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Growing environment contributes more to soybean yield than cultivar under organic management

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ABSTRACT

Most non-genetically modified (GM) soybean (*Glycine max* Merr.) cultivars are bred and performance-tested under conventional conditions and have rarely been tested in organic production. Twelve non-GM soybean cultivars were evaluated in weed-free and weedy conditions on 5 organic farms and 1 transitional farm in southern Manitoba in 2014 and 2015. The mean cultivar yield ranged from 1384 to 1807 kg ha^{-1}. Weed biomass at soybean maturity ranged from 1289 to 2553 kg ha^{-1} and was significantly affected by cultivar. Significant site–cultivar interactions were observed for soybean biomass, height, and yield. Site accounted for 72.4% of yield variability; cultivar accounted for only 1%. Our hypothesis that cultivars with greater early season height are more competitive with weeds was not supported. Yield loss due to weeds ranged between 20 and 44%; lower yield loss was associated with timely weed management. Partial least squares regression was used to assess the main factors controlling grain yield. Higher soil nitrate (N) status negatively impacted final grain yield in this study, suggesting that soil nutrient status impacted the soybean cultivars' competitive ability against weeds. Results suggest that weed management and soil N status are of equal importance to cultivar choice for successful organic soybean production in Manitoba.

1. Introduction

Organic soybean (*Glycine max* Merr.) production is important as a protein feed source to meet demand for organic livestock production (IFOAM, 2015), and as an important N-fixing rotation crop. Genetic yield advancement in soybean has been attributed to increased photosynthetic rate, light interception, radiation use efficiency, and greater partitioning of biomass to seed (Koester et al., 2014; Morrison et al., 1999). However, soybean breeding has been conducted under mostly weed-free environments (Koester et al., 2014). Few non-genetically modified (GM) soybean cultivars have been tested in organic production (Bussan et al., 1997; Cober and Morrison, 2015; Wortman et al., 2013) despite the fact that organically managed soils have different soil nutrient dynamics, soil microbial activity, and increased weed competition (Mäder et al., 2002; Braman et al., 2016) than conventional production.

Therefore, it would be valuable to identify soybean cultivars that possess the necessary characteristics for success in organic production; rapid and efficient nitrogen fixation (Kiers et al., 2007; Vollmann and Menken, 2012) and high weed suppression and tolerance (Place et al., 2011). By evaluating 12 soybean varieties across 10 different site-years, we were able to test the genotype × environment interaction for a range of yield components. Genotype × environment investigations have assisted many previous workers in identifying cultivars that possess characteristics across a wide range of regional locations and production management (Dashiell et al., 1994; Cober and Morrison, 2015).

Weeds remain a central challenge in organic pulse crop production (Evans et al., 2016). Weed suppression is the ability for a plant to reduce the growth of a neighbouring competing plant (Goldberg and Landa, 1991). Early season vigour has been identified as one of the most important characteristics contributing to weed suppression in annual grain crops (Lemerle et al., 1996; Zhao et al., 2006), something that has been documented several times in soybean (Bussan et al., 1997; Jannink et al., 2000; Place et al., 2011). Given this positive role, we hypothesized that cultivars with rapid biomass assimilation and height early in the season would have improved weed suppression.

Developing a hypothesis for crop tolerance to weeds, i.e., a plant's ability to perform well despite interference from another plant's presence (Callaway, 1992), was more challenging owing to the conflicting reports by previous workers. For example, Vollmann et al. (2010) reported that early maturing soybean cultivars had greater weed tolerance ability than later maturing cultivars while Rose et al. (1984) reported that weed tolerance increased with

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increasing maturity across 20 soybean accessions. Some of the discrepancy may arise from the weed species in question. Further, soybean crops have been shown to react differently to the same weed in different studies. Examples include common ragweed (*Ambrosia trifidia* L.), common waterhemp (*Amaranthus rudis* J. Sauer), and giant foxtail (*Setaria faberi* F. Herrm) (Gibson et al., 2008); as well as under competition with pigweed (*Amaranthus* spp.) and barnyardgrass (*Echinochloa crus-galli* L. Beauv) (Cowan et al., 1998); and between 12 different weed species in competition with soybean for different durations of time (Bussan et al., 1997). This suggests that other factors can also be involved.

One such variable is indigenous soil N status. The role of fertilizer N in increasing competitiveness of weeds in spring wheat has been widely investigated (e.g., Blackshaw et al., 2004). However, this phenomena is of particular interest in grain legumes, especially in organic production where the competitive advantage of biological N fixation may indeed provide the crop with an important advantage over weeds at low soil N levels. Ugen et al. (2002) reported that nutrient uptake and growth of *Phaseolus* bean was indeed greater relative to weed nutrient uptake as N and P fertilizer rates decreased. A similar observation was made by Liebman (1989) who used a model weed, white mustard (*Brassica hirta* Moench.) in pea (*Pisum sativum* L.). Nitrophilic weeds, such as the mustard species used by Liebman, are coincidently the most prevalent weeds on organic farms in the Canadian prairie region (Entz et al., 2001). Cowan et al. (1998) and Bussan et al. (1997) reported that broadleaved weed species were more competitive than grass weed species. The present study included 10 different site-years and included a range of soil N levels. Thus, our study allowed for the examination of the soil N weed interference relationship.

Our study included both a traditional genotype × environment interaction and a partial least squares regression analysis (PLS). PLS is able to accommodate high multicollinearity and extract significant factors contributing to the observations (Sawatsky et al., 2015). PLS was recently used by soil scientists (Kumaragamage et al., 2012) and in large datasets such as vegetative health and spectral indices to predict corn (*Zea mays*) and peanut (*Arachis hypogaea*) yield (Elsayed et al., 2015; Salazar et al., 2008). Supplementing the G × E approach with PLS enabled us to better understand the main factors controlling soybean yield under the conditions of our study.

2. Materials and methods

2.1. Site descriptions

Field experiments were conducted over 10 site-years in 2014 and 2015. In 2014, experiments were located at the Organic Field Crops Laboratory on the Ian N. Morrison Research Farm in Carman MB, four organic farms located in Somerset, St. Pierre-Jolys, Swan Lake, Woodmore MB, and one organic transitional farm in Elie MB. In 2015 experiments were established at the Organic Field Crops Laboratory on the Ian N. Morrison Research Farm in Carman MB, and the same organic farms located in Somerset, St. Pierre-Jolys, and Woodmore MB. The management, location and soil texture of each site is found in Table 1.

Weather data were obtained from weather monitoring stations located at the sites. If that was not possible, data from weather stations located in close proximity were obtained from Manitoba Agriculture, Food and Rural Development (MAFRD). Climate data (long-term average) was obtained from Environment Canada weather stations close to sites. Each experimental site varied in soil nutrient status and previous crop which provided a wide diversity of growing environments (Table 2).

3. Experimental design and treatments

This experiment compared 12 non-genetically modified (GM) soybean cultivars sourced from across Canada and North Dakota that varied in heat units and relative maturity (Table 3). Heat unit requirements and relative maturity information for each cultivar was provided by the seed company. In 2014, seed stock used was sourced directly from the seed supplier listed. In 2015, seed stock used was saved from harvested material in 2014, and blended for uniformity.

Cultivars were compared in a randomized complete block design with four replicates at each study site. In Carman 2014, experimental units were 6 rows, 5 m long with 30 cm row spacing. On satellite farms in 2014, experimental units were 4 rows, 7 m long, with 30 cm row spacing. A 1 m × 1 m sub-plot was kept weed-free to evaluate weed competitiveness. In Carman 2015, each experimental unit was 6 rows wide with 30 cm row spacing and 7 m long. On satellite farms in 2015, experimental units were 8 rows, 7 m long, with 30 cm row spacing. The experimental unit size was enlarged in 2015 for an additional biomass sampling and to allow a larger weed-free sub-plot. The weed-free sub-plots in 2015 spanned the width of each experimental unit (6-rows in Carman, 8-rows at satellite farms) and were 1 m long. Border plots of OAC Prudence were established, and border rows of fall rye (*Lolium perenne* L.) (var. Hazelet) were seeded in between each block and on either side of each experiment to minimize edge effects.

4. Field experiment management

At all sites, the seedbed was prepared by using a tandem disc, with diamond harrows if needed either immediately before seeding, or shortly after seeding depending on coordination with the farmers at the satellite farms. In Carman 2014 and 2015, experiments were seeded using a disc drill (Fabro Industries, Swift Current, SK) on May 23 2014 and May 21 2015. On all other farms, seeding was done using a custom made 4-row single disc drill equipped with a cone for seed distribution (University of Manitoba, Winnipeg, MB). Seeding occurred on May 27 2014 and May 27 2015 in Somerset, May 30 2014 and May 23 2015 in St. Pierre Jolys, May 28 2014 and May 26 2015 in Woodmore, June 3 2014 in Swan Lake, and May 30 2014 in Elie. Soybeans were seeded into moisture (approximately 3–5 cm depth) at all sites at approximately 545,600 seeds hectare^{-1} (Place et al., 2009). All experimental units were inoculated using Monsanto BioAg Cell-Tech C granular (*Bradyrhizobium japonicum*) inoculant at a rate of 7.9 kg ha^{-1}. The rate of inoculant was between two to three times the recommended levels

Table 1

Management, location, and soil texture information for each experimental site.

Research site	Site-year	Land management *(first organic year)*	Latitude (*N*)	Longitude (*W*)	Soil subgroup	Soil series *(texture)*	Drainage
Carman	2014, 2015	Organic *(2004)*	49°29′52	98°02′12	Orthic Black	Hibsin *(fine sandy loam)*	Well
Somerset	2014	Organic *(2007)*	49°19′40	98°43′39	Orthic Dark Grey	Dezwood *(clay loam)*	Well
St. Pierre-Jolys	2014, 2015	Organic *(2006)*	49°25′47	96°57′44	Orthic Black	Red River *(clay loam)*	Imperfect
Swan Lake	2014	Organic *(2006)*	49°29′00	98°47′46	Orthic Dark Grey Luvisol	Pembina *(clay loam)*	Well
Woodmore	2014, 2015	Organic *(2009)*	49°07′18	96°53′54	Gleyed Rego Black	Lenswood *(Loam sand)*	Imperfect
Elie	2014	Transition *(2nd transition year)*	49°56′44	97°44′19	Orthic Black	Altamont *(clay-silt loam)*	Imperfect
Somerset	2015	Organic *(2007)*	49°21′19	98°43′27	Dark Grey Luvisol	Nayler *(loam)*	Well