditions

Mean monthly air temperatures from June to October did not vary greatly by location in this study, ranging from 9-22°C, with July being the warmest. Early season precipitation in June, however, was markedly different across locations (Table 1.1). With an average of 259 mm, Madison experienced the greatest total rainfall in June compared to the other locations. This variation in precipitation, and especially excessive spring moisture, may have impacted bean populations and yield, as well as weed dynamics. Reductions in dry bean yield attributed to early-season soil water and weed growth have been reported (Smith and Yonts, 1988).

Bean Yield

The effect of Phase 1 crops on bean yield in Phase 2 was not consistent over locations (Table 1.2). Bean yield was greater following alfalfa at Madison and Rosemount. Bean yield was similar for the two previous crops at Becker; although actual yield was about 10% greater following alfalfa than following corn. These results were expected, as alfalfa's ability to contribute N to following crops in rotation is well documented (Yost et al., 2014). In contrast, bean yield was greater following corn at Lamberton, potentially due to residual effects of high levels of composted manure applied to the corn in the first year of the cropping sequences.

Within locations, relative bean yield was not affected by Phase 1 crops (i.e., no previous crop by bean type interaction; $P > 0.05$). Bean yield, averaged across bean types, were 45% lower at Lamberton than at the other locations. At Madison, yields were similar across bean types, except kidney which yielded at least 730 kg ha^{-1} less than the others. While soybean was always among the highest yielding types, pinto and black beans had similar yields as soybean at Becker and Rosemount (Table 1.3). Kidney and heirloom were often among the lowest yielding. These results agree with previous organic research that showed that black and pinto are often the highest yielding dry bean types while kidney is among the lowest in conventional and organic systems (Heilig and Kelly, 2012).

Wheat Yield and Nitrogen Response

For wheat yield in Phase 3, there was again significant ($P < 0.05$) effects of Phase 1 crop, but no Phase 1 crop by Phase 2 bean type interaction. At Becker and Rosemount, wheat yield was greater following alfalfa than following corn; while at Lamberton and Madison, wheat yield was greater following corn than alfalfa (Table 1.4). This response difference between locations could be related to delayed mineralization and carryover effects from the application of high rates of manure to the corn in Phase 1 at the organic sites, Lamberton and Madison.

Bean type only affected wheat yield at Becker, where yields were similar following bean types; though wheat following soybeans had greater yield than those following kidney beans (Table 1.5). This is consistent with Przednowek et al. (2004) and Miller et al. (2002), who found variable wheat yield response, but noted a positive protein response in wheat following dry bean. Most of the N from the beans was likely removed in the form of grain at harvest, and any N that is left in the residue decomposes slowly or becomes immobilized by the decomposing microflora (Lupwayi and Kennedy, 2007).

Soil Nitrate

Within locations, total soil nitrate sampled in Phase 2 differed by Phase 1 corn or alfalfa crop. The Phase 1 crop affected soil nitrate at Rosemount, where total soil nitrate levels were 76 kg ha^{-1} higher following alfalfa than corn, and in contrast at Becker where nitrate levels were 21 kg ha^{-1} higher following corn than alfalfa (Table 1.6). Previous crops had no effect on soil nitrate levels at Lamberton or Madison (Table 1.6). On average, Becker had lower total soil nitrate compared to the other locations. This is not surprising, given Becker's sandy soil that provides for low N mineralization and high levels of nitrate leaching.

Total soil nitrate in spring of Phase 3 before wheat planting was also affected by Phase 1 crops within locations (Table 1.6), but not by bean type in Phase 2. Nitrate levels in Phase 3 followed a similar pattern to those observed the previous spring regarding Phase 1 treatment effects. Total soil N was higher following alfalfa at both Lamberton and Rosemount, but higher following corn at Madison (Table 1.6). There were not previous crop effects at Becker. Soil nitrate was similar for the six bean types (*P* = 0.32). These grain legumes are expected to contribute little to soil N, sometimes even resulting in net removal of nitrogen from the soil (van Kessel and Hartley, 2000).

Soil nitrate tests have been used as a pre-or in-season diagnostic tool for adaptive N management (Yost et al., 2014), but may not be an indicator of dry bean performance because of the plants' ability to rely on both soil and atmospheric sources of N (van Kessel and Hartley, 2000; Farid and Navabi, 2015). Indeed, we found little correlation (r = -0.036) between Phase 2 total soil nitrate and bean yield. When sufficient or excess nutrients are present in the soil, others have actually reported reduced dry bean yield with the addition of manure (Quakenbush and Wilson, 1981). Further, Przednowek et al. (2004), reported masking of apparent N benefits from legumes by high soil N status, which could explain why we saw little effect of bean type on wheat yield (Table 1.5). In general, based on 0-61 cm samples, low levels of soil nitrate range from 43-83 kg ha^{-1}; medium levels range from 84-124 kg ha^{-1} comprises; high levels are considered anything above 124 kg ha^{-1} (Agvise Laboratories). Based on these standards, the soil nitrate levels at our locations were relatively high, except for at Becker (Table 1.6).

Weed Biomass

Total weed biomass in Phase 2 varied within locations by Phase 1 crop and bean type (Table 1.7). No effect of Phase 1 crop occurred at either Rosemount or Lamberton. At Becker, there was more weed pressure, particularly from grasses, in the alfalfa treatments as opposed to corn; whereas weed biomass at Madison was higher following corn (Table 1.7). The inconsistent effects of alfalfa versus corn in suppressing weeds may be related to differences in weed seed banks prior to the start of our research. On average, navy bean plots were the least competitive with weeds and had the most total weed biomass on average with 3,491 kg ha^{-1}, while soybean plots had the least with 2,324 kg ha^{-1}. Soybean has greater seedling vigor and canopy closure as compared to dry beans, leading to this enhanced competition with weeds (Saberali et al., 2012). Overall, based on our correlation analysis, bean yield was negatively impacted by weed presence ($r = -0.71$), with yield expected to decrease by almost 200 kg ha^{-1} for every 100 kg ha^{-1} weed biomass.

Total weed biomass in Phase 3 again varied by Phase 1 crop; but in contrast to Phase 2, was not affected by bean type. Wheat at Becker and Lamberton had more weeds in alfalfa treatments compared to the corn treatments, but no difference in total weed biomass was seen at Madison or Rosemount across these treatments (Table 1.7). Across locations, wheat was minimally impacted by weeds during this phase ($r = -0.30$).

Rotations can exert selection pressures that will either favor adapted or reduce populations of maladapted weed species; however, because of weed seedbank carryover effects may not have been observable in our short-term experiment (Burnside et al., 1996; Teasdale et al., 2004). Common grass weeds in our cropping sequence were barnyardgrass *(Echinochloa crusgalli)*, crabgrass *(Digitaria sanguinalis)*, and giant foxtail (*Setaria faberi)*. The main broadleaf weeds identified between the locations were lambsquarters *(Chenopodium album)*, redroot pigweed (*Amaranthus retroflexus)*, Pennsylvania smartweed *(Polygonum pensylvanicum)*, and some Canada thistle *(Cirsium* *arvense)* pressure was also present. While annual grass weeds dominated in the alfalfa treatments because they tolerated mowing, alfalfa can reduce Canada thistle during it's three years of production, as well as in the following winter wheat crop (Teasdale et al., 2004; Tautges et al., 2015). Given the large quantities of seed that common lambsquarters and pigweed species are capable of producing and the difficulty of controlling these weeds in organic row crops, it is understandable that these weed species dominated the seed bank in the corn treatments. Further, these weed species were identified by Burnside et al. (1996) as species with greatest seed longevity in the soil. This research suggests that maintaining a low weed seedbank is critical to the success of weed management programs for organic farming systems.

Economic Analysis

Profitability of edible soybeans and dry beans is affected by widely fluctuating bean prices and varying production costs. Conventional dry beans can return \$73 to \$109 ha^{-1} at the average expected price for 2013 (\$40 per hundredweight), if averaging 2,242 kg ha^{-1} (Lee, 2013). Organic dry bean economics is even harder to estimate, as large quantities of organic or untreated seed is often unavailable. Personal communication with local seed suppliers estimate 40% higher costs in organic seed compared to conventional, which is typically coupled with lower yields and potentially higher production costs. Nevertheless, many large-scale bean producers are considering organic production given the price advantage compared to conventional crops, such as ~150% for organic dry bean (Heilig, 2010) and 136% premium for organic soybean (Mahoney et al., 2003).

Organic soybean production costs are estimated at \$447 ha^{-1}, and dry bean production ranges based on market class from \$502-\$659 ha^{-1} (Table 1.8). Still, our results indicate that the price advantage of dry bean compared to soybean outweighed the potential additional costs of weed and fertility management, as evident in the lower break-even yield for dry bean types (Table 1.9). The net return for organic soybean in our analysis is 1.5 times lower than any of the dry bean classes. Pinto bean, the highest yielding of the dry beans, produced the highest net returns, up to \$3,983 ha^{-1}. While kidney beans may receive the best price (\$2.63 kg^{-1}), achieved yields in this study were the lowest, in comparison with the other classes. Overall, yield of all bean market classes (Table 1.3) consistently exceeded the break-even level at all locations and in both alfalfa and corn treatments (Table 1.2).

As seen with lentils and field peas in Fernandez et al. (2012), the value of organic dry beans in rotation is likely to be greater than the market value calculated here. Organic dry beans are well suited for local markets such as farmer's markets, CSAs, restaurants, and co-ops, where growers may receive a higher price (RSDP, 2014, unpublished). For instance, recent surveys conducted with restaurants in the Twin Cities, indicate a substantial market price for both local, non-heirloom (\$6.28 kg^{-1}) and heirloom dry beans (\$10.5 kg^{-1}; RSDP, 2014, unpublished).

Conclusions

Nitrogen availability to a subsequent crop from legumes grown in rotation can vary with management options, such as tillage; soil and climate conditions such as temperature and soil moisture; and tissue quality characteristics. Our results support previous findings that rotation benefits of dry bean appear to depend somewhat on location and each legume's adaptation to local growing conditions (Przednowek et al., 2004). 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 nitrogen is limited, alfalfa prior to dry beans should increase yield. More long term studies on rotations need to be conducted to build upon the knowledge of rotation effects, including a more in-depth analyses of nitrogen dynamics, and ecological benefits in organic dry bean systems. Information gained in the present study will be utilized to facilitate an expansion of this important pulse crop in Minnesota.

Table 1.1 Air temperature and precipitation during the growing season at the four MN locations averaged across 2011-2015.

	Rosemount	**Lamberton**	**Madison**	**Becker**	**30-year average**
	--------------------Mean monthly temperature, °C----------------------				
June	20	21	21	20	21
July	23	23	21	21	24
Aug	21	21	22	21	22
Sept	17	18	17	18	17
Oct	9	9	10	9	10
	--------------------Mean monthly precipitation, mm--------------------				
June	76.2	120.5	259.2	74.4	106.9
July	38.7	38.5	64.5	38.5	112.0
Aug	34.5	83.0	88.4	29.9	120.9
Sept	8.3	63.8	63.9	17.4	83.1
Oct	30.3	31.6	63.3	50.6	73.9
Total	187.9	337.3	539.2	210.9	496.8

* 30-year average indicates mean across locations

Table 1.2 Grain yield (kg ha^{-1}) of soybean and dry bean classes following either corn or alfalfa in Phase 1 at four MN locations in 2011-2014.

Phase 1 Crop	Becker		Lamberton		Madison		Rosemount		Mean
Alfalfa	2198	a	1188	b	2239	a	2335	a	1990
Corn	2026	a	1506	a	1781	b	1939	b	1813
Mean	2112		1347		2010		2137		1902

* Within a location, means followed by the same letter are not significantly different at (α= 0.05), as determined by Tukey’s HSD.

Table 1.3 Grain yield (kg ha^{-1}) of soybean and five dry bean classes at four MN locations from 2011-2014.

Bean Market Class	**Becker**		**Lamberton**		**Madison**		**Rosemount**		**Mean**
Black	2446	a	1254	bc	1988	a	2110	abc	1950
Heirloom	1791	b	1085	c	2083	a	1922	bc	1720
Kidney	1698	b	980	c	1257	b	1655	c	1398
Navy	1973	ab	928	c	2052	a	2319	ab	1818
Pinto	2261	ab	1493	b	2557	a	2539	a	2213
Soybean	2505	a	2343	a	2125	a	2276	ab	2312
Mean	2112		1347		2010		2137		1902

* Within a location, means followed by the same letter are not significantly different at (α= 0.05), as determined by Tukey's HSD.

Table 1.4 Wheat yield (kg ha^{-1}) following either corn or alfalfa in Phase 1 at four MN locations in 2012-2015.

Phase 1 Crop	Becker		Lamberton		Madison		Rosemount		Mean
Alfalfa	2284	a	2829	b	1060	b	2521	a	2174
Corn	1966	b	3316	a	1613	a	2120	b	2254
Mean	2125		3073		1337		2321		2214

* Within a location, means followed by the same letter are not significantly different at (α= 0.05), as determined by Tukey's HSD.

Table 1.5 Wheat yield (kg ha^{-1}) following soybean and five dry bean classes at four MN locations in 2012-2015.

Bean Market Class	Becker		Lamberton		Madison		Rosemount		Mean
Black	2003	ab	2990	a	1243	a	2142	a	2095
Heirloom	2314	ab	3018	a	1473	a	2404	a	2302
Kidney	1895	b	3082	a	1545	a	2411	a	2233
Navy	2019	ab	3152	a	1190	a	2139	a	2125
Pinto	2026	ab	3139	a	1036	a	2393	a	2149
Soybean	2492	a	3054	a	1530	a	2434	a	2378
Mean	2125		3073		1337		2321		2214

* Within a location, means followed by the same letter are not significantly different at (α= 0.05), as determined by Tukey's HSD.

Table 1.6 Effect of corn or alfalfa previous crops on spring total soil nitrate (kg ha^{-1}) measured at combined depths of 0- 61 cm following before bean planting beans (Phase 2) and in April the following year before wheat planting (Phase 3).

Rotation Phase	**Location**	**Phase 1 Crop**				
		Alfalfa		**Corn**		**Mean**
Phase 2		------------------ kg ha^{-1} ------------------				
	Becker	52	b	73	a	62
	Lamberton	157	a	147	a	152
	Madison	165	a	193	a	179
	Rosemount	195	a	119	b	157
Phase 3		------------------ kg ha^{-1} ------------------				
	Becker	79	a	75	a	77
	Lamberton	106	a	80	b	93
	Madison	145	b	189	a	167
	Rosemount	95	a	80	b	87

* Within rotation phases and locations, means followed by the same letter are not significantly different at (α= 0.05), as determined by Tukey’s HSD.

Table 1.7 Mean total weed biomass (kg ha^{-1}) taken at bean harvest (Phase 2) and wheat harvest (Phase 3) following either corn or alfalfa at each location.

Rotation Phase	**Location**	**Phase 1 Crop**				
		Alfalfa		**Corn**		**Mean**
Phase 2		---------------- kg ha^{-1} ---------------				
	Becker	1567	a	1006	b	1287
	Lamberton	4230	a	4364	a	4297
	Madison	903	b	1294	a	1099
	Rosemount	2794	a	2826	a	2810
Phase 3		---------------- kg ha^{-1} ---------------				
	Becker	2819	a	2286	b	2553
	Lamberton	1198	a	628	b	913
	Madison	3388	a	3114	a	3251
	Rosemount	4442	a	4519	a	4481

*Within rotation phases and locations, means followed by the same letter are not significantly different at (α= 0.05), as determined by Tukey’s HSD.

Table 1.8 Predicted yearly costs of organic dry bean market classes and soybean production.

Expense	**Cost**				
	Black	**Kidney**	**Navy**	**Pinto**	**Soybean**
	------------------------------$ ha^{-1}------------------------------				
Seed	222,395 seeds ha^{-1} at $ 0.37 kg^{-1}	172,974 seeds ha^{-1} at $ 0.54 kg^{-1}	222,395 seeds ha^{-1} at $ 0.37 kg^{-1}	172,974 seeds ha^{-1} at $ 0.54 kg^{-1}	370,658 seeds ha^{-1} at $ 0.38 kg^{-1}
	$91.24	$244.20	$86.77	$123.77	$132.49
Inoculant	$22.24	$22.24	$22.24	$22.24	$19.47
Fertilizer					
Liquid manure at $8.45 per m^{3}	$79.07	$79.07	$79.07	$79.07	--
Equipment					
Fall-disk	$20.26	$20.26	$20.26	$20.26	$20.26
Pre-plant field cultivate	$14.58	$14.58	$14.58	$14.58	$14.58
Plant	$26.19	$26.19	$26.19	$26.19	$26.19
Rotary hoe (1-2x)	$15.81	$15.81	$15.81	$15.81	$7.91
Row cultivate (2x)	$52.39	$52.39	$52.39	$52.39	$52.39
Direct harvest	$58.32	$58.32	$58.32	$58.32	$58.32
Labor					
8.4 hrs ha^{-1} at $15/hr	$126.02	$126.02	$126.02	$126.02	--
7.7 hrs ha^{-1} at $15/hr	--	--	--	--	$114.90
Total	$506.12	$659.08	$501.65	$538.65	$446.51

* Based on calculations by Chase and Delate (2014).

Table 1.9 Price, production cost, break-even yield, and observed yield of bean market classes

Bean Market Class	**Price**	**Production cost**	**Break-even yield**	**Observed yield range***
	$ kg^{-1}	**$ ha^{-1}**	**-------------kg ha^{-1}**	**-------------**
Black	$1.82	$506.12	278	34-3777
Kidney	$2.63	$659.08	251	6-2929
Navy	$1.97	$501.65	255	11-3980
Pinto	$1.80	$538.65	299	75-3808
Soybean	$1.05	$446.51	425	141-4381

*Minimum and maximum averaged across corn and alfalfa treatments within replications, locations, and years

CHAPTER TWO

Response of Dry Bean and Soybean Varieties to Tillage and Row Spacing in Organic Systems

Summary

Weed control is a primary concern in organic production systems. Organic farmers rely on a combination of mechanical and cultural practices to mitigate weed competition with their crops, such as alternative tillage, row-spacing, and variety selection. Dry beans are notoriously poor competitors with weeds, though some varieties are more vigorous than others. Our objective was to evaluate alternative tillage practices and row spacing effects on dry bean and soybean yield, as well as weed control. From 2012 to 2014, experiments were conducted to determine the combined effects of tine weeding in 38 cm rows, tine weeding and cultivation in 76 cm rows, or cultivation in 76 cm rows on black, kidney, and soybean variety yield and weed biomass. Across years, excessive early season moisture led to high weed populations and reduced bean yield. Both dry bean and soybean yields were 25% less in the narrow row treatments. Correspondingly, weed biomass was 30-40% higher in the narrow tine weeded treatments as compared to the two wide row cultivated treatments. Total weed biomass differed among classes, with the lowest in soybean treatments (2,360 kg ha^{-1}). Soybean yield was greater than the two dry bean varieties in all years yielding on average 1,980 $kg \cdot ha^{-1}$ compared to 1,086 and 1,071 $kg \cdot ha^{-1}$ for the kidney and black bean, respectively. While narrow rows have lead to dry bean and soybean yield increases in some conventional studies, our results demonstrate that wider rows that facilitate tillage operations may lead to better weed control and subsequently higher yields in organic systems.

Introduction

Mirroring recent trends in the sales and consumption of organic food within the United States, organic dry bean (*Phaseolus vulgaris)* production nearly quadrupled in the state of Minnesota from 2008-2011 (USDA, 2013). Minnesota farmers planted 2,498 acres of organic dry beans making the state the third largest producer of organic dry beans in the US, behind Michigan and California (USDA, 2013). Minnesota is also the leading producer of organic soybeans (*Glycine max)* in the US, with 18,821 acres accounting for 14% of the total US organic soybean acreage (USDA, 2013). Recent surveys with local restaurants, co-op's, farmer's markets, and distributors conducted in Minnesota by the Regional Sustainable Development Partnerships (RSDP) have shown a substantial interest in consumption and marketing of locally produced organic dry beans (unpublished, 2013). This interest in local organic production of soybeans and dry beans has revealed the need for efficient and economically viable production systems.

Weed control is a critical issue in all crop production systems, especially organic (Moncada and Sheaffer, 2012). Relative to soybeans, dry beans are generally poor competitors with weeds, as they are slow to establish ground cover (Saberali et al., 2012). As such, weed control in dry beans is especially critical during the first four to nine weeks after planting or up to the sixth trifoliate leaf stage (Saberali et al., 2012). Dry bean grain yield reductions of up to 99% have been reported if weeds are present throughout the growing season (VanGessel et al., 1998; Amador-Ramirez et al., 2001).

Conventional dry bean farmers in Minnesota have also cited weed control as a major production problem, even with herbicide options (Knodel et al., 2013). Multiple studies have been conducted comparing mechanical and herbicide control of weeds in dry beans, with mixed results. Burnside et al. (1994) reported mechanical weed control was not as effective as mechanical weeding plus herbicides in dry beans. VanGessel et al. (1998) and Amador-Ramirez et al. (2001) found that at low weed densities, mechanical tillage alone was effective in suppressing weeds. Colquhou et al. (1999) concluded that use of either a brush hoe and/or shovel cultivator, preceded by tine-weeding, allowed for weed control and a snap bean yield comparable to that obtained with broadcast herbicides.

Mechanical tillage practices typically focus on cultivation between rows and often overlook the weeds within the row. In-row cultivation has proven beneficial in dry bean production, with weed control up to 85% when dry bean fields were rotary hoed at the time of crop emergence (VanGessel et al., 1995). A spring-tine weeder is another early-season cultivation tool that can be used to kill the first flush of small emerging weeds within rows. While rotary hoeing and tine weeding have been reported to reduce dry bean populations (Burnside et al., 1994; Leblanc and Cloutier, 2001), VanGessel et al. (1995) found no reductions in dry bean grain yield.

Beyond mechanical tillage, farmers can use strategies such as crop rotation and modified row spacing for organic weed management, as well as selecting varieties and species that are competitive with weeds (USDA-NOP, 2015). Research in conventional production systems has suggested that large seeded legumes like soybeans and dry beans may be good candidates for production in narrow rows (Lehman and Lambert, 1960; Xu and Pierce, 1998). Moreover, many studies have documented an interaction between production system and genotypes (Singh et al., 2009). For instance, Cooper (1977) found differential response of two soybean varieties, where ‘Corsoy’ the smaller and earlier maturing of the two, responded more favorably to narrow row production. In a similar study, Carter and Boerma (1979) found soybean genotype × row spacing interactions for yield, seed size, and number of pods per unit area. Reducing row spacing from 75 to 25 cm has been shown to increase pinto bean yield by 52% and determinant navy bean by 44% (Grafton et al.,1998). In general, dry bean yield increases ranging from 5- 48% when grown in narrow rows (20-35 cm) as compared to wide rows (60-90 cm) have been reported in conventional systems, with the yield response attributed to more uniform maturity and higher plant populations (Kelly, 1988; Xu and Pierce, 1998; Blackshaw et al., 2000). Further, coupled with denser populations, the greater canopy closure of the beans in narrow rows may allow for greater competition with the weeds.

Research to evaluate the effects of tillage method and row spacing on soybean and dry bean yield in organic systems is limited. Taylor et al. (2012) did find that rotary hoeing every 300 GDD was more efficient, economical, and caused less crop injury than flaming or the combination of the two weed management strategies in soybean and dry bean. Still, no research has investigated the interactive effects of production method and bean type on weed control and yield in organic soybean and dry bean systems. Therefore, the objective of this study was to evaluate the effects of these cultural practices on weed control and grain yield of two dry bean varieties and a food-grade soybean in organic systems in Minnesota.

Materials and Methods

Field experiments were conducted from 2012-2014 on organically certified land at the University of Minnesota's Southwest Research and Outreach Center in Lamberton, MN (44.14 °N, - 95.19 °W; elevation of 346 m) and at an on-farm site in Madison, MN (45.00 °N, -96.15 °W; elevation of 332 m). The soil type in Lamberton was a Webster clay loam with pH of 6.6 and organic matter of 4.7%. The previous crop at Lamberton was corn (*Zea mays* L.), fertilized in the spring before planting with composted livestock manure applied at a rate of 9 Mg ha^{-1}, with an analysis of 1.28N-1.94P-1.48K. The field site at Madison had previously been planted to barley (*Hordeum vulgare* L.) in 2011 and fertilized with liquid hog manure at a rate of 37,415 liters ha^{-1} with an analysis of 22N-7P-17K kg per thousand liters applied. Soil type was Webster clay loam at Madison with a pH of 6.6 and 5.0% organic matter.

The experimental design was a randomized complete block with four replicates and a split-plot arrangement of treatments. Tillage method and row spacing combinations were the whole-plot treatment and bean type was the sub-plot treatment. The three whole plot treatments were: 1) tine weeding on 38 cm row spacing (TW38), 2) tine weeding and cultivation on 76 cm row spacing (TWCULT76), and 3) cultivation alone on 76 cm row spacing (CULT76). Plot size was 3 m wide by 6 m long with four rows of beans in the 76 cm spacing and 8 rows in the 38 cm spacing. A 3 m alleyway between replicate blocks was established to obtain the desired tractor speed before entering the plots with cultivation equipment.

Sub-plot treatments of ‘MN1505SP’ food-grade soybean (Minnesota Agricultural Experiment Station, St. Paul, MN), ‘Eclipse’ black bean (Osorno et al., 2004), and ‘Red Hawk’ kidney bean (Kelly et al., 1988), were chosen to provide a range of plant vigor and seed size within the desired upright, determinant growth habit. The beans were inoculated with complementary N-fixing bacteria, *Rhizobium tropici* CIAT899. Seedbeds were prepared with field cultivation two weeks prior to planting. Seeds were planted at 258,224 seeds ha^{-1} for all treatments. Plots were planted on: 7 June 2012, 17 June 2013, and 25 June, 2014 at Madison, MN and on: 6 June 2012, 3 June 2013, and 11 June 2014 at Lamberton, MN. Bean stand counts from 4.65 m^2 were used to estimate plant populations. Bean yield was determined by hand-harvesting 3 m of the center two rows of each plot on 21 September 2012, 13 September 2013, and 1 October 2014. Plants were threshed using a rasp bar type Almaco Plot Thresher (LPT-RRB; Nevada, IA). Seeds were then dried at 35 °C, and yield was calculated on a 13% moisture basis.

For the tine weeding treatments (TW38 and TWCULT76), tine weeding was initiated three to five days after the beans had been planted. Tine weeding was continued until the beans were at the 1-2 trifoliate stage to kill emerging weeds. For the cultivation treatments (TWCULT76 and CULT76) inter-row cultivation was done three to five weeks post planting, and up to three times. The cultivator used was a John Deere 10’ (875; Moline, IL) pulled by a John Deer tractor (7610; Moline, IL), and the tine-weeder was a Kovar (25-5; Anoka, MN) 10’ Spring Tooth Harrow, Tooth 20”, plus 5” length bent forward at 45° angle.

At the end of each season, broadleaf and grass weed biomass was measured by sampling weeds from ½ m^2. Weeds were dried at 35 °C and reported on a dry matter basis. Number of broadleaf and grass weeds in a ½ m^2 area were counted prior to each tillage application in 2014.

Data sets were analyzed in the R statistical programming environment using the ‘stats’ and ‘nlme’ packages (Pinheiro and Bates, 2013; R Development Core Team, 2015). All data were verified for normality and constant variance of residuals. To test for differences in bean population, bean yield, and total weed biomass between treatments, mixed effects ANOVA was performed with bean variety and tillage system (the combination of tillage method and row spacing) as the main fixed-effects. The effect of year was also treated as a fixed-effect as many interactions occurred with the main effects due to environmental differences (Table 2.1). Blocks were nested within locations, which were treated as random effects. Treatment means were separated using the Tukey’s Honestly Significant Difference (HSD) at 5% level of significance. Pearson’s correlation coefficients were used to assess correlations among bean yield and total weed biomass using the ‘cor.test’ function in R.

Results and Discussion

Weather Conditions

Mean daily air temperature from 1 June to 1 October was 18.4°C in 2012, 18.0°C in 2013, and 17.9°C in 2014 (Table 2.2). Accumulation of growing degree days followed a similar pattern across years, with 2012 having slightly higher and 2014 having slightly lower GDDs.

In contrast to the similarity of temperature patterns between 2012-14, precipitation patterns varied across the three years (Table 2.2). Averaged across the two locations, total precipitation from 1 June to 1 October was 159 mm in 2012, 335 mm in 2013, and 422 mm in 2014, as compared with the 30-year average of 408 mm. The below-normal moisture in 2012 allowed for early planting and timely cultivation. Early-season moisture in 2013 and 2014, set back the tillage operations, and weed biomass exceeded the pressure seen in 2012 (Table 2.2).

This variation in precipitation could help explain the different effects of the weed control treatments across years. Greater weed density and biomass have been attributed to higher early-season moisture, in turn causing dry bean yield reductions (Smith and Yonts, 1988; Aleman, 2001). Alternatively, drought conditions can also affect bean yield by delaying maturity (Heilig and Kelly, 2012).

Bean Population

Bean populations were effected by a year x tillage system x variety interaction ($P < 0.01$; Table 1). Still, regardless of tillage system treatment or bean variety, 2012 had the highest plant populations compared to the other two years. In 2012 and 2014, all varieties had similar plant populations, while in 2013, the soybean ‘MN1505SP’ had greater populations than the two dry beans. Average plant populations by bean variety were 190,481, 139,540, and 127,190 plants ha^{-1} for ‘MN1505SP’, ‘Eclipse’, and ‘Red Hawk’, respectively.

Schneiter and Nagle (1980) and Grafton et al. (1988) found a population of 222,000 plants ha^{-1} allowed for maximum seed yield with determinate dry bean varieties in conventional production. Similarly, Coulter et al. (2008) cite a higher soybean population of 294,700 plants ha^{-1} to obtain good yields in organic systems. Our low populations may be attributable to excessive spring moisture, weed pressure, or to soil borne disease as our organic seed was not treated with fungicides.

Bean Yield

Bean yield was affected by year ($P < 0.001$); Table 2.1), with the highest average bean yield observed in 2012 with 1,810 kg ha^{-1}, followed by 1,401 kg ha^{-1} in 2014, and 2013 had the lowest yield with 927 kg ha^{-1} (Table 2.3). These differences between years could be attributed to weather patterns as discussed earlier (Table 2.2). Drier conditions, like those seen in 2012, made it possible for planting and tillage equipment to get into the fields in a timely manner, and therefore may have led to the increase in yield.

Bean yield was also affected by tillage system treatments and bean variety, but not the interaction (Table 2.1). Across years, the beans in the 38 cm rows that were only tine weeded (TW38) yielded 25% less than the other two 76 cm row spacing treatments (TWCULT76 and CULT76) that were also cultivated (Table 2.3). However, in the relatively dry year of 2012, the TW38 treatment had comparable yields to the CULT76 and TWCULT76 treatments (mean = 1,810 kg ha^{-1}).

The soybean 'MN1505SP' substantially outperformed the two dry bean varieties in all years, yielding on average 1,980 kg ha^{-1} compared to 1,086 and 1,071 kg ha^{-1} of 'Red Hawk' and 'Eclipse', respectively (Table 2.3). Notably, 'MN1505SP' yield was highest in the TW38 treatment in 2012, yielding 2,519 kg ha^{-1}. This could be due to the relatively effective weed control that year (Table 2.4). While tested yields for these dry bean varieties in conventional systems are 2,190 kg ha^{-1} for 'Red Hawk' and 2,632 kg ha^{-1} for 'Eclipse', average dry bean yield in organic systems range from 1,718 to 3,951 kg ha^{-1} (Heilig and Kelly, 2012). Moreover, Heilig and Kelly (2012) reported a 21.5% reduction in yield of 'Red Hawk' when grown under organic production compared to conventional. Overall, our low yields are indicative of excessive early-season moisture, high weed pressure, and overall low populations. Indeed, bean yields in this study were negatively affected by total weed biomass (r = -0.61), averaged across treatments.

Our results contrast with findings from conventionally grown dry beans that reported narrower rows led to higher populations and yields (Grafton et al., 1988; Malik et al., 1993; Xu and Pierce, 1998; Blackshaw et al., 2000). These studies, though, employ additional herbicide weed control measures not permitted in organic systems. Focusing solely on tillage operations for weed management, the less intense cultivation of the tine-weeded narrow row treatment (TW38) appeared to place the beans at a yield disadvantage compared to the 76 cm row treatments (TWCULT76 and CULT76; Table 3). Kluchinski and Singer (2005) support this finding in organic soybean, reporting that the ability to cultivate for a longer period of time in their wide row (76 cm) treatments as compared to narrow row treatments (20 cm) led to greater yield stability.

Weed Control

Bean variety and tillage system treatment, as well as the interaction between tillage system and year impacted total weed biomass (Table 2.1). Total weed biomass amounted to 4,187, 3,374, and 1,726 kg ha^{-1} in 2014-2012, respectively (Table 2.4). Total weed biomass of 'Eclipse' and 'Red Hawk' treatments averaged 3,464 kg ha^{-1}, which was greater than the ‘MN1505SP’ treatments which contained 2,360 kg ha^{-1} of total weed biomass on average. While these dry bean varieties form relatively large canopies and are quick growing (Kelly et al., 1988; Osorno et al., 2004)*,* they still do not compete as strongly with weeds as do soybeans.

The TW38 treatment had 150% more weed biomass than the 76 cm row spacing treatments (Table 2.4). With the small window allowed for tillage operation in the spring with a tine-weeder, this abundance of weeds is not surprising. Kluchinski and Singer (2005) also reported reduced weed control in organic soybeans grown in 20 cm rows compared with 76 cm rows. In contrast, other research in conventional systems found reduced weed biomass in narrow row dry bean production (Malik et al., 1993; Xu and Pierce, 1998; Blackshaw et al., 2000). Still, these studies implemented cultivation on these narrower rows, unlike in the present study.

Total weed biomass was separated into grasses and broadleaves. Grass weeds identified were barnyardgrass *(Echinochloa crusgalli)*, crabgrass *(Digitaria sanguinalis)*, and giant foxtail (*Setaria faberi)*. The main broadleaf weeds identified between the two locations were lambsquarters *(Chenopodium album)*, redroot pigweed (*Amaranthus retroflexus)*, Pennsylvania smartweed *(Polygonum pensylvanicum)*, and some Canada thistle *(Cirsium arvense)* pressure was also present. Overall, substantially more weed pressure was seen from broadleaf weeds with 2477 kg ha^{-1} compared to 796 kg ha^{-1} of grass weeds. Based on weed population estimates in 2014, counted before each tillage operation, we also had greater numbers of broadleaf weeds with an average of 14 plants $plot^{-1}$ compared to one grass weed. We did not detect any effect of bean variety on broadleaf weed biomass, but the soybean plots had 20-50% less grass weed biomass than the dry bean plots. According to a study conducted by Burnside et al. (1994) and a survey of Minnesota dry bean farmers (Knodel et al., 2013), grass weeds were the more difficult species to control. The relatively late emergence trends of grass weeds like barnyardgrass and crabgrass, are important to understand when developing a weed management system (Buhler et al., 2008). Differences in weed biomass observed could further be attributed to crop rotation history and yearly seedbank, as well as variations in weather patterns as reported in Table 2.2.

Conclusions

In Minnesota dry bean production, typical cultivation practices in organic as well as conventional systems include working the seed bed, rotary hoeing or tine weeding before weeds emerge, and then cultivating as needed (ADM, 2015). Yet, little to no research has been done in organic systems on the efficacy of this approach to maximize weed control and dry bean yield in the Upper Midwest. As emphasized by Burnside et al. (1994) and Taylor et al. (2012), it is necessary to determine a point when added tillage would not significantly increase weed control or bean yield. Within our 76 cm row treatments (TWC76 and C76), we saw no significant yield increases with the added tine weeding and both were comparable in terms of weed control. Tine weeding alone on 38 cm row spacing was not effective for weed management and both dry bean and soybean yield suffered as a result.

Overall, these findings on the interactive effects of variety, row spacing, and tillage treatment on bean yield and total weed biomass in organically managed systems are contradictory to those reported from previous research in conventionally managed systems in the Midwestern United States. Complex differences in rotation practices, fertility management, or weed and disease pressures between these two systems could help explain these disparities of cultural practice effectiveness. Nevertheless, in any system relying on tillage for weed control, timeliness is key. New implements, such as between-row mowers or flame-weeders, could potentially replace rotary hoeing, especially in the event that wet weather prevented timely mechanical weed control measures (Donald et al., 2001; Taylor et al., 2012). Further, breeding efforts could focus on selection for weed tolerance or suppression in new cultivar development. Future research in organic dry bean and soybean production should focus on alternatives like this, as well as basic agronomic questions regarding cultural practices and variety selection that have been overlooked in organic systems.

Table 2.1 Results from mixed-effects analysis of variance testing responses of bean population, bean yield, and weed biomass.

Source of Variation	**df**	**Bean Population**	**Bean Yield**	**Weed Biomass**
Year	2	***	***	***
Tillage System	2	NS	***	***
Variety	2	***	***	**
Year x Till	4	NS	**	***
Year x Var	4	***	NS	NS
Till x Var	4	NS	NS	NS
Year x Till x Var	8	*	NS	NS

* Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

* Location and Rep treated as random

* Tillage system refers to the combination of tillage method and row spacing treatments

Table 2.2 Air temperature and precipitation received during the growing season at Lamberton and Madison, MN.

Month	**2012**		**2013**		**2014**		**30-year mean**
	Lamberton	Madison	Lamberton	Madison	Lamberton	Madison	
	--------------------------------Mean monthly temperature, °C---------------------------------------						
June	22	23	20	18	20	21	20
July	26	26	22	21	20	21	23
Aug	21	22	21	22	21	22	21
Sept	16	16	19	19	16	17	16
Oct	7	7	9	9	10	11	9
	--Precipitation, mm---						
June	32.0	46.7	134.1	124.0	187.7	166.9	99.9
July	18.8	9.7	9.4	78.7	29.7	29.7	91.9
Aug	77.7	50.0	46.5	26.2	94.5	126.7	80.5
Sept	28.2	7.6	48.3	61.5	154.2	24.1	77.1
Oct	23.6	23.1	82.0	59.9	12.4	17.5	58.5
Total	180.3	137.2	320.3	350.3	478.5	365.0	408.1

* 30-year mean is averaged across locations

Table 2.3 Dry bean and soybean yield in 2012-2014 as influenced by tillage system and bean variety.

Tillage System	**Bean Cultivar**	**Grain yield kg ha $^{-1}$**			
		2012	2013	2014	Mean
CULT76	Eclipse	1572	657	1350	1193
	Red Hawk	1522	701	883	1035
	MN1505SP	2245	1976	2055	2092
	Mean	1780 **a**	1111 **b**	1429 **ab**	1440
TWCULT76	Eclipse	1550	893	1296	1246
	Red Hawk	1753	1065	1125	1314
	MN1505SP	2301	2114	1954	2123
	Mean	1868 **a**	1357 **ab**	1458 **ab**	1561
TW38	Eclipse	1264	63	994	773
	Red Hawk	1560	125	1040	908
	MN1505SP	2519	745	1913	1726
	Mean	1781 **a**	311 **c**	1316 **ab**	1136

* Abbreviations are as follows: C76= Cultivation of 76 cm rows; TWCULT76= Tine weeding and cultivation of 76 cm rows; TW38= Tine weeding of 38 cm rows.

* ‘Eclipse’ black bean; ‘Red Hawk’ kidney bean; ‘MN1505SP’ soybean

* Means followed by the same letter are not significantly different at (α= 0.05).

Table 2.4 Total weed biomass in 2012-2014 as influenced by tillage system and bean variety.

Tillage System	**Bean Cultivar**	**Total weed biomass kg ha^{-1}**			
		2012	2013	2014	Mean
CULT76	Eclipse	1423	2974	4839	3079
	Red Hawk	1078	2795	7219	3697
	MN1505SP	720	1526	3088	1778
	Mean	1074 **f**	2432 **e**	5049 **b**	2851
TWCULT76	Eclipse	2974	2987	5665	3875
	Red Hawk	2795	1092	315	1401
	MN1505SP	1526	546	4122	2065
	Mean	2432 **e**	1542 **f**	3367 **d**	2447
TW38	Eclipse	2043	6749	3615	4136
	Red Hawk	1590	7335	4856	4594
	MN1505SP	1384	4361	3964	3236
	Mean	1672 **f**	6148 **a**	4145 **c**	3989

* Abbreviations are as follows: C76= Cultivation of 76 cm rows; TWCULT76= Tine weeding and cultivation of 76 cm rows; TW38= Tine weeding of 38 cm rows.

* ‘Eclipse’ black bean; ‘Red Hawk’ kidney bean; ‘MN1505SP’ soybean

* Means followed by the same letter are not significantly different at (α= 0.05).

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