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Seeding Rate Effects on Weed Control and Yield For Organic Soybean Production

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The organic grain sector is one of the fastest growing sectors of the organic market, but farmers in the mid-Atlantic cannot meet the organic grain demand, including the demand for organic soybean. Weed management is cited by farmers as the largest challenge to organic soybean production. Recent soybean population studies show that lower seeding rates for genetically modified organism soybean farmers provide maximum economic return due to high seed technology fees and inexpensive herbicides. Such economic analysis may not be appropriate for organic soybean producers due to the absence of seed technology fees, stronger weed pressures, and price premiums for organic soybean. Soybean seeding rates in North Carolina have traditionally been suggested at approximately 247,000 live seeds/ha, depending on planting conditions. Higher seeding rates may result in a more competitive soybean population and better economic returns for organic soybean producers. Experiments were conducted in 2006 and 2007 to investigate seeding rates of 185,000, 309,000, 432,000, and 556,000 live seeds/ha. All rates were planted on 76-cm row spacing in organic and conventional weed management systems. Increased soybean seeding rates reduced weed ratings at three of the five sites. Increased soybean seeding rates also resulted in higher yield at three of the four sites. Maximum economic returns for organic treatments were achieved with the highest seeding rate in all sites. Results suggest that seeding rates as high as 556,000 live seeds/ha may provide organic soybean producers with better weed control, higher yield, and increased profits.
Nomenclature: Soybean, *Glycine max* (L.) Merr.
Key words: Alternative weed management, cultural weed control, organic grain production.

The market for organic food products has consistently increased for more than 20 yr. Rapid growth in the organic meat and dairy industries (Paulson 2006) have increased demand for organic grains (USDA Economic Research Service 2008). As a result, organic grain prices have been more than twice the conventional price for the last decade (Hamilton and Rzewnicki 2007). Farmers often have much larger profit margins on organic grain acreage compared to conventionally produced acreage (Archer et al. 2007).

Although organic grain production is a profitable enterprise for many farmers, North Carolina still imports millions of dollars worth of organic grains each year (M. Hamilton, personal communication). Farmers in the mid-Atlantic United States cannot meet the organic grain demand, including the demand for organic soybean. Weed management is cited by farmers as the biggest challenge to higher yield in organic soybean (Walz 1999).

Currently, organic soybean weed management relies on mechanical weed control (Hamilton et al. 2007). Cultivation provides adequate weed control between rows. Within row weed control in organic soybean production is difficult (Vangessel et al. 1995) but critical since weeds in the crop row are most competitive for resources (Garrett and Dixon 1998). Without the use of herbicides as a management option, organic soybean producers must rely on a variety of tactics to reduce weed pressures (Liebman and Gallandt 1997), especially to assist within row weed management. Increased soybean seeding rates may be another tactic for organic soybean producers to add to the overall weed management program.

Profitability of soybean production systems depends on yield, cost of production, and soybean prices. For genetically modified soybean systems that utilize conventional herbicides, the increased cost of higher seeding rates often is not economical because of high seed costs ($1.41/kg seed) in glyphosate-resistant soybean systems, minimal improvements in weed management, and lower market value of conventional soybean. Alternatively, in organic systems, increased seeding rates for weed suppression have a greater potential for profit margin improvements due to a lower cost per kilogram of seed, stronger weed pressures in organic systems, and price premiums that are usually more than twice the conventional soybean price.

Few demonstrations exist of the effect of seeding rates on weed control and soybean yield in the absence of herbicide use. In untreated checks in a Michigan study, mean weed biomass was lowest in soybean planted with 76-cm row spacing at seeding rates of 432,000 seeds/ha compared to 308,000 and 185,000 seeds/ha, and the largest soybean yield resulted from the highest seeding rate in both locations in 2002 (Rich and Renner 2007). Harder et al. (2007) reported higher soybean yield for the weedy check plots with 76-cm row spacing with 445,000 plants/ha compared to lesser seeding densities with the same row spacing. However, weed biomass was not affected by a soybean seeding rate increase from 296,000 plants/ha to 445,000 plants/ha regardless of row spacing. Such results demonstrate that increased seeding rates may not be an effective stand-alone weed control tactic, but very few investigations have tested the effect of seeding rate on weed control in organic soybean systems utilizing other tactics such as mechanical weed control.

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Objectives of this research were to (1) compare higher seeding rates in organic and conventional soybean production systems, (2) determine if higher seeding rates effectively suppress weeds, and (3) determine how organic soybean yield and economic return are affected by seeding rate.

Materials and Methods

In 2006 'Hutcheson' soybean (maturity group V and one of the most commonly used varieties by North Carolina organic soybean producers) was planted on June 6 on a Wickham loamy sand in Goldsboro, NC (Gold 06) and on June 9 on a Cape Fear loam in Plymouth, NC (Ply 06). In 2007 Hutcheson soybean was planted on June 4 on a Wickham Loamy Sand in Goldsboro (Gold 07), June 18 on a Belhaven Muck in Plymouth (Ply 07), and on June 6 on a Kenansville loamy sand in Kinston, NC (Kin 07). All fields utilized were previously under conventional weed management. Soybean between-row spacing was 76 cm. Weed management and soybean seeding rate treatments were arranged in a split-plot design; main plots consisted of organic and conventional weed management and subplots (47 m^2) consisted of four seeding rates: 185,000, 309,000, 432,000, and 556,000 live seeds/ha. Organic weed management consisted of two post-plant passes with a rotary hoe (1–2 d after planting and 10 d after planting) and a between-row cultivation (4 wk after planting [WAP]). Conventional weed management consisted of a PRE herbicide application of metolachlor at 1.3 kg/ha, a POST herbicide application (3 WAP) of imazethapyr at 0.07 kg/ha, and a between-row cultivation (4 WAP). Data collected included: stand counts (10 WAP), visual weed ratings estimating percent canopy cover by weeds (10 WAP), redroot pigweed (*Amaranthus retroflexus* L.) or barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] counts per 15.2 m of two soybean rows (10 WAP), and soybean yield (20 to 24 WAP) data in both years at all environments.

All statistical analyses were carried out using the SAS[1] statistical analysis software package. Analysis of variance (ANOVA) was performed on nontransformed stand counts, weed ratings, weed counts, and soybean yield. Location and year were considered random. Linear and quadratic effects of seeding rate were tested by partitioning sums of squares (Draper and Smith 1981). Data are presented separately for each environment due to a significant treatment interaction with location. Treatment effects were considered significant at $P < 0.05$ for all analyses.

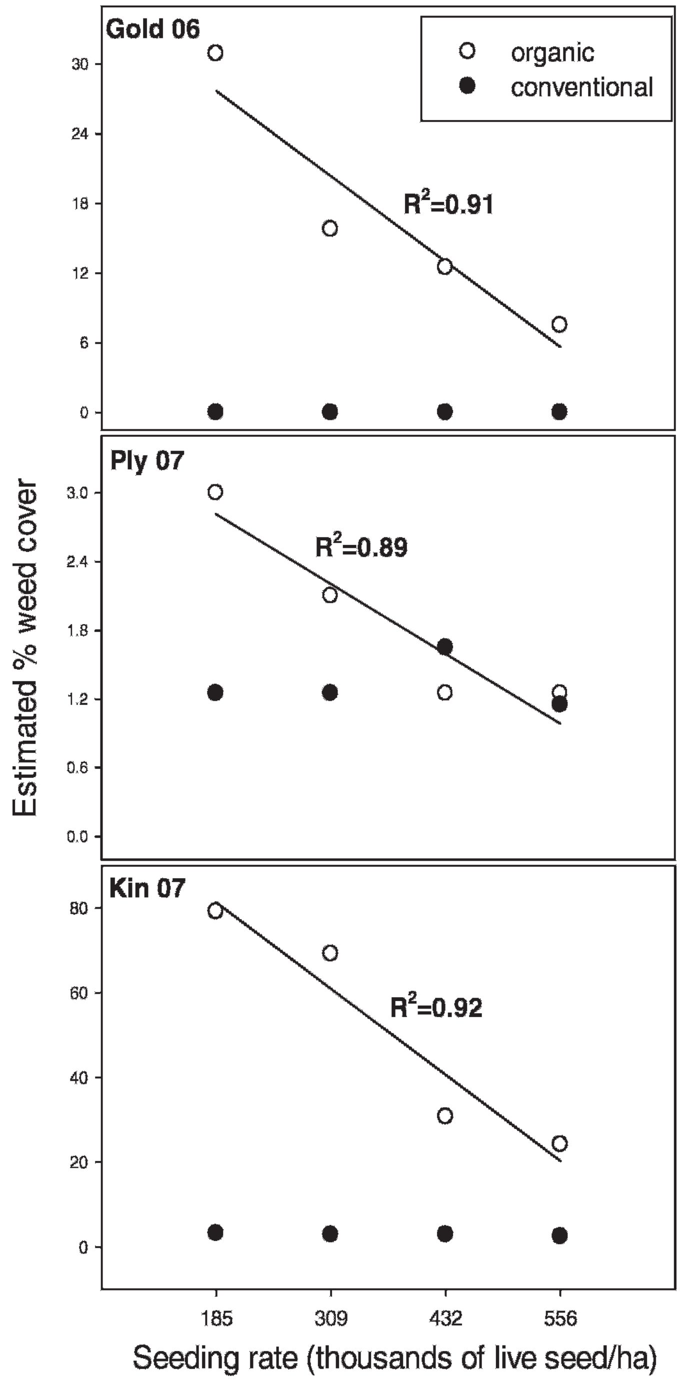

Figure 1. Effect of soybean seeding rate on percent weed cover in conventional and organic weed management treatments at Goldsboro 06, Plymouth 07, and Kinston 07.

Results

Weed Ratings. Increased soybean seeding rates reduced weed ratings at Gold 06, Ply 07, and Kin 07 (Figure 1). Seeding rates did not affect weed ratings at Ply 06 or Gold 07 (Table 1). Management effects, organic versus conventional weed management, were detected in weed rating data at all environments (Table 1). Seeding rate and management interactions were detected on weed ratings at Gold 06, Ply 07, and Kin 07 (Table 1). The interaction was due to the fact that only organic plots had less weed cover due to higher seeding rates.

Weed Counts. In general, dense weed populations occurred at Gold 06 and Kin 07, while low weed density was found at Ply 06, Ply 07, and Gold 07. Pigweed was by far the dominant weed in the Gold 06, Gold 07, and Kin 07 locations. Weed populations in Ply 06 and Ply 07 were completely dominated by barnyardgrass. Because of single weed dominance at all locations, all weed count data refers to the respective location-dominant weed species only. Increased

Table 1. Values for ANOVA and partitioned sum of squares contrasts for main effects and interactions at all environments investigated.

Environment	Effect	% Weed cover	Weed counts	Soybean yield
		P > *F*		
Gold 06	Seeding rate	< 0. 001	0.002	< 0.001
	Weed management system	< 0. 001	< 0.001	< 0.001
	Seeding rate × management	< 0. 001	NS[a]	NS
Ply 06	Seeding rate	NS	NS	NS
	Weed management system	< 0.001	< 0.001	NS
	Seeding rate × management	NS	NS	NS
Gold 07	Seeding rate	NS	NS	No data
	Weed management system	0.004	0.003	No data
	Seeding rate × management	NS	NS	No data
Ply 07	Seeding rate	0.01	NS	< 0.001
	Weed management system	0.04	NS	NS
	Seeding rate × management	0.01	NS	NS
Kin 07	Seeding rate	< 0.001	NS	0.02 (quadratic)
	Weed management system	< 0.001	< 0.001	NS
	Seeding rate × management	0.004	NS	NS

[a] Abbreviation: NS, nonsignificant at the 0.05 level.

soybean seeding rates decreased redroot pigweed counts at Gold 06 (Figure 2), but seeding rate effects were not detectable in weed count data at Ply 06, Gold 07, Ply 07, and Kin 07 (Table 1). Management effects were detected in weed count data at Gold 06, Ply 06, Gold 07, and Kin 07 (Table 1). No management effect on barnyardgrass counts was detected in Ply 07 (Table 1). A seeding rate × management interaction was not detected in weed counts in any of the environments (Table 1). Gold 06 and Ply 06 conventional weed management treatments were weed-free, while conventional treatments had some pigweed presence in Gold 07 due to a reduced soybean canopy from severe drought. Ply 07 and Kin 07 conventional treatments had minimal weed presence.

Yield. Increased soybean seeding rates resulted in higher yield at Gold 06, Ply 07, and Kin 07 (Figure 3), but no effect was seen at Ply 06 (Table 1). No lodging effects were seen at any of the locations due to higher seeding rates (data not shown).

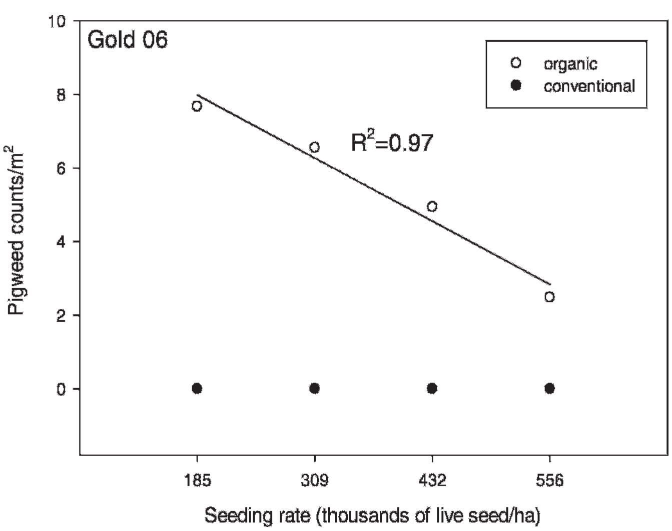

Figure 2. Effect of soybean seeding rate on redroot pigweed counts in conventional and organic weed management treatments at Goldsboro 06.

No yield data were taken for Gold 07 due to severe drought losses. There was a management effect on soybean yield at Gold 06, where organic soybean yielded 21% less than conventional soybean averaged across all seeding rates (Figure 3). No effect of management on soybean yield was detected at Ply 06, Ply 07, or Kin 07 (Table 1). Seeding rate × management interactions on soybean yield were not detected at any site (Table 1). Maximum economic returns for organic treatments were achieved with the highest seeding rate in Gold 06, Ply 06, Kin 07, and Ply 07 (Table 2), even with conservative estimates for seed costs ($16 for 120,000 live seed) and price premiums. The analysis used 2007 average selling price of organic feed grade soybean at $ 0.551/kg and conventional feed grade soybean at $ 0.257/kg, although current organic soybean prices are over $0.92/kg (USDA Economic Research Service 2008).

Discussion

Increasing seeding rates improved weed control in organic systems but not in conventional systems in three of the environments tested. However, increasing seeding rates significantly improved yield with no interaction of the seeding rate on weed management systems in the same three environments. The yield increase under conventional management was unexpected based on 6 yr of North Carolina research at over 50 locations showing that maximum soybean yield can be achieved with 120,000 seed/ha (J. Dunphy, personal communication) In other states, conventional yield increases with increased seeding rates have been observed (Norsworthy and Oliver 2001). With the absence of a significant interaction between seeding rate and weed management system on soybean yield, the suggestion is that improved weed management (seen in the organic system but not in the conventional system) does not entirely account for the increased yield response seen in both organic and conventional systems. This suggests that yield increases in the organic plots came not only from improved weed control but also from increased plant population. However, higher

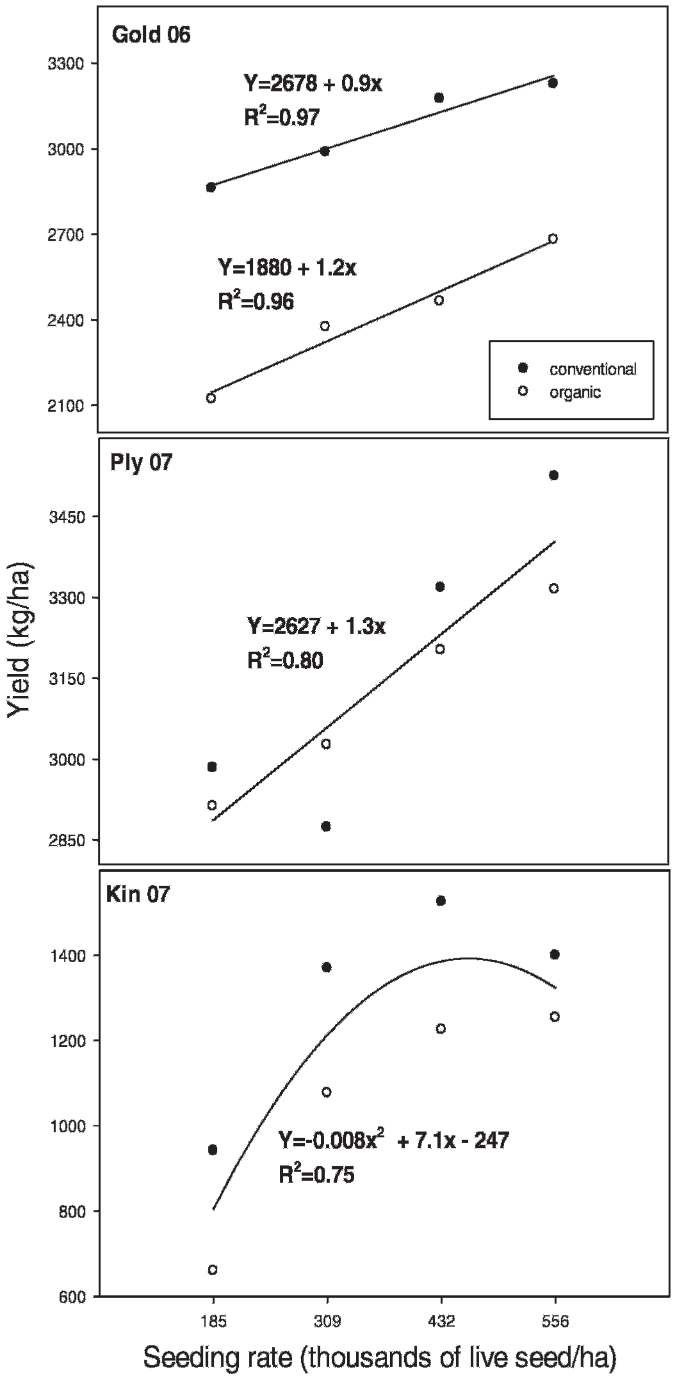

Figure 3. Effect of soybean seeding rate on soybean yield in conventional and organic weed management treatments at Goldsboro 06, Plymouth 07, and Kinston 07.

seeding rates in the organically managed plots consistently resulted in improved weed control.

The effect of soybean population increases on weed control and yield has been extensively investigated in conventional and Roundup Ready soybean production systems. Weed control improvements have been demonstrated with narrow soybean rows in several investigations (Burnside and Moomaw 1977; Légère and Schreiber 1989; Nice et al. 2001). However, improved weed control with higher seeding rates is not always economically favorable. In one study, high seeding rates (533,000 plants/ha) in 19-cm rows were shown to suppress both grass and broadleaf weeds more effectively than populations of 238,000 plants/ha and 178,000 plants/ha in 57- and 95-cm rows, respectively, even with the use of PRE and POST emergence herbicides. Because the selling price for conventionally grown soybean was $.20/kg on average, the mid population in 57-cm rows had the highest mean economic return (Reddy 2002). In another recent study comparing differing seeding densities and row spacing on weed control in glyphosate-resistant systems, it was found that in weed-free conditions soybean yield was stable from 185,000 plants/ha to 445,000 plants/ha with 38- and 76-cm row spacing. However, when weeds were present, soybean yield with 38-cm row spacing was highest in populations of 445,000 plants/ha and on 76-cm row spacing yield was highest when populations were at least 296,000 plants/ha (Harder et al. 2007). Increased seeding rate to improve crop competitiveness has been demonstrated in other crops as well. Wiese et al. (1964) clearly demonstrated that increased seeding rates improved weed control in grain sorghum yield regardless of between-row spacing.

For conventional systems using Roundup Ready technology, research regarding seeding rates addresses the question, "How low can you go?" to minimize seed technology fees but maintain yield. With increasing soybean grain prices in both conventional and organic markets, this paradigm may be in need of review. Increased seeding rates in our conventional treatments showed maximum yield at the 432,000 seeds/ha (Kin 07) and 556,000 seeds/ha (Gold 06 and Ply 07) seeding rates. Other studies have shown maximum conventional yield at similar seeding rates (Ablett et al. 1991) while Norsworthy and Oliver (2001) found maximum yield at 988,000 seeds/ha. For organic systems the question in this investigation was, "How high can you stand?" to achieve plant populations for maximum weed control and tolerable soybean lodging. Drier growing conditions in both years resulted in submaximal soybean growth at all locations. End of season observations in both years and all locations were that none of the soybean seeding rate treatments resulted in the full soybean canopy needed for maximum photosynthetically active radiation (PAR) interception. Consequently, soybean lodging was not seen in the highest populations.

Because yield increased with seeding rates in both organic and conventional treatments, increased light interception must also be considered in conjunction with improved weed control to understand causes of yield increases with increasing soybean density. Light interception was not measured in this study, but previous studies have shown that increasing within row density will lead to faster canopy closure, increased leaf area index (LAI), and increased light interception (Bertram and Pederson 2004). Harder et al. (2007) found that with 76-cm row spacing, soybean densities of 445,000 plants/ha closed canopy 11 WAP while densities of 300,000 plants/ha and less closed canopy 12 WAP. Similarly, Rich and Renner (2007) found that with 76-cm row spacing, soybean seeding rates of 432,000 seeds/ha had a greater LAI than the 308,000 seeds/ha treatment by 78 days after planting. Treatments with the higher seeding rate may have had a greater soybean canopy

Table 2. Relative net return compared to lowest seeding rate based on seed costs estimated at $16 per bag of 120,000 live seed. The 2007 average selling price of organic feed grade soybean at $ 0.551/kg and conventional feed grade soybean at $ 0.257/kg were also utilized in calculated net return.

	Goldsboro, NC 2006				Plymouth, NC 2006				Plymouth, NC 2007				Kinston, NC 2007			
	Organic		Conventional		Organic		Conventional		Organic		Conventional		Organic		Conventional	
Seeding rate	Yield kg/ha	Return $/ha	Yield kg/ha	Return $/ha	Yield kg/ha	Return $/ha	Yield kg/ha	Return $/ha	Yield kg/ha	Return $/ha	Yield kg/ha	Return $/ha	Yield kg/ha	Return $/ha	Yield kg/ha	Return $/ha
185,000	2,122	$0	2,862	$0	1,055	$0	1,077	$0	2,913	$0	2,984	$0	660	$0	942	$0
309,000	2,376	$123	2,989	$16	782	−$167	1,018	−$32	3,027	$46	2,874	−$45	1,077	$213	1,370	$93
432,000	2,466	$156	3,175	$48	842	−$150	1,135	−$18	3,202	$127	3,318	$53	1,226	$279	1,526	$117
556,000	2,682	$259	3,228	$45	1,165	$11	820	−$116	3,315	$172	3,525	$90	1,254	$279	1,400	$68

LAI and more PAR interception than the lower seeding rate treatments. If dry conditions and submaximal growth precluded any of the seeding rate treatments from achieving critical LAI and maximum PAR interception, this would explain the unexpected yield increases with higher seeding rates in the conventional soybean treatments.

Higher seeding rates improved weed control in organically managed soybean, while it did not have an effect on weed control in conventionally managed soybean. However, higher seeding rates increased yield in both conventional and organic systems. With current prices for organic soybean at over $0.92/kg, organic soybean producers may improve profits by increasing seeding rates beyond currently recommended rates.

Sources of Materials

[1] SAS software for Windows, Version 9.1.3. SAS Institute Inc., 100 SAS Campus Dr., Cary, NC 27513.

Acknowledgment

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