ABSTRACT

PLACE, GEORGE THOMAS. Applying Crop and Weed Competitive Dynamics For Weed Management in Soybean and Peanut. (Under the direction of Dr. Chris Reberg-Horton and Dr. Tommy Carter).

Demand for organic food products has consistently increased for more than 20 years. Demand for organic grain has been particularly high, leading to price premiums of over double the conventional price. The largest obstacle to organic soybean production is weed management. The first investigation aimed at improving weed management in organic soybean tested the effectiveness of pre-plant rotary hoeing to reduce the need for multiple post-plant rotary hoeing. Pre-plant rotary hoe treatments included a weekly rotary hoeing four weeks before planting, two weeks before planting and none. Post-plant rotary hoe treatments consisted of zero, one, two, three, and four post-plant rotary hoe uses. Weed control was increased with pre-plant rotary hoeing at Plymouth in 2006 and 2007 but this effect disappeared with the first post-plant rotary hoeing. Multiple post-plant rotary hoe uses decreased soybean plant populations, decreased soybean canopy height, lowered soybean pod position and decreased soybean yield.

In another experiment, the effect of soybean population on weed control was investigated. This research was 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 3 of the 5 sites. Increased soybean seeding rates also resulted in higher yield at 3 of the 4 sites. Maximum economic returns for organic treatments were achieved with the highest seeding rate in all sites.

In a separate experiment, the effect of soybean genotype on weed suppression was investigated. Twenty seven genotypes were chosen based on varying seed sizes, leaf shape, and height. Genotypes were compared in weedy and weed free conditions. Canopy traits and percent ground cover estimates were measured in weed free plots. Soybean and weed biomass has harvested at 7 weeks after emergence. Differences in weed biomass were detected between genotypes in both years. Optimum models from multiple regression showed seed size to be the most significant trait measured in overall genotype competitive ability in both years.

In an additional experiment, the influence of soybean seed size within a genotype was investigated. Three popular soybean varieties: Hutcheson, NC-Roy, and NC-Raleigh were separated into four or five seed size classes. Seed sizes ranged from 10 to 20 g/100 seed. Each seed size class was grown in weedy and weed free conditions at Kinston, NC in 2007 and 2008 and at Plymouth, NC in 2008. The effect of soybean seed size on increased soybean biomass was detected in all environments when grown in competition with weeds. In the two environments with higher weed population densities, planting larger soybean seed reduced weed biomass at 7 weeks after emergence (R^2=0.42 and R^2=0.54 in Kinston 2007 and Kinston 2008 respectively).

A study in peanut production systems was conducted to define interactions of three levels of weed management (clethodim applied postemergence, cultivation and hand removal of weeds, clethodim and appropriate broadleaf herbicides applied postemergence), three levels of planting pattern (single rows spaced 91 cm apart, standard twin rows spaced 20 cm apart on 91-cm centers, narrow twin rows consisting of twin rows spaced 20 cm apart on 46-cm centers), and two levels of cultivar (NC 12C and VA 98R) on weed control, peanut yield, and estimated economic return. Cultivar and planting pattern had only minor effects on weed control and interactions of these treatment factors seldom occurred. Weed control with cultivation and hand removal was similar to weed management with grass and broadleaf herbicides. Pod yield did not differ among treatments when these broadleaf weeds were dominant, but did differ when Texas panicum was dominant.

Applying Crop and Weed Competitive Dynamics For Weed Management in Soybean and Peanut

by
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DEDICATION

I dedicate this work to my extremely supportive family. My wife, Soraya Place, has been an incredible source of physical and emotional assistance to me throughout my years as a graduate student. Soraya has worked side by side with me in the lab and field, enduring long hours, uncomfortable environments, and difficult challenges. My parents, Liz and Jerry Place, have made tremendous sacrifices over the years to extend every opportunity to me. My sister, Amy Place, has been a great friend and spiritual advisor along with my wise nieces Casteel and Brantley. Finally, I am grateful to my niece/adopted daughter Gabriela Valdez whose presence in our home has focused me to succeed in graduate school.

BIOGRAPHY

George Thomas Place II was born in Kansas City, Missouri. Upon graduation from high school at age 18, he entered the American Kenpo Karate Academy. He lived in Kansas City until the age of 21 at which time he moved to Santa Fe, New Mexico to continue training and working with his instructor in the Karate Academy. Upon completion of his 2° black belt requirements at age 25, he moved to Albuquerque, New Mexico to train with and work for Grandmaster Bill Packer. During his time in Albuquerque, he finished his Bachelor of Science at the University of New Mexico in May of 2001. After graduation he entered the Peace Corps and served as an agroforestry volunteer in El Salvador from October 2001 to January of 2004. He married Soraya Eleonora Valdez Romero in January 2004 and returned with her to Kansas City to continue karate training and instructing. In December of 2004 he completed 3° black belt requirements and shortly thereafter moved with Soraya to Raleigh, North Carolina to begin graduate studies in the Department of Crop Science at North Carolina State University. George completed a Masters of Science in Crop Science in December of 2006. In January of 2007 he began studies and research toward a doctorate in Crop Science under the guidance of Dr. Chris Reberg-Horton. His motivation to pursue graduate studies was to acquire the knowledge, skills and credentials necessary to continue working in international agriculture and development.

ACKNOWLEDGMENTS

I would like to thank my angelic wife Soraya V. Place. She has been tremendously supportive in every way and a valuable assistant in the many field measurements and harvests for this project. I could not have done this without Soraya's help and encouragement. I also extend thanks to my parents, Liz and Jerry Place who continue to unconditionally encourage my ventures. This August was the fourth anniversary of the passing of my mentor Mr. Bill Packer, Grandmaster of the American Kenpo Karate Academy. I have pursued excellence in this project with determination to honor him and everything that his teachings stand for.

I am very appreciative of the help and guidance from my committee members: Dr. Chris Reberg-Horton, Dr. Tommy Carter, Dr. David Jordan, and Dr. Nancy Creamer. Working with Chris has been a tremendously empowering experience. Chris has interacted with me as a colleague and allowed me to develop from a graduate student into a fellow scientist/project manager. I consider myself extremely lucky to have had such a wise, patient, and mindful major advisor.

I would also like to thank all of the university community members that have contributed to this research including: Carrie Brinton, Adam Smith, Dr. Tom Isleib, Dr. Jim Dunphy, Dr. Carl Crozier, Scott Brinton, Dr. Alan York, John Graber, Dewayne Johnson, Bridget Lassiter, Steve Hoyle, and the numerous research station crew members and university staff.

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Introduction

Demand for organic food products has consistently increased for more than 20 years. Demand for organic grain has been particularly high leading to price premiums of over double the conventional price (Dimitri 2008; Hamilton and Rzewnicki 2007). High price premiums for organic grains have been driven by rapid growth of the organic animal product industry. Organic meat and dairy products grew by 55 and 24%, respectively, in 2005 (Paulson 2006). Farmers often have much larger profit margins on organic grains acreage compared to conventionally produced acreage (Archer et al. 2007). Currently, farmers in the southeastern U.S.A. cannot meet the organic grain demand (M. Hamilton, personal communication), including the demand for organic soybeans. Weed management is cited by farmers as the largest obstacle to producing organic soybeans (Cavigelli et al. 2008).

Currently, organic soybean production in the southeastern U.S.A. relies on between-row and broadcast post-plant mechanical practices for weed control (Hamilton et al. 2007). Cultivation provides adequate weed control between row spaces, however within-row weed control in organic soybean production remains difficult (Vangessel et al. 1995) but critical since weeds in the crop row are most competitive for resources (Garrett 1998). The rotary hoe is one implement that allows for within-row weed control through early broadcast cultivation, also called "blind cultivation," because the rotary hoe disturbs the entire soil surface without regard to soybean row position (Bowman 1997). Broadcast cultivation is crop selective because the soil disturbance only takes place in the top 1-3 cm of the soil. The soybean is planted deeper and has a deeper root than the weed seedlings killed by the rotary hoe. Effective weed control is mostly achieved for weed seedlings that have germinated but not yet emerged, referred to as the white thread stage (Bowman 1997). Larger weeds are not well controlled by the rotary hoe (Lovely et al. 1958). Approximately 10% of soybean stand loss due to rotary hoeing is typical (Bowman 1997; Lovely et al. 1958; Schweizer et al. 1992). Seeding rate increases are often recommended in anticipation of these losses (Bowman 1997). Although soybean stands are often reduced in rotary hoeing, most studies report no loss in yield (Buhler and Gunsolus 1996; Leblanc and Cloutier 2001; Vangessel et. al. 1995). However, yield loss from rotary hoe damage has been demonstrated in other crops (Leblanc et al. 2006; Lotijonen and Mikkola 2000).

Rotary hoe use has been well regarded for post-plant weed control in soybeans. Lovely et al. (1958) reported 70% weed control in soybeans with 2 post-plant rotary hoe uses. Similarly, weed density reductions of 75% were reported by Buhler et al. (1992). Hooker et al. (1997) found one rotary hoe pass in soybean reduced the weed population more than 68%. In conventional soybean production, rotary hoeing can reduce herbicide use (Buhler and Gunsolus 1996; Forcella 2000). For organic soybean producers, 3 to 5 post-plant rotary hoe uses in conjunction with between-row cultivation is the primary weed management system (Hamilton et al. 2007). Because the rotary hoe is not effective at controlling large weeds, timely hoeing is critical (Gunsolus 1990; Lovely et al. 1958; Peters et al. 1959) but sometimes precluded by wet soils or farm labor demands. Pre-plant rotary hoeing was hypothesized to be one tactic to reduce dependency on post-plant rotary hoe use and improve the flexibility of timing for weed management activities.

Pre-plant rotary hoeing is one method for reducing viable weed seed in the top few centimeters of soil. Often referred to as "stale seedbedding," this approach has shown its weed control effectiveness in spinach (Boyd et al. 2006), lettuce (Balsari et al. 1994), cucumber (Johnson and Mullinix 1998), peanut (Johnson and Mullinix 1995) and rice (Sharma et al. 2008). The key principles in establishing a stale seedbed are the induction of weed germination through soil disturbance and destruction of the weed seedlings prior to crop planting without bringing other weed seeds to the surface. Flaming (Balsari et al. 1994), contact herbicides (Caldwell and Mohler 2001) and light cultivation tools such as the rotary hoe (Boyd et al. 2006) have been used in stale seedbedding.

The objectives of this study were to examine whether pre-plant rotary hoe use was effective enough to reduce dependency on post-plant rotary hoe use in organic soybeans and if so, which combinations of pre- and post-plant rotary hoeing were most effective at controlling weeds. The cost of stale seedbedding utilizing the rotary hoe should be identical to the cost incurred by the same number of passes with the rotary hoe after planting. If pre-plant passes of the hoe could reduce the number of post-plant passes, it would help spread the labor demands of cultivation over a longer time frame and reduce the risk of a severe weed infestation developing in wet springs where post-plant passes are prevented.

Materials and Methods

Experimental design was a split-block design (Steel et al. 1997) with pre-plant and post-plant rotary hoe treatments as crossing strips in each block. Pre-plant treatments included: a weekly rotary hoeing beginning 4 weeks before planting (4 total pre-plant rotary hoe uses), a weekly rotary hoeing beginning 2 weeks before planting (2 total pre-plant rotary hoe uses) and none. Post-plant treatments consisted of no post-plant rotary hoeing; 1 post-plant rotary hoeing 3 days after planting (DAP); 2 post-plant rotary hoe uses at 3 DAP and 8 DAP; 3 post-plant rotary hoe uses at 3, 8 and 13 DAP; and 4 post-plant rotary hoe uses at 3, 8, 13 and 18 DAP. Rotary hoeing time was delayed by 1-2 days by precipitation greater than 0.5 cm. Between-row cultivation was done on all plots 4 and 6 weeks after planting. Six replications of all treatments were established at the Goldsboro and Plymouth research stations in 2006 and 2007. Goldsboro soils types were a Wickham loamy sand and a Johns sandy loam in 2006 and 2007 respectively. Plymouth soil types were a Portsmith fine sandy loam and a Belhaven muck in 2006 and 2007 respectively. Rains prevented the 3rd and 4th post-plant rotary hoe treatments in Goldsboro 2006. The soybean cultivar Hutcheson (maturity group V) was planted 4 cm deep in 0.76-m-wide rows at 382,850 seeds ha^{-1} on June 6 and 9, 2006 and June 5 and 14, 2007 at Goldsboro and Plymouth respectively. The rotary hoe was adjusted to only disturb the top 2-3 cm of the soil. The rotary hoe consisted of

44 gangs with 16 spoked wheels per gang. Spokes were 20 cm long with 4 cm long by 2 cm wide spoon shaped tips. The spoke wheels were 7 cm apart. Total width of the unit was 3.05 m. Disking followed by seedbed preparation was done 2 days before beginning the pre-plant rotary hoe treatment. In the case of no pre-plant treatment, disking and seedbed preparation took place immediately prior to planting soybeans. Once pre-plant rotary hoe treatments were initiated no further disking or soil conditioning took place to avoid bringing up weed seeds from greater depths. Rotary hoeing was done with a target speed of 16 km $hour^{-1}$.

In 2006 and 2007 percent of ground cover by weeds was visually estimated for all plots 12 weeks after soybean planting. Soybeans were harvested in late November and sub-sampled for moisture to convert all yield data to weight at 13% moisture. Weed counts were taken for the dominant weeds at each site. Weeds were counted in the area of the center two rows (1.52 m wide) for the entire plot length of 15.25 m in all plots 12 weeks after soybean planting.

Because height effects were noted in 2006, in 2007 soybean height and soybean plant mapping data were collected. Soybean heights were measured on 5 randomly selected plants $plot^{-1}$ 12 weeks after soybean planting. For soybean plant mapping, randomly selected samples of soybean plants were cut at soil level. Each sample consisted of all plants in 1 meter of row length in one of the center rows of the plot. Samples were cut 1 day prior to soybean harvest from each post-plant treatment in each of the six reps at Plymouth 2007. Plant mapping consisted of counting the number of pods and nodes on each plant at heights of: < 30 cm, 30-50 cm, and > 50 cm. Height was also recorded for each plant (length from soil level to terminal bud) as well as total plot sample seed yield and total number of plants per plot sample. Soybean pods remaining on stubble below 12 cm in height following harvest were also counted for the entire 12.2 m length of the 2 center rows in the same plots used for plant mapping. In 2007, the Goldsboro site resulted in total yield losses for many plots due to drought. Yield data and plant mapping data are not presented for this location.

All statistical analyses were carried out using the SAS[1] statistical analysis software package. Analysis of variance (ANOVA) was performed on non transformed weed ratings (percent cover by weeds), weed counts, soybean stand counts, plant heights and soybean yield. Location was considered fixed and year random. Appropriate error terms for split-block design were used to test main plot factors and interactions. Linear, quadratic and cubic effects of pre-plant and post-plant treatments were tested by partitioning sums of squares (Draper and Smith 1981). Data is presented separately for each location and year due to a significant treatment interaction with location and year. Treatment effects were considered significant at $P < 0.05$ for all analyses.

Results and Discussion

Pre-Plant Rotary Hoeing. Although pre-plant rotary hoe use did not significantly influence soybean yield at any of the locations (Table 1), it showed a modest effect on weed ratings at Plymouth in 2006, reducing percent weed cover by 51% in zero post-plant plots (Figure 1). Again at Plymouth in 2007, four weeks of stale seedbedding reduced percent weed cover by

57% (Figure 2). These levels of control are lower than is typically observed in stale seedbeds created by flaming (Boyd et al. 2006) or with contact herbicides (Caldwell and Mohler 2001). Other studies utilizing the rotary hoe or other shallow cultivators have found a highly variable level of control. Use of a power tiller to create stale seedbeds resulted in rates of control ranging from 93% fewer weeds to 150% more weeds than same day planting preparations (Johnson and Mullinix 1995, 1998). Boyd et al. 2006 documented destruction of 97% of the weeds that emerged during stale seedbedding by a rotary hoe. Nonetheless, stale seedbed treatments had as many weeds by day 21 as the control, suggesting new weed seed had been brought into the germination zone by the rotary hoe.

Only one environment, Plymouth 2006, showed an interaction between pre- and post-plant rotary hoe use (Figure 2). The interaction consisted of a significant stale seedbed effect in zero post-plant plots, but no stale seedbed effect was detected in plots where any post-plant treatment was conducted. The apparent lack of an additive or synergistic benefit to combinations of pre- and post-plant rotary hoe use suggests that this approach to stale seedbedding cannot be recommended to farmers. Other approaches which seem to be more effective, such as flaming and contact herbicides, are far more expensive for organic growers. A broadcast application of an organically approved herbicide costs approximately \$1350 ha^{-1} and broadcast flaming costs approximately \$43 ha^{-1} (Boyd et al. 2006). In contrast, a single rotary hoe pass costs \$5.44 ha^{-1} (Lazarus and Selley 2005) (Table 2).

Post-Plant Rotary Hoeing. Post-plant rotary hoe treatments increased soybean yields in locations with more weeds (Goldsboro in 2006 and Plymouth in 2006) (Figure 3). Only one rotary hoe pass was needed to attain maximum yield. Further rotary hoeing resulted in increased weed control (Table 3) but ultimately caused yield losses. Stand counts were reduced by 28% from 0 to 4 post-plant rotary hoe passes at Plymouth in 2007 (data not presented). Similar stand reductions have been demonstrated with multiple post-plant rotary hoe treatments (Leblanc and Cloutier, 2001). Because of low weed pressures at Plymouth in 2007, increased frequency of post-plant rotary hoe treatments had no effect on weed control but resulted in yield loss. Reduction in soybean population did not entirely explain this yield reduction because even with 28% stand reduction, the plant population was 273,000 plants ha^{-1}. Plant populations can be reduced to 247,000 plants ha^{-1} without yield reductions (Board 2000). In North Carolina, soybean seeding rate studies with the cultivar 'Hutcheson' resulted in no yield penalty with populations as low as 185,000 plants ha^{-1} (J. Dunphy, personal communication). Leblanc and Cloutier (2001) reported 2, 3 and 4 post-plant rotary hoeings caused soybean stand reduction of 16%, 21%, and 29% respectively, but soybean yields were not affected or were slightly improved with multiple passes, even when conducted in weed free conditions. Similarly, Buhler et al. (1992) found both yield and weed control improved in soybeans with two versus one rotary hoeing and observed no injury to soybean plants other than reduced stands. Cereals exhibit a different pattern with weed control improving with multiple passes of a flex tine harrow, but yield losses increasing as well due to leaf burial (Rasmussen et al. 2008; Melander et al. 2005). Other studies have found that multiple rotary hoe passes may not be warranted. A single rotary hoe pass was as effective as two passes plus alachlor in corn (Vangessel et al. 1995), where timing appeared to be more critical than the number of cultivations. Some weed species were well controlled with one pass in a legume-cereal cover crop (Boyd and Brennan 2006), though other species required two passes.

Effect of Post-Plant Rotary Hoe Treatments On Pod and Node Positioning. Post-plant rotary hoe treatments reduced the height of soybean plants at Goldsboro in 2007 and at Plymouth in 2007 (Figure 4). Height data was not taken in 2006. Plant stunting due to mechanical injury from post-plant rotary hoe treatments may have occurred. Wells et al. (1993) reported a linear relationship of photosynthetically active radiation (PAR) interception and soybean height (r^2=0.97), regardless of row width, in both years studied. Reduced percent interception of PAR resulted in significant seed yield reductions (Wells et al. 1993). The zero post-plant rotary hoe treatments at Plymouth in 2007 had a canopy height of 80 cm at the initiation of pod fill, with height significantly decreasing with additional post-plant rotary hoe use.

In addition to soybean height reduction and stand reductions, the percentage of total plant pods below 30 cm was increased by more post-plant rotary hoe treatments while the percentage of total plant pods above 50 cm was reduced (Figure 5). Edwards and Purcell (2005) reported that decreased plant populations resulted in a significant lowering of the first pod position. Increased combine losses due to lower pod position, referred to as stubble losses, have been previously demonstrated (Herbek and Bitzer 1997). Stubble losses were also suspected as an explanation of the observed yield losses with multiple post-plant rotary hoeing at Goldsboro in 2006 and at Plymouth in 2006. The results from hand harvested plant mapping data at Plymouth in 2007 showed that total pod number and total seed yield was not significantly affected by post-plant rotary hoe treatments, but combine harvested data at

Plymouth in 2007 showed a linear decrease in yield with increased post-plant rotary hoe treatments. Yields from the plant map data showed no significant differences amongst post-plant rotary hoe treatments, supporting the hypothesis that stubble losses were contributing to yield losses seen in combine harvested data. However, these results should be interpreted with caution. Only 1 m of row length was harvested for the plant map data, versus 12.2 m by two rows for yields measured with the combine. The coefficients of variation (CV) reflected the different harvest lengths with a CV of 22% for the plant map yield data and 10% for the combine data. The two tests for yield differences therefore had substantially different powers of detection. When actual stubble losses were measured by counting pods along the entire 12.2 m by two-row harvest area, no post-plant treatment effect was observed (data not shown). These data suggest that although post-plant rotary hoe treatments lowered the soybean pod position, this did not result in significant stubble losses. The reduction in PAR interception due to a decreased soybean canopy height is the explanation for reduced yields most supported by these data. Further research on why rotary hoe use reduces soybean height is needed.

In conclusion, results from this study suggest little benefit in pre-plant rotary hoeing. Pre-plant rotary hoeing did not result in soybean yield gains in any of the locations. Weed control was increased with pre-plant rotary hoeing at Plymouth in 2006 and 2007 but this effect disappeared with the first post-plant rotary hoeing. No evidence was found to support our hypothesis that pre-plant rotary hoeing could reduce the need for post-plant rotary hoeing. Multiple post-plant rotary hoe uses decreased soybean plant populations, decreased soybean canopy height, lowered soybean pod position and decreased soybean yield. Organic soybean producers in the southeastern U.S.A. currently post-plant rotary hoe soybeans between three and five times. While this practice is reducing weed densities, these data suggest they are also damaging soybean yields. Organic farmers, however, are not just managing for the current year's yield. Reducing the number of rotary hoe passes would lead to higher weed seed rain in the fall and might reduce yield in future years. Because post-plant rotary hoeing can be so damaging to soybeans, more research is needed to develop alternatives to the rotary hoe that could achieve similar levels of weed control without reducing yield. The rotary hoe may not be the best implement for stale seedbed creation because of soil disturbance. Flaming or organic herbicides may be effective options but are currently cost prohibitive for organic soybean producers. Further investigation of tactics for stale seedbedding is needed to decrease the dependency on post-plant weed management for organic soybean producers.

Table 1: Values for ANOVA and partitioned sum of squares contrasts on pre- and post-plant rotary hoe main effects and interaction.

Environment		% weed cover	weed counts	soybean yields
			----- Prob. > F -----	
Goldsboro 2006	Pre-plant main effect	NS	NS	NS
	Post-plant main effect	.002 (quadratic)	.002 (quadratic)	.004 (quadratic)
	Pre * Post interaction	NS	NS	NS
Plymouth 2006	Pre-plant main effect	NS	NS	NS
	Post-plant main effect	<.001	<.001	.001 (qudratic)
	Pre * Post interaction	<.001	<.001	NS
Goldsboro 2007	Pre-plant main effect	NS	NS	not measured
	Post-plant main effect	<.001 (cubic)	.03 (quadratic)	not measured
	Pre * Post interaction	NS	NS	not measured
Plymouth 2007	Pre-plant main effect	<.001 (linear)	.005 (linear)	NS
	Post-plant main effect	NS	NS	.009 (linear)
	Pre * Post interaction	NS	NS	NS

Table 2: Relative net return compared to control based on rotary hoe costs estimated at $5.44 ha^{-1} and the value of organic soybeans at $ 0.513 kg^{-1}.

Rotary Hoeing		Goldsboro 2006		Plymouth 2006		Plymouth 2007	
		Yield	Return	Yield	Return	Yield	Return
Pre	Post	kg ha^{-1}	ha^{-1}	kg ha^{-1}	ha^{-1}	kg ha^{-1}	ha^{-1}
---- 0 ----	0	2425	$0	1602	$0	2977	$0
	1	3346	$473	2307	$362	3133	$80
	2	2516	$47	2106	$258	2798	-$92
	3			1822	$113	2704	-$140
	4			1831	$117	2644	-$171
---- 2 ----	0	2018	-$209	1987	$197	3264	$147
	1	2491	$34	2390	$404	3286	$159
	2	2026	-$205	2179	$296	3209	$119
	3			1950	$178	3244	$137
	4			2051	$230	3180	$104
---- 4 ----	0	2267	-$81	1877	$141	3025	$24
	1	2798	$192	2298	$357	2761	-$111
	2	2001	-$217	2069	$240	2736	-$124
	3			2060	$235	2580	-$204
	4			1914	$160	2677	-$154

Table 3: Effect of pre- and post-plant rotary hoeing on the average weed count per m^2 (*Amaranthus retroflexus* in Gold 06 and 07; *Chenopodium album* in Ply 06 and *Brachiaria platyphylla* in Ply 07).

Rotary Hoeing		Goldsboro		Plymouth	
Pre	Post	2006	2007	2006	2007
0	-	2.7	0.1	1.2	0.4
2	-	6.1	0.1	0.8	0.2
4	-	3.2	0.2	0.8	0.1
LSD		2.9	**NS**	**NS**	0.1
-	0	5.8	0.3	3.9	0.2
-	1	2.5	0.1	0.5	0.3
-	2	4.0	0.1	0.2	0.3
-	3	-	0.1	0.0	0.2
-	4	-	0.1	0.0	0.2
	LSD	2.9	0.1	**NS**	**NS**
0	0	4.5	0.1	5.6	0.4
0	1	1.1	0.1	0.4	0.5
0	2	2.0	0.1	0.0	0.5
0	3	-	0.1	0.0	0.5
0	4	-	0.1	0.0	0.3
2	0	7.1	0.4	3.4	0.2
2	1	5.0	0.1	0.2	0.1
2	2	6.4	0.1	0.2	0.2
2	3	-	0.1	0.0	0.1
2	4	-	0.1	0.0	0.2
4	0	5.8	0.3	2.7	0.2
4	1	1.2	0.2	0.8	0.2
4	2	1.9	0.1	0.3	0.2
4	3	-	0.1	0.0	0.1
4	4	-	0.1	0.0	0.0
LSD		**NS**	**NS**	0.8	**NS**

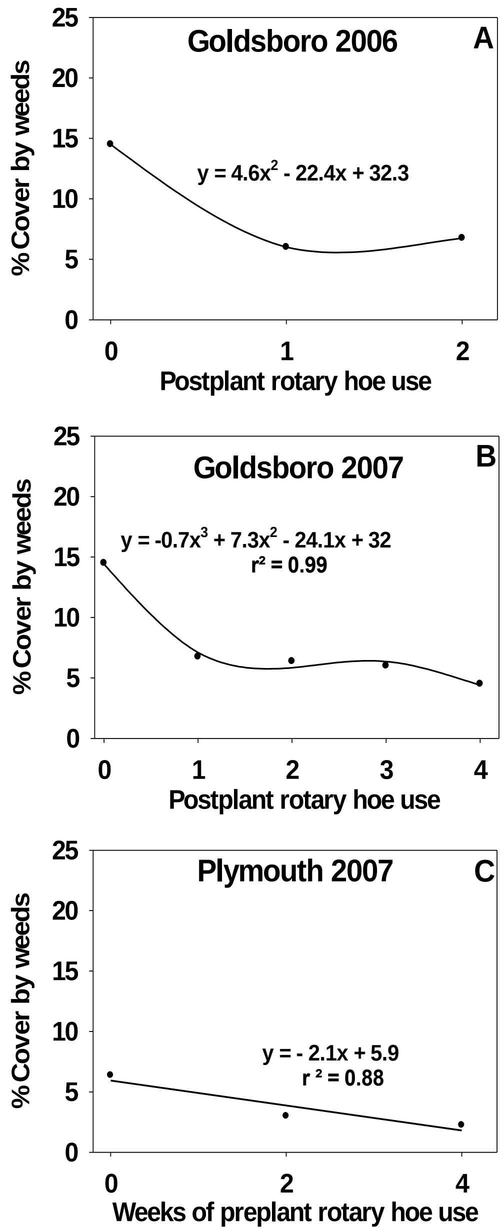

Figure 1: Main effects of post-plant rotary hoe use on mean percent cover by weeds at Goldsboro 2006 (**A**), and Goldsboro 2007 (**B**). Main effects of pre-plant rotary hoe use on percent cover by weeds at Plymouth 2007 (**C**).

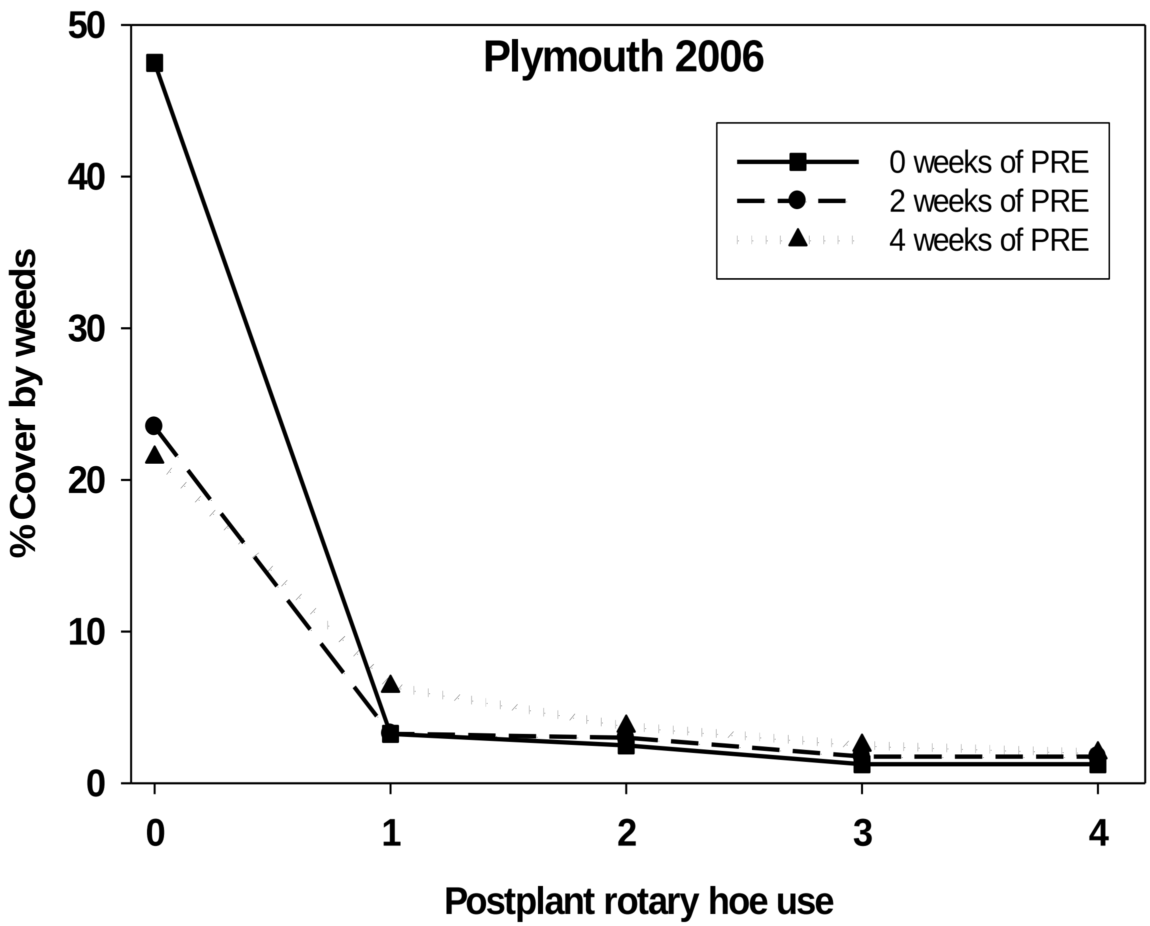

Figure 2: Pre-plant rotary hoe *post-plant rotary hoe interaction on mean percent cover by weeds at Plymouth 2006.

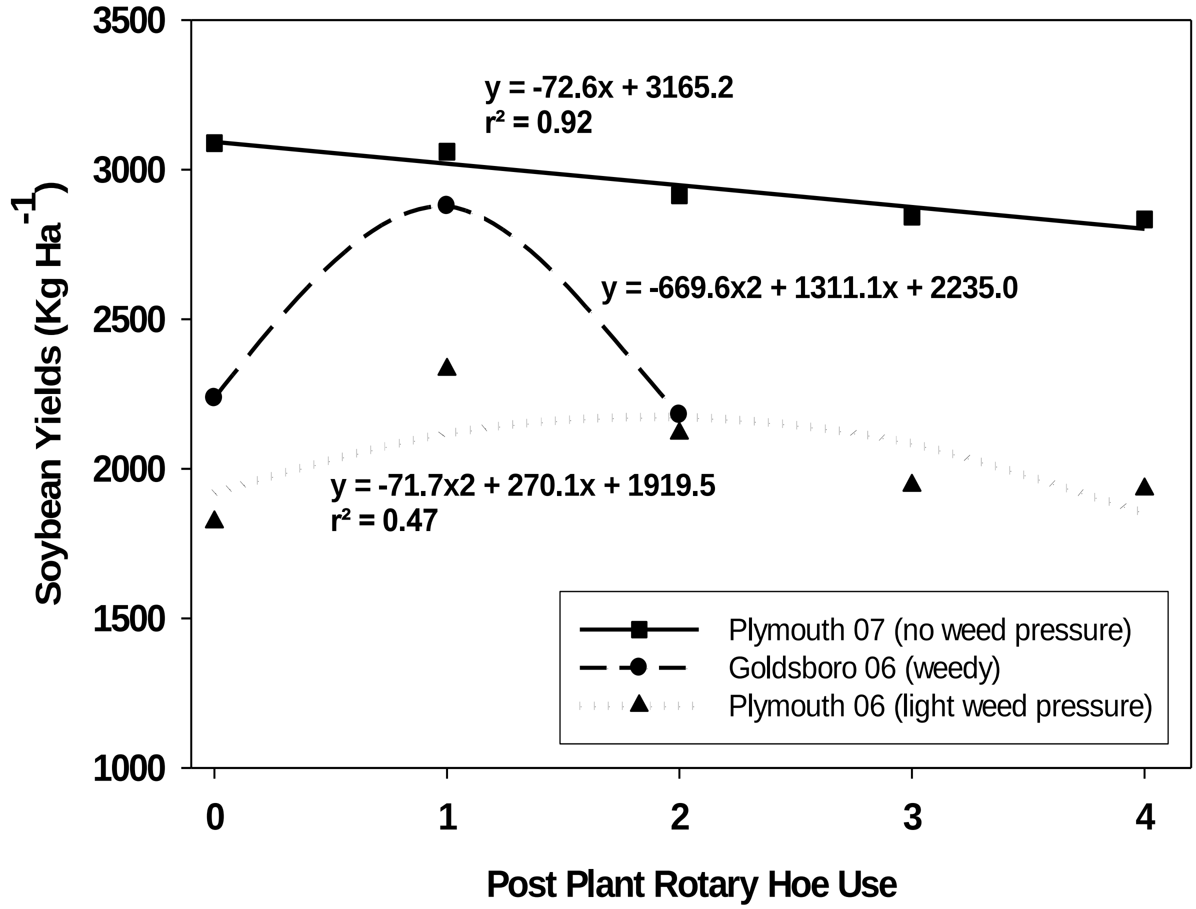

Figure 3: Effect of post-plant rotary hoe use on soybean yield. Mean yield values are averaged across pre-plant rotary hoe treatments.

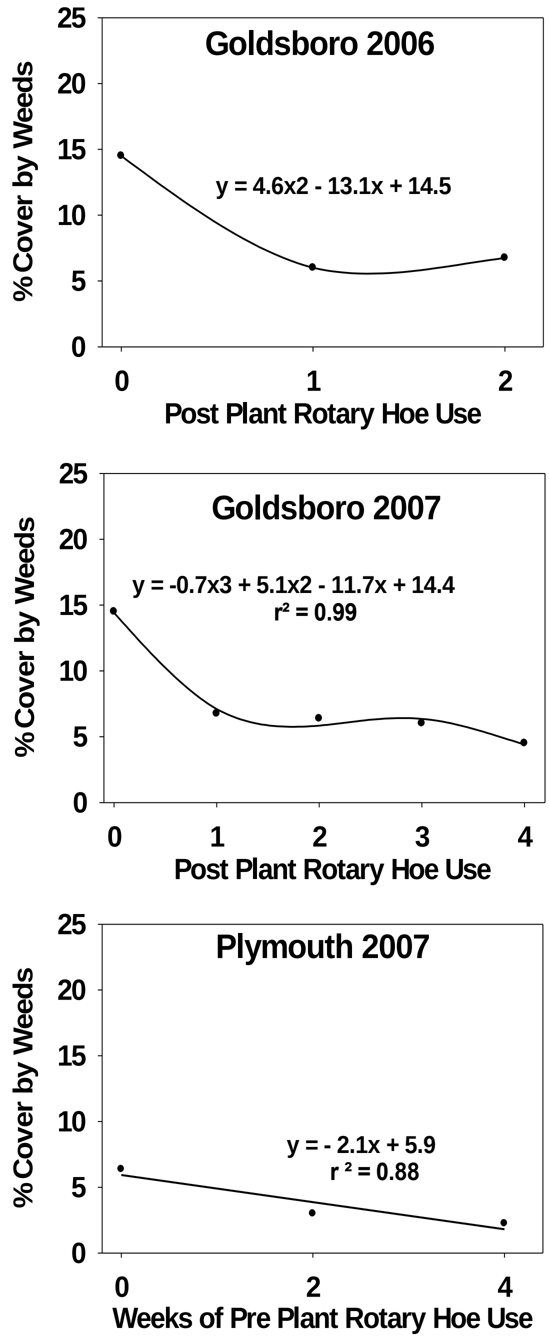

Figure 4: Effect of post-plant rotary hoe use on mean soybean height; (p<.001) for both dates.

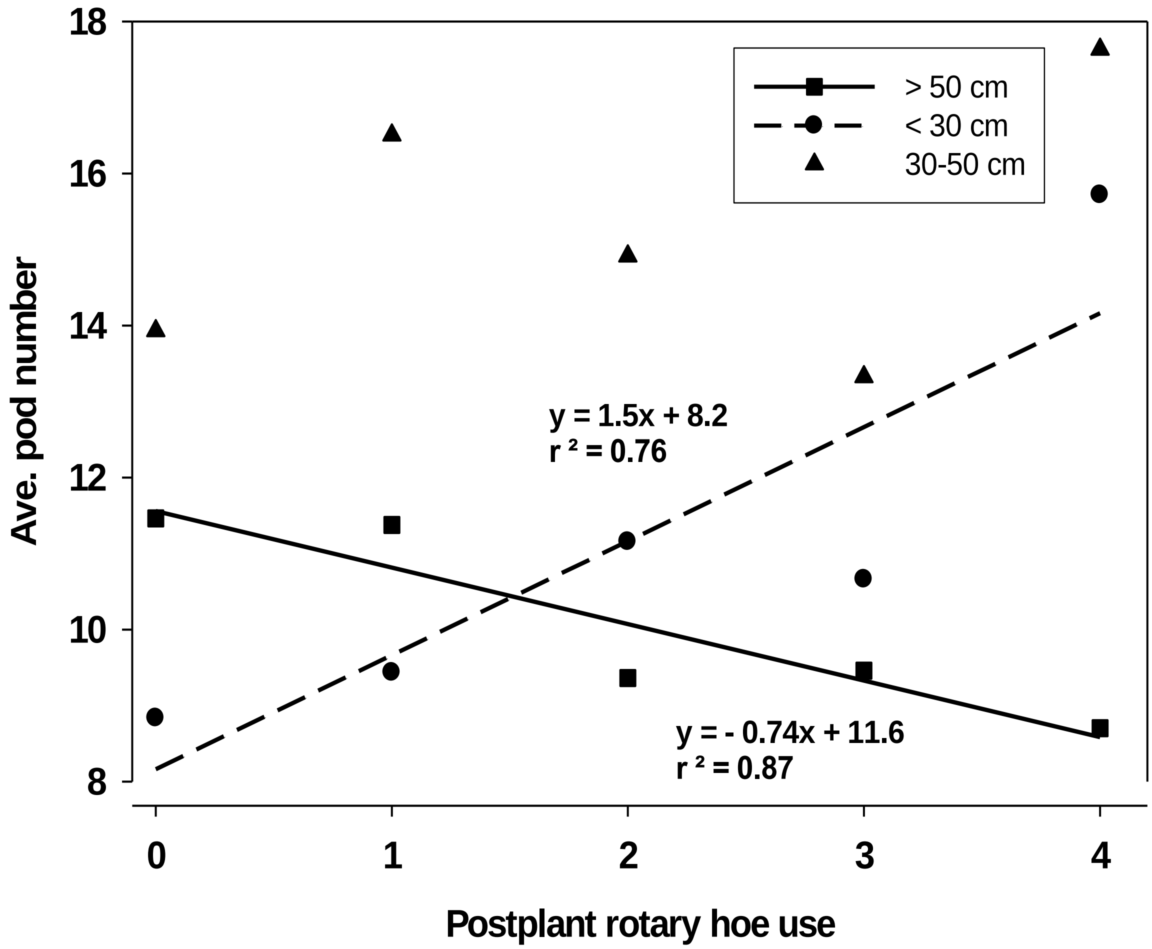

Figure 5: Effect of post-plant rotary hoe use on mean soybean pod position height less than 30 cm (p=.003) and greater than 50 cm (p=.05).

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Chapter 2

Seeding Rate Effects on Weed Control and Yield For Organic Soybean (*Glycine max*) Production

Introduction

The market for organic food products has consistently increased for more than 20 years. Rapid growth in the organic meat and dairy industries (Paulson 2006) have increased demand for organic grains (Dimitri 2008). As a result, organic grain prices have been over twice the conventional price for the last decade (Hamilton and Rzewnicki 2007). Farmers often have much larger profit margins on organic grains 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 (Hamilton, personal communication). Farmers in the mid-Atlantic USA cannot meet the organic grain demand, including the demand for organic soybean (*Glycine max*). 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^{-1}) 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 on 76 cm rows at seeding rates of 432,000 seeds ha^{-1} compared to 308,000 and 185,000 seeds ha^{-1} 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 on 76 cm row spacing in the 445,000 plants ha^{-1} compared to lesser seeding densities on the same row spacing. However, weed biomass was not affected by a soybean seeding rate increase from 296,000 plants ha^{-1} to 445,000 plants ha^{-1} 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.

Objectives of this research were to: i) compare higher seeding rates in organic and conventional soybean production systems, ii) determine if higher seeding rates effectively suppress weeds, and iii) determine how organic soybean yield and economic return is 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 sub plots (47 m^2)

consisted of four seeding rates: 185,000; 309,000; 432,000; and 556,000 live seeds ha^{-1}. Organic weed management consisted of two post-plant passes with a rotary hoe (1-2 days after planting and 10 days after planting) and a between row cultivation (4 weeks after planting (WAP)). Conventional weed management consisted of a PRE herbicide application of metolachlor (2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide) at 1.3 kg ha^{-1}, a POST herbicide application (3 WAP) of imazethapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid) at 0.07 kg ha^{-1}, 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), pigweed (*Amaranthus retroflexus*) or barnyardgrass (*Echinocloa crus-galli*) counts per 15.2 m of 2 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 non transformed 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.

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 Ply 07 and Kin 07 (Table 1).

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 (*Amaranthus retroflexus*) 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 (*Echinocloa crus-galli*). Because of single weed dominance at all locations, all weed count data refers to location dominant weed specie only. Increased soybean seeding rates decreased 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 x 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). 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 x management interactions on soybean yield were not detected in 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^{-1} and conventional feed grade soybean at \$ 0.257 kg^{-1}, although current organic soybean prices are over \$0.92 kg^{-1} (Dimitri 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 six years of North Carolina research at over 50 locations showing that maximum soybean yield can be achieved with 120,000 seed ha^{-1} (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 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^{-1}) in 19 cm rows were shown to suppress both grass and broadleaf weeds more effectively than populations of 238,000 plants ha^{-1} and 178,000 plants ha^{-1} 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^{-1} 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^{-1} to 445,000 plants ha^{-1} in 38 and 76 cm row spacing. However, when weeds were present, soybean yield on 38 cm row spacing was highest in populations of 445,000 plants ha^{-1} and on 76 cm row spacing yield was highest when populations were at least 296,000 plants ha^{-1} (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^{-1} (Kin 07) and 556,000 seeds ha^{-1} (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^{-1}. 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 sub-maximal 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 in 76 cm row spacing, soybean densities of 445,000 plants ha^{-1} closed canopy 11 WAP while densities of 300,000 plants ha^{-1} and less closed canopy 12 WAP. Similarly, Rich and Renner (2007) found that in 76 cm row spacing, soybean seeding rates of 432,000 seeds ha^{-1} had a greater LAI than the 308,000 seeds ha^{-1} treatment by 78 days after planting. Treatments with the higher seeding rate may have had a greater soybean canopy LAI and more PAR interception than the lower seeding rate treatments. If dry conditions and sub-maximal 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^{-1}, organic soybean producers may improve profits by increasing seeding rates beyond currently recommended rates.

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

Environment	Effect	% weed cover	weed counts	soybean yield
		P > F		
Gold 06	seeding rate	<.001	0.002	<.001
	weed management system	<.001	<.001	<.001
	seeding rate x management	<.001	NS	NS
Ply 06	seeding rate	NS	NS	NS
	weed management system	<.001	<.001	NS
	seeding rate x managemen	NS	NS	NS
Gold 07	seeding rate	NS	NS	no data
	weed management system	0.004	0.003	no data
	seeding rate x managemen	NS	NS	no data
Ply 07	seeding rate	0.01	NS	<.001
	weed management system	0.04	NS	NS
	seeding rate x manageme	0.01	NS	NS
Kin 07	seeding rate	<.001	NS	0.02 (quad.)
	weed management system	<.001	<.001	NS
	seeding rate x management	0.004	NS	NS

*Abbreviation: NS, nonsignificant at the 0.05 level.

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^{-1} and conventional feed grade soybean at $ 0.257 kg-1 were also utilized in calculated net return.

	Goldsboro, NC 2006				Plymouth, NC 2006			
Seeding Rate	Organic Yield kg ha^{-1}	Organic Return ha^{-1}	Conventional Yield kg ha^{-1}	Conventional Return ha^{-1}	Organic Yield kg ha^{-1}	Organic Return ha^{-1}	Conventional Yield kg ha^{-1}	Conventional Return ha^{-1}
185,000	2122	$0	2862	$0	1055	$0	1077	$0
309,000	2376	$123	2989	$16	782	-$167	1018	-$32
432,000	2466	$156	3175	$48	842	-$150	1135	-$18
556,000	2682	$259	3228	$45	1165	$11	820	-$116

	Plymouth, NC 2007				Kinston, NC 2007			
	Organic Yield kg ha^{-1}	Organic Return ha^{-1}	Conventional Yield kg ha^{-1}	Conventional Return ha^{-1}	Organic Yield kg ha^{-1}	Organic Return ha^{-1}	Conventional Yield kg ha^{-1}	Conventional Return ha^{-1}
185,000	2913	$0	2984	$0	660	$0	942	$0
309,000	3027	$46	2874	-$45	1077	$213	1370	$93
432,000	3202	$127	3318	$53	1226	$279	1526	$117
556,000	3315	$172	3525	$90	1254	$279	1400	$68

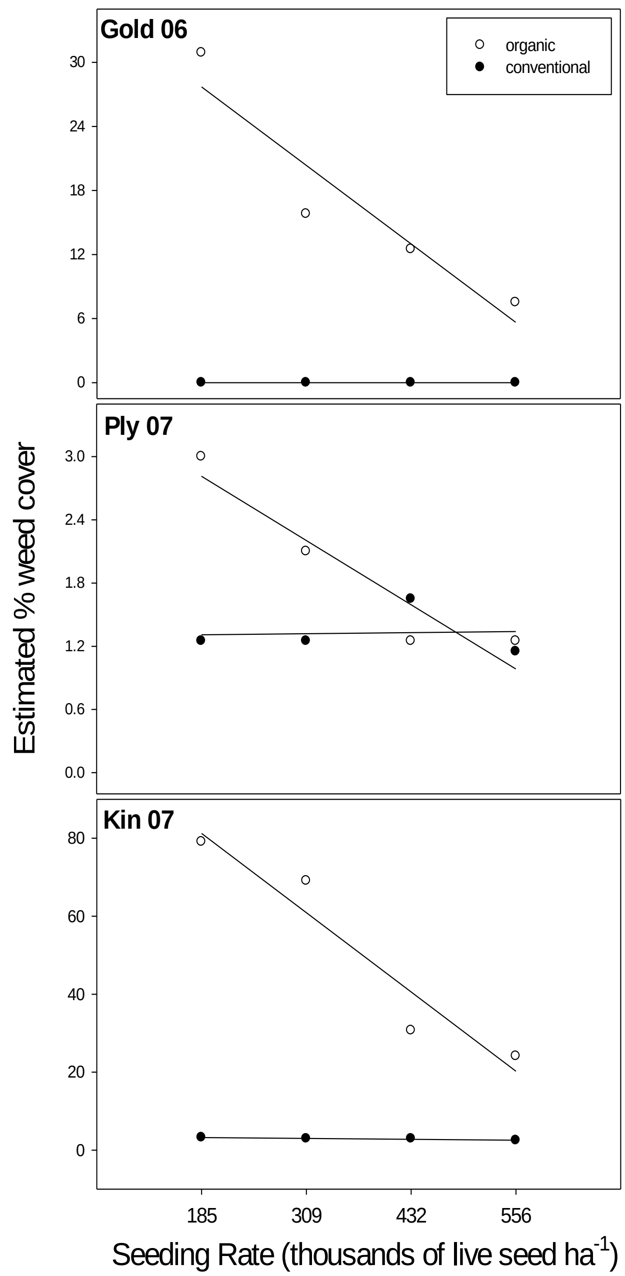

Figure 1. Effect of soybean seeding rate on percent weed cover in conventional and organic weed management treatments at Goldsboro 06, Plymouth 07, and Kinston 07.

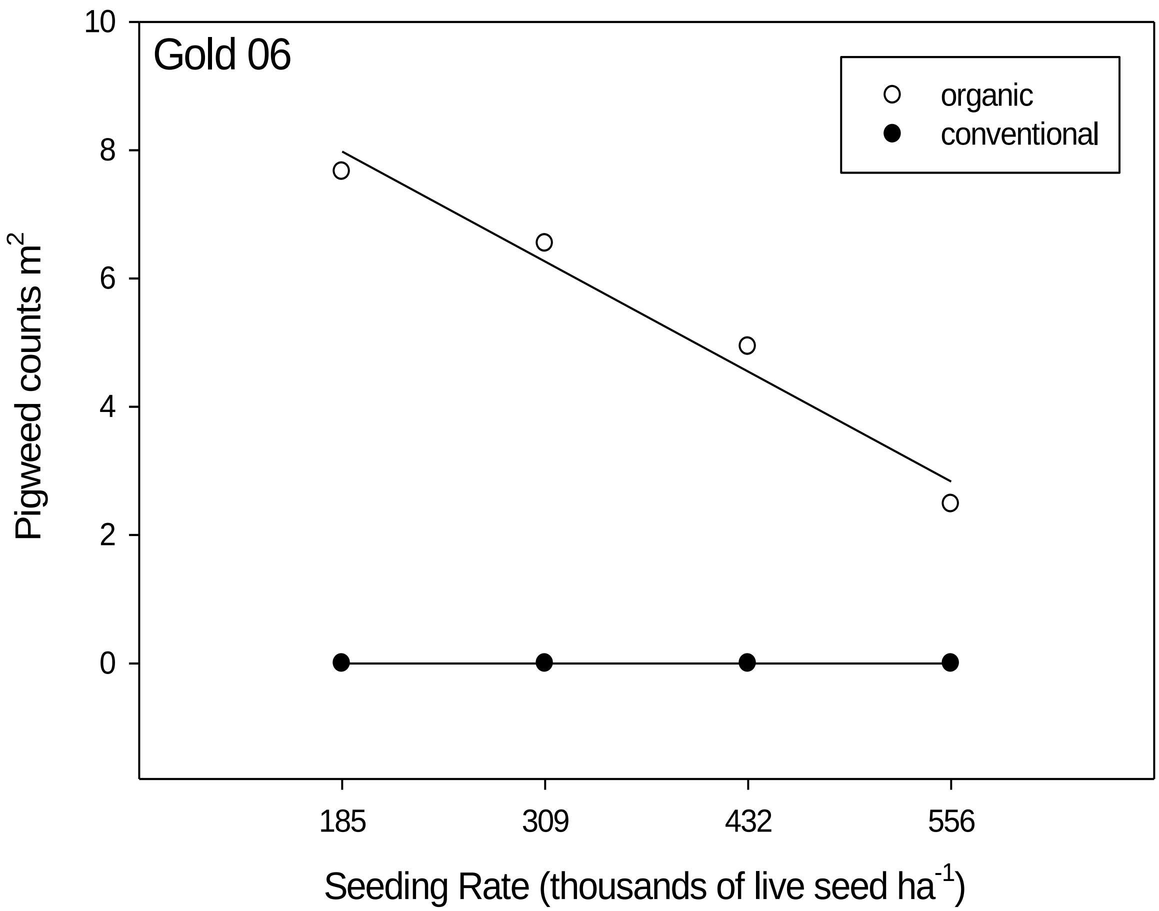

Figure 2. Effect of soybean seeding rate on pigweed counts in conventional and organic weed management treatments at Goldsboro 06.

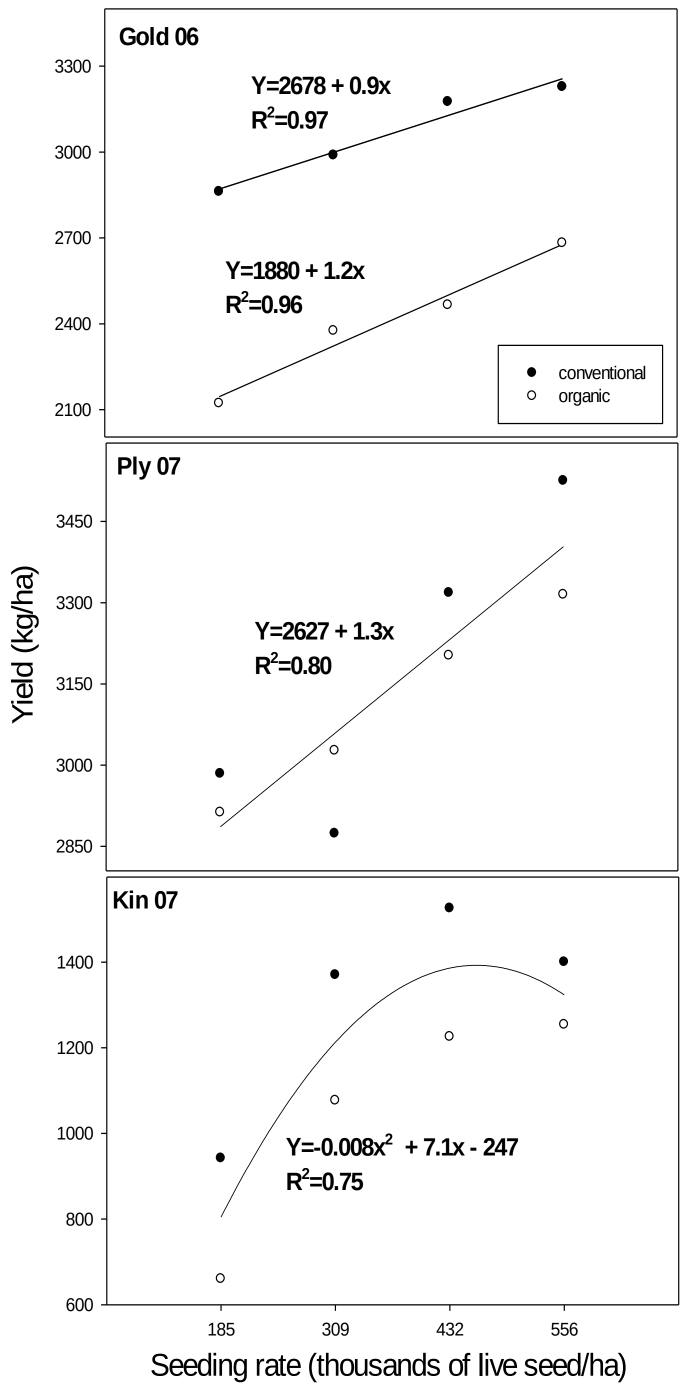

Figure 3. Effect of soybean seeding rate on soybean yield in conventional and organic weed management treatments at Goldsboro 06, Plymouth 07, and Kinston 07.

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Chapter 3

Identifying Soybean Traits of Interest For Weed Competition

Introduction

Currently over 90% of soybeans grown in the United States utilize glyphosate resistance technology (Cerdeira and Duke 2006). An even greater percentage of soybeans are cultivated with the use of herbicides. But the acreage of organic soybeans is increasing as the organic milk, beef and egg markets grow each year (Dimitri 2008). The profit margin for organic soybeans can be substantial (Archer et al., 2007) but farmers making the transition to organic soybean production cite weed management as their top challenge (Archer and Kludze 2006; Cavigelli et al. 2008; Hamilton et al. 2007; Walz 1999). Without the use of herbicides as a management option, organic soybean producers must rely on a variety of tactics to reduce weed pressures (Liebman et al., 1997). The utilization of more competitive soybean cultivars may be another supplemental weed management tactic. A highly competitive cultivar would not only be useful for organic producers but conventional producers could also benefit if less herbicide applications are needed in season (Norsworthy & Shipe, 2006).

Genotypic differences in competitiveness for weeds have been identified for several agricultural species including: wheat (*Triticum aestivum* L.) (Ramsel & Wicks 1988), rice (*Oryza sativa* L.) (Haefele et al., 2004), cowpea (*Vigna unguiculata* L.) (Remison 1978), corn (*Zea mays* L) (Wooley & Smith 1986) and many others (Callaway 1992). Similar studies have suggested differences in competitiveness of soybean genotypes (Jannink et al., 2000; Rose et al., 1984) but high variation often overshadows possible differences (Norsworthy & Shipe, 2006; Bussan et al., 1997).

Soybean breeding programs have typically focused on improving characteristics such as yield and disease resistance with little or no attention to weed competitive improvement since the majority of soybean breeding trials are conducted in weed free conditions (Baenziger et al. 2006; Egli 2008; Gepts and Hancock 2006; Heisey et al. 2001). However, genetic variation in soybean competitive ability has been described by other research groups. Reports of traits that may be related to competitive ability have included height (Jannink et al. 2000), leaf area (Jordan 1993), and early vigor (Guneyli et al., 1969; Rose et al., 1984). However, identifying characteristics imparting competitive advantage has been difficult (Norsworthy & Shipe, 2006). Root characteristics may also influence soybean competitiveness (Dunbabin 2007; Place et al. 2008), but screening for and selection on canopy characteristics that improve competitive ability will be most feasible for soybean breeders.

Because traits of interest for increased competitiveness such as canopy cover or height may be variable depending on the growth stage, such traits should be investigated during the most critical period for weed competition. This period is defined as the interval in the life cycle of the crop when it must be kept weed free to prevent yield loss (Zimdahl 1980; Van Acker et al., 1993). This period is variable depending on environmental conditions (Van Acker et al., 1993) but has been estimated between the soybean stages V2 and V8

(Eyherabide et al., 2002) which occur at approximately 2 and 7 weeks after emergence (WAE), respectively.

We investigated the weed competitiveness of 27 soybean genotypes that were selected based on differing characteristics of seed size, petiole length, petiolule length, leaflet width and length, and main stem height. Our main objectives were to (1) determine if differences in weed competitive ability exist between cultivars of varying canopy traits and seed sizes and (2) determine the relation of these traits on the competitive ability of a genotype.

Materials and Methods

Experimental design consisted of a split plot design. The main plots consisted of 3 soybean trait groupings: 14 genotypes with varying seedsize, 6 genotypes with varying soybean leaf morphologies, and 7 genotypes with varying petiole and petiolule lengths (Table 1). Subplots consisted of soybean genotypes, each planted six rows, 4 m in length and spaced at 96.5 cm. Half of each subplot (3 rows) was maintained weed free. Canopy traits were measured in the weed free area and weed biomass was taken from the weedy half. Which half was weed free was randomly assigned for each block. One location was planted in two years with 9 replications in each year.

Prior to soybean planting, three random subsamples of 100 seed for each genotype were collected, weighed and tested for germination using germination chambers set at 30˚ C.

Soybean seeding rates were adjusted for each genotype to achieve 39 live seed row m^{-1} based on germination tests. A custom designed plot cone planter was used to plant soybeans at the Kinston Research Station in Kinston, NC on May 22, 2007 on a Kenansville Loamy Sand and on May 21, 2008 on a Pocalla Loamy Sand.

Immediately following soybean planting, the weedy subplots were overseeded with redroot pigweed (*Amaranthus retroflexus* L.) seed to increase weed pressure uniformity. Weed free plots were treated with alachlor at 5.84 L ai ha^{-1} immediately following soybean planting. Weed free plots were maintained weed free with weekly hand weeding. Between row areas for both weedy and weed free plots were maintained weed free with between row cultivation at 4 and 7 weeks after emergence (WAE), leaving only the weeds within 10 cm of the crop row in the weedy plots. At 1 and 4 WAE, sethoxydim with crop oil adjuvant was sprayed over the entire trial at 1.75 L ai ha^{-1} to limit weed presence to broadleaf weeds for more uniform weed pressures.

Soybean measurements were taken in the weed free plots over the 7 week period following soybean emergence to quantify canopy characteristics. Measurements were taken in all 9 replications for both years. Stand counts were taken at 1 WAE (early) and 2 WAE (late). Soybean height was measured at 3 WAE (early) and 7 WAE (late). Overhead photographs taken at 3 WAE (early) and 5 WAE (late) were used to estimate soybean canopy percent ground cover in weed free plots. In 2007, images were processed with Adobe Photoshop 5.0 to convert soybean canopy to black pixels and visible ground to white pixels. A Javascript pixel counting software as described by Stewart et al. (2007) was then utilized to estimate the percent canopy coverage from the ratio of black pixels to the total number of black and white pixels. In 2008, images were processed utilizing SigmaScan Pro with a macro language software for batch analysis as described by Karcher and Richardson (2005) with the hue settings from 47 to 107 and the saturation setting from 10-100. Photos were taken with a Canon PowerShot A360 Digital Camera (8.0 mega pixels) using a custom built camera stand which was centered over the middle row of each weed free plot. Plots were shaded during photography to avoid shadow effects in image processing. The digital image size was 1.37 m wide and 1.87 m of the row, capturing approximately 70 plants. Leaf petiole, leaf petiolule, leaflet length and leaflet width were measured on the 3^{rd} most fully expanded leaf at 4 WAE. At 7 WAE node number was measured.

At 7 WAE, an area 0.36 m wide and 3.05 m long of the center row of each weedy and weed free genotype subplot was harvested using a Haldrup forage plot harvester. Weeds and soybean plants were separated by hand in weedy plots. Fresh weight biomass was measured for the entire harvest area. For each genotype subplot, 3 biomass measures were recorded: the soybean biomass maintained weed free, the soybean biomass in weedy conditions, and the weed biomass. Every individual biomass measure was sub-sampled, dried, and weighed to estimate biomass moisture percentage. Total plot dry biomass was calculated for each individual biomass measure for analysis.

Statistical analysis was conducted using SAS 9.1. Year effects were treated as random. Year*treatment effects were significant for many treatments, thus results were reported by separate years. Model predicted values versus residual error graphs were utilized to confirm assumptions of error variance. Weed weight was square root transformed for analysis. The ratio of weedy to weed free soybean biomass was natural log transformed. All other dependent variables met model assumptions. Least squares mean values were utilized for reporting of treatment means. Multiple regression was utilized to determine which soybean characteristics were most influential in end of season weed biomass and percent ground cover estimation.

Multiple regression optimal model selection was determined using model information criteria methods. It was shown that in simulated model testing, optimal model selection using information criteria methods selected the true models significantly more often than heuristic methods or model diagnostic methods (Beal 2005). The model chosen for predicting soybean competitive ability was the model with the lowest value for the Schwarz Bayesian Criteria (SBC), Bayesian Information Criteria (BIC), and Akaike's Information Criteria (AIC) and dependent on all parameters being significant at $p<0.10$. Beal (2005) also found that in testing of known true models with 10 independent variables and one dependent variable, the SBC criteria was consistently the superior criteria for identifying the true optimal models. Thus, in cases where models had variable rank for the SBC, BIC, and AIC values, the model with the lowest SBC value was chosen in most cases as the optimal model for predicting soybean competitive ability. Full and reduced model testing was conducted to determine significant interactions of model variables.

Results and Discussion

Competitive cultivars have sometimes been classified in two main ways, weed tolerant and weed suppressive (Callaway 1992; Jannink et al. 2000). Weed tolerant cultivars maintain yield or show minimal yield reductions when growing with weeds. In contrast, weed suppressive cultivars reduce weed biomass. Weed suppressive ability is the preferred component in crop competitiveness (Jordan 1993) for reducing weed seed rain and future weed infestations, although the tolerance to weeds may be important for acceptable yields (Norsworthy & Shipe, 2006).

In this experiment, less weed biomass associated with a soybean genotype was interpreted as a greater weed suppressive ability. In both years, weed suppressive differences were detected in the grouping of genotypes with variable seed size (Table 2). In 2008, differences in weed suppressive ability were also detected in the varying petiole and petiolule grouping of genotypes. In both years, the natto (small seeded and narrow leaflet) soybean genotypes N7103, N94-7440, N96-6429, and TCAXBXX-717 were the least effective genotypes in suppressing weeds in the variable seed size group.

Weed free soybean biomass differences between genotypes were detected in the same three genotype groupings that showed weed suppressive differences (Table 3). Weedy soybean biomass differences between genotypes were detected in the seed size grouping of genotypes as well as the petiole/petiolule group in 2007. No weedy soybean biomass differences were detected in 2008.

Because each genotype subplot was split by a weedy and weed free treatment, the soybean biomass reduced by weedy conditions for each genotype was calculated. A smaller soybean biomass reduction due to the presence of weeds was interpreted as a greater ability to tolerate the presence of weeds. No significant differences were detected (Table 3), suggesting no obvious differences between genotypes in ability to tolerate the presence of weeds.

The ability of a soybean genotype to effectively intercept light and increase canopy cover during the critical period for weed competition is crucial for suppressing weed growth (Peters et al. 1965; Yelverton and Coble 1991). Measurement of canopy coverage is often made to estimate leaf area index (LAI), a critical canopy characteristic for light competition (Gibson et al. 2003). The digital imaging technique used in this experiment was previously found by Stewart et al. to have a strong relationship ($r^2 = 0.74$) with measured leaf area index (LAI). Larger percent ground cover estimates from digital images were interpreted as greater ability to compete for light. Early images taken at 3 WAE showed light competitive differences between all genotype groupings in both years (Table 4). Late images taken at 5 WAE showed genotypic differences in 2 of the 3 groupings in 2007 and in 2008.

All of the canopy traits measured (Table 5) were included in multiple regression models to determine which of these characteristics most influenced competitive ability. Separate multiple regression models were developed with the dependent variables: early estimated percent ground cover (Table 6), late estimated percent ground cover (Table 6), and weed biomass (Table 7). By utilizing models with dependent variables specific to light competition (percent ground cover estimates) and dependent variables for overall competition (weed biomass) we can discern the importance of these measured canopy traits for competition for light and overall competition with weeds.

In both years, seed size, early soybean stand density, and leaflet width were the most influential traits in competitive ability for light (Table 6). In 2007, late soybean stand density and total leaf length had an influence while petiole length was an influential characteristic in 2008. Seed size was the most influential trait for early light competition, with both years of data suggesting that larger seeded genotypes resulted in improved ability to compete for light at 3 WAE. Two weeks later, the influence of seed size on percent ground cover had subsided dramatically. The reduction of seed size influence on soybean canopy traits over time has been previously reported (Oexemann 1942). The late ground cover was most affected by total leaf length (the sum of petiole, petiolule, and leaflet length) in 2007 while petiole length was the most influential trait in 2008 (Table 6). Increased leaflet width also increased late ground cover in both years. Thus, later competition for light was improved by longer leaves and wider leaflets. Wells et al. (1993) reported that narrower leaflets were less effective at PAR interception. However, Suh et al. (2000) points out that soybean genotypes with narrow leaves have better light distribution through their canopy and a higher photosynthetic rate than those genotypes with oval leaf shape. The narrow leaflet trait may demonstrate a trade-off advantage of improved light distribution through the canopy in weed free conditions but a disadvantage in light competition in weedy conditions.

The optimal models for how genotype canopy characteristics affected weed suppressive ability were somewhat unexpected. In both years, seed size was the most influential trait with larger seeded genotypes showing an improved ability to suppress weeds.

Surprisingly, the 2007 model showed that a shorter leaflet length resulted in more weed suppressive ability (Table 7 and Figure 1). When it was seen that the very competitive genotype N00-7153 with a large seed and short leaflet may have been disproportionately influencing the model, that genotype was removed and the multiple regression was re-calculated. Even with the absence of that influential genotype, the relationship of a larger seed and a shorter leaflet improving overall competitive ability was maintained. Similarly in 2008, a shorter petiole resulted in more weed suppression. Why a shorter leaflet or petiole would improve competitive ability is not clear, particularly since longer leaves resulted in improved percent ground cover at 5 WAE. One possible explanation is that a shorter leaflet or petiole length is a trait that is linked to another trait not measured in this experiment which may be improving the overall competitive ability of the genotype.

The influence of seed size was strong 3 WAE but was barely detectable by 5 WAE. Yet, seed size was the most influential soybean trait for overall competitive ability (reduced weed biomass) measured at 7 WAE. Two general interpretations can be made. The first possible explanation is that overall competition was influenced by factors other than competition for light. Longer et al. (1986) showed large soybean seed was superior to smaller seed in root mass. Such a root mass advantage could have reduced weed biomass. The second interpretation is that the light competition at 3 WAE was more important than light competition at 5 WAE in the overall weed competition. Early vigor in seedling development is important in competitive ability (Guneyli et al., 1969). Regardless of these interpretations, seed size seems to be the single most important trait measured in this study for overall competitive ability with weeds. However, how seed size is imparting competitive ability is more difficult to discern.

Some insight into the influence of seed size may be seen in simple linear regression of seed size on all the soybean canopy traits measured (Table 8). In both years increased soybean seed size was associated with wider leaflets, increased height at 3 WAE, increased height at 7 WAE, and a reduced soybean stand density. The association of larger seeds and wider leaflets was expected since a high number of seeds per pod and the narrow leaflet trait is considered to be a pleiotropic effect of the same allele (Johnson and Bernard 1962). More seeds per pod associated with narrow leaflets results in a lower individual seed weight. Burris et al. (1973) found that larger soybean seeds resulted in cotyledonary area increases and greater heights than small seed seedlings. In 2007, larger seeds were also associated with increased petiole and petiolule length. A correlation between larger soybean seed and petiole length was also demonstrated by Oexemann (1942). The reason for the influence of seed size on stand count is not obvious but it could have been related to soil moisture. Smaller seeds may have imbibed and germinated faster than larger seeds. If larger seeds experienced a germination delay this may have ultimately resulted in reduced soybean stand density. Investigations of soybean seeding rate effects on weed competition show that a reduced stand density would be a disadvantage for ability to compete with weeds (Burnside and Moomaw 1977; Légère and Schreiber 1989; Nice et al. 2001, Place et al. 2009). Such a reduced stand count disadvantage may suggest a slight competitive ability trade off with the larger seed size.

In conclusion, overall competitive ability was most affected by seed size with larger seeded genotypes better able to suppress weed biomass. Narrow leaflet genotypes were poor competitors with weeds. Estimations of early canopy ground cover also showed larger seeded genotypes to have an early advantage in light competition. Although larger seed size has been implicated in improved seedling vigor and height, more research is needed to clarify what advantages in weed competition are imparted from a larger seed size.

Sources of Materials

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

[2]Adobe Photoshop 5.0. Adobe Systems Inc., 801 N. 34th St., Seattle, WA 98103.

[3]SigmaScan Pro version 5.0, SPSS Inc., Chicago, IL 60606-6412.

Table 1: Soybean genotype maturity groups, seed sizes, and germination rates for 2007 and 2008.

	Genotype	Maturity Group	2007		2008	
			Seed Size	Germination	Seed Size	Germination
			— g 100 seed $^{-1}$ —	—— % ——	— g 100 seed $^{-1}$ —	—— % ——
Genotypes with Varying seed size	N04-8803	8	22.4	90	22.9	77
	N04-8866	8	22.3	87	22.9	80.5
	N93-7133	7	23.2	90		
	N00-7153	6	23.0	87	21.9	70
	N02-9079	6	24.3	82	20.4	90.3
	N04-8906	6	24.9	92	23.3	76
	N01-10974	6	20.5	89	22.7	80.5
	N7103	7	8.0	99	8.7	90.5
	N94-7440	6	7.8	98	8.7	95.5
	N96-6429	6	8.9	100	9.5	92.5
	TCAXBXX-717	8	6.2	89	6.8	98
	NC-Roy	6	13.2	97	13.3	94.5
	NC-Raleigh	7	13.8	96	15.6	86
	Cook	8	17.1	90	15.8	86
Genotypes with varying leaf morphology	PI 416937	6.3	17.4	90	18.4	78.5
	N95-7424	6.5	17.7	86	16.4	81.5
	N90-7254	7	19.8	100	18.5	79
	Derry	6	14.8	90	15.7	96
	Tyrone	7	12.2	86	15.4	95.5
	Dillon	6	15.2	87	16.6	92.5
Genotypes with varying petiole and petiolule lengths	Spry	4.5	18.4	90	17.9	76.5
	Stressland	4.5	13.7	84	13.4	74
	SRF 400 (PI 548682)	4	14.7	85	12.9	99
	Clark 63 (PI 548532)	4	14.9	80	13.6	98.5
	SRF450 (PI 548685)	4	16.8	94	14.8	96.5
	Kent (PI 548586)	4	18.0	97	16.7	95.5
	5002T	5	14.7	84	15.4	91

Table 2: Weed biomass associated with each soybean genotype.

	Genotype	Kinston, NC 2007	Kinston, NC 2008
		Weed Biomass	
		g m^{-1}	
Genotypes with Varying seed size	N04-8803	35	36
	N04-8866	39	31
	N93-7133	40	
	N00-7153	33	31
	N02-9079	38	32
	N04-8906	35	31
	N01-10974	40	31
	N7103	54	46
	N94-7440	54	53
	N96-6429	48	36
	TCAXBXX-717	48	41
	NC-Roy	41	35
	NC-Raleigh	40	31
	Cook	41	33
	p value	**0.007**	**< .001**
	lsd	**10.2**	**17.5**
Genotypes with varying leaf morphology	PI 416937	39	29
	N95-7424	46	30
	N90-7254	39	33
	Derry	35	26
	Tyrone	46	24
	Dillon	43	23
	p value	**0.26**	**0.16**
	lsd	**NS**	**NS**
Genotypes with varying petiole and petiolule lengths	Spry	49	39
	Stressland	45	40
	SRF 400 (PI 548682)	49	26
	Clark 63 (PI 548532)	48	27
	SRF450 (PI 548685)	48	33
	Kent (PI 548586)	36	26
	5002T	37	28
	p value	**0.17**	**0.004**
	lsd	**NS**	**10.8**

Table 3: Weed free soybean biomass (WF), weedy soybean biomass (W), and soybean biomass loss due to weeds (loss).

	Kinston, NC					
	2007			2008		
Genotype	Soybean Biomass					
	WF	W	loss	WF	W	loss
	$g\ m^{-1}$					
N04-8803	156	136	20	150	72	78
N04-8866	155	139	16	145	70	75
N93-7133	180	167	13			
N00-7153	155	132	23	135	75	60
N02-9079	158	150	8	155	76	79
N04-8906	162	151	11	162	83	79
N01-10974	157	128	29	151	84	67
N7103	138	98	40	131	62	69
N94-7440	141	110	31	136	61	75
N96-6429	137	105	32	126	64	62
TCAXBXX-717	134	103	31	132	66	66
NC-Roy	161	125	36	148	79	69
NC-Raleigh	168	130	38	150	75	75
Cook	163	151	12	148	71	77
p values	**0.02**	**< .001**	**0.14**	**0.001**	**0.33**	**0.84**
PI 416937	167	135	32	145	79	66
N95-7424	145	129	16	160	88	72
N90-7254	160	142	18	147	77	70
Derry	164	139	25	147	94	53
Tyrone	165	139	26	151	89	62
Dillon	163	132	31	150	87	63
p values	**0.73**	**0.68**	**0.84**	**0.62**	**0.55**	**0.66**
Spry	162	133	29	145	86	59
Stressland	180	159	21	143	75	68
SRF 400 (PI 548682)	147	107	40	124	79	45
Clark 63 (PI 548532)	150	130	20	131	69	62
SRF450 (PI 548685)	137	120	17	130	70	60
Kent (PI 548586)	160	137	23	125	80	45
5002T	151	140	11	147	70	77
p values	**0.09**	**0.03**	**0.67**	**0.03**	**0.71**	**0.15**

Table 4: Canopy ground coverage estimates from overhead photography.

	Kinston, NC			
	2007		2008	
Genotype	Early (3 WAE)	Late (5 WAE)	Early (3 WAE)	Late (5 WAE)
	% ground cover			
N04-8803	15.8	56.7	7.3	26.3
N04-8866	17.2	57.4	8.0	27.1
N93-7133	18.5	59.6		
N00-7153	15.9	47.9	7.6	25.5
N02-9079	16.9	62.1	8.2	27.9
N04-8906	18.5	56.8	9.9	31.2
N01-10974	15.6	53.4	8.2	27.3
N7103	11.1	48.8	4.6	23.3
N94-7440	10.3	45.5	4.8	25.5
N96-6429	12.5	47.3	5.0	23.0
TCAXBXX-717	10.9	44.4	4.1	22.4
NC-Roy	15.0	51.0	6.6	24.9
NC-Raleigh	16.7	63.8	9.0	31.9
Cook	18.2	58.2	9.2	30.6
p values	**< .001**	**< .001**	**< .001**	**< .001**
PI 416937	18.1	57.0	9.1	27.3
N95-7424	13.1	52.0	8.1	25.8
N90-7254	15.3	51.1	8.8	25.1
Derry	16.0	55.3	7.4	25.2
Tyrone	18.7	60.2	7.6	27.6
Dillon	17.2	58.0	7.2	26.0
p values	**< .001**	**0.004**	**< .001**	**0.32**
Spry	14.4	60.6	5.6	23.8
Stressland	14.8	59.1	4.6	21.0
SRF 400 (PI 548682)	13.3	56.1	7.2	23.2
Clark 63 (PI 548532)	14.4	56.9	8.0	25.9
SRF450 (PI 548685)	14.0	55.1	6.8	24.3
Kent (PI 548586)	15.6	60.7	7.1	22.5
5002T	17.4	59.0	7.9	25.8
p value	**0.02**	**0.64**	**< .001**	**0.003**

Table 5: Genotype canopy characteristics.

	Kinston, NC																	
	2007									2008								
Genotype	Early Stand	Late Stand	Node Count	Petiole Length	Petiolule Length	Leaflet Width	Leaflet Length	Early Height	Late Height	Early Stand	Late Stand	Node Count	Petiole Length	Petiolule Length	Leaflet Width	Leaflet Length	Early Height	Late Height
	plants m^{-2}			cm						plants m^{-2}			cm					
N04-8803	17.6	17.8	8.5	19.0	3.6	8.5	12.5	5.7	48.4	36.6	35.9	7.6	13.1	1.6	4.7	6.3	9.3	35.0
N04-8866	16.2	18.2	10.3	16.4	3.3	9.4	13.0	5.6	49.8	33.3	33.4	7.9	12.4	1.4	5.4	7.8	9.0	36.3
N93-7133	15.4	18.5	11.0	17.4	3.7	8.7	12.5	5.4	50.0									
N00-7153	15.3	12.6	10.7	16.3	2.4	7.4	9.3	5.0	45.7	31.6	36.3	7.9	11.6	1.0	4.4	6.2	9.7	36.7
N02-9079	14.7	16.2	11.3	17.4	3.6	9.6	12.4	4.9	60.1	36.6	36.7	7.4	11.6	1.7	4.7	5.4	8.3	40.6
N04-8906	16.7	17.2	11.3	16.1	3.6	8.4	12.4	5.9	61.3	38.8	41.2	7.4	13.5	1.9	4.8	6.1	11.5	45.0
N01-10974	16.1	16.7	10.5	16.8	3.2	8.3	12.0	6.0	55.1	35.9	36.0	7.4	11.9	1.5	4.6	5.9	10.6	40.5
N7103	18.7	20.8	10.3	14.7	2.9	5.3	12.2	4.4	37.8	35.6	37.1	8.6	10.3	0.9	3.0	6.0	6.4	31.0
N94-7440	15.1	20.3	9.8	14.4	3.1	5.0	12.3	4.1	36.4	36.3	39.0	8.3	12.8	1.2	3.1	6.9	7.1	34.7
N96-6429	17.1	19.0	11.5	13.8	3.3	4.8	12.4	4.1	42.9	34.8	42.2	8.8	11.8	1.7	3.5	8.0	6.8	32.5
TCAXBXX-717	20.5	23.8	10.5	13.2	2.5	4.7	10.2	4.2	46.9	37.0	39.8	9.6	11.1	1.4	2.9	6.1	6.8	35.2
NC-Roy	17.0	21.0	9.5	14.6	3.0	7.6	11.9	4.3	50.0	31.0	34.3	8.2	12.9	2.3	4.7	7.7	6.6	36.2
NC-Raleigh	18.2	18.7	10.3	16.5	4.1	9.0	12.0	4.2	50.6	40.3	38.2	7.9	12.4	2.1	5.1	7.0	6.7	34.9
Cook	21.1	20.1	10.5	18.6	3.6	8.4	12.5	5.3	51.9	41.9	41.1	8.2	15.5	1.9	4.8	6.7	9.1	35.3
p values	**0.11**	**0.002**	**0.006**	**< .001**	**0.003**	**< .001**	**0.002**	**< .001**	**< .001**	**0.001**	**0.003**	**<.001**	**< .001**	**< .001**	**< .001**	**0.01**	**< .001**	**< .001**
PI 416937	18.4	19.7	9.4	16.5	2.7	8.9	11.9	4.7	42.5	37.7	38.6	7.7	10.4	1.3	4.7	6.1	8.6	34.4
N95-7424	13.6	13.1	10.8	16.6	3.9	8.5	12.3	4.4	42.3	38.9	38.5	7.8	13.5	2.2	4.7	6.8	7.1	33.1
N90-7254	14.3	15.6	10.8	16.5	3.1	8.7	12.5	4.3	44.9	39.0	39.2	7.4	12.5	1.8	5.5	7.2	8.6	33.5
Derry	22.7	25.8	8.5	15.5	2.4	6.8	10.3	4.1	49.3	38.8	37.6	7.7	11.1	1.4	4.1	5.9	6.5	37.4
Tyrone	21.4	23.3	8.3	17.8	3.3	8.6	11.7	4.6	50.3	32.7	33.3	8.0	12.4	1.9	5.2	7.7	8.1	37.6
Dillon	17.9	21.7	9.3	19.1	3.7	8.5	11.9	4.6	48.8	33.2	32.9	7.4	12.8	2.2	4.9	6.6	8.6	35.8
p values	**<.001**	**<.001**	**0.003**	**0.007**	**< .001**	**< .001**	**0.03**	**0.15**	**0.04**	**0.04**	**0.02**	**0.87**	**0.005**	**0.006**	**0.08**	**0.22**	**< .001**	**0.01**
Spry	13.4	14.2	9.3	18.3	3.8	9.9	13.7	5.2	53.1	28.5	31.0	8.1	13.2	1.8	5.1	6.8	8.1	39.9
Stressland	18.3	21.8	9.0	17.5	3.8	8.1	11.7	4.4	46.3	28.2	27.2	7.8	12.2	1.8	5.1	7.2	6.5	32.6
SRF 400 (PI48682)	17.0	18.2	10.4	15.8	3.0	5.5	14.0	4.0	47.5	36.4	38.6	7.3	10.5	0.9	3.0	6.2	6.5	31.9
Clark 63(PI548532)	17.0	20.2	10.5	16.1	3.2	8.3	10.9	4.2	49.6	34.6	34.6	7.0	11.0	1.7	4.4	5.6	7.0	32.8
SRF450 (PI548685)	15.7	20.5	10.0	14.7	2.7	6.0	13.0	4.0	47.3	35.1	35.3	8.2	9.6	0.9	3.5	7.2	6.5	32.8
Kent (PI548586)	15.9	19.4	9.5	15.2	2.7	9.1	11.5	4.1	45.4	32.3	33.9	7.3	9.2	1.1	4.5	5.1	7.2	30.3
5002T	22.0	25.0	10.3	15.2	2.7	7.9	10.8	4.7	47.9	36.0	36.6	8.0	12.0	1.6	5.1	7.1	7.0	35.1
p value	**0.01**	**<.001**	**0.27**	**0.002**	**0.006**	**< .001**	**< .001**	**< .001**	**0.16**	**0.006**	**<.001**	**0.11**	**< .001**	**< .001**	**< .001**	**0.02**	**0.003**	**< .001**

Table 6: Multiple regression models for influence of soybean genotype characteristics on percent ground cover estimates. Model variables include: seed size (g/100 seed), early and late stand (soybean plants/m), leaflet width (cm), total leaf length (cm), and petiole (cm). Model criteria include Akaike Information Criteria (AIC), Schwarz's Bayesian Criterion (SBC), and Sawa's Bayesian Information Criteria (BIC).

		Model Variable	Partial R^2	Model R^2	Variable p value
Early ground cover	Kinston 2007	seed size	0.46	0.46	<.0001
		early stand	0.24	0.70	<.0001
		leaflet width	0.06	0.76	0.004
		early stand x leaflet width	0.04	0.80	0.01
		late stand	0.02	0.78	0.07
		Y = 19.47 + 0.32(seed size) – 1.03(early stand) - 2.34(leaflet width) + 0.17(early stand x leaflet width) + 0.21(late stand)			
		Full model SBC = 21.9 (lowest value), BIC = 17.9 (lowest value), and AIC = 13.2 (lowest value)			
	Kinston 2008	seed size	0.53	0.53	<.0001
		early stand	0.20	0.73	<.0001
		Y = -2.97 + 0.26(seed size) + 0.17(early stand)			
		Full model SBC = -14.0 (lowest value), BIC = -16.6 (2nd lowest value), and AIC = -19.2 (3rd lowest value)			

Table 6: continued

Late ground cover	Kinston 2007	total leaf length	0.35	0.35	<.0001
		late stand	0.15	0.5	0.001
		leaflet width	0.11	0.61	0.003
		seed size	0.03	0.64	0.07
		Y = -15.19 + 1.19(total leaf length) + 1.05(late stand) + 1.32(leaflet width) + 0.31(seed size)			
		Full model SBC = 120.2 (lowest value), BIC = 114.6 (lowest value), and AIC = 109.8 (2nd lowest value)			
	Kinston 2008	petiole length	0.28	0.28	0.0003
		leaflet width	0.08	0.37	0.03
		early stand	0.07	0.43	0.05
		Y = 0.04 + 0.006(petiole length) + 0.02(leaflet width) + 0.002(early stand)			
		Full model SBC = -309.3 (3rd lowest value), BIC = -313.2 (3rd lowest value), and AIC = -316.2 (2nd lowest value)			

Table 7: Multiple regression models for influence of soybean genotype characteristics on weed biomass. Model variables include: seed size (g/100 seed), leaflet length (cm), petiole (cm), and petiolule (cm). Model criteria include Akaike Information Criteria (AIC), Schwarz's Bayesian Criterion (SBC), and Sawa's Bayesian Information Criteria (BIC).

		Model Variable	Partial R^2	Model R^2	Variable p value
weed biomass	Kinston, NC 2007	seed size	0.26	0.26	0.0006
		leaflet length	0.12	0.37	0.01
		Y = 0.29 + 0.01(leaflet length) - 0.003(seed size)			
		Full model SBC = -312.4 (lowest value), BIC = -314.4 (lowest value), and AIC = -317.6 (2nd lowest value)			
	Kinston, NC 2008	seed size	0.25	0.25	0.0003
		petiole	0.06	0.31	0.02
		petiolule	0.05	0.36	0.04
		Y = 0.28 - 0.004(seed size) + 0.01(petiole) - 0.03(petiolule)			
		Full model SBC = -291.34 (2nd lowest value), BIC = -294.7 (lowest value), and AIC = -298.3 (lowest value)			

Table 8: Simple linear regression of seed size on measured canopy traits.

Kinston 2007			
Dependent variable	p value	R^2	predicted equation
leaflet width	< .0001	0.4	Y=5.0 + 0.18 (seed size)
leaflet length	NS		
petiolule length	0.09	0.07	Y=2.8 + 0.02 (seed size)
petiole length	< .0001	0.31	Y=13.7 + 0.17 (seed size)
node count	NS		
early height (3 WAE)	< .0001	0.52	Y=3.1 + 0.09 (seed size)
late height (7 WAE)	< .0001	0.36	Y=37.2 + 0.64 (seed size)
early stand density (1 WAE)	0.09	0.07	Y=19.2 - 0.13 (seed size)
late stand density (2 WAE)	0.002	0.22	Y=23.6 - 0.29 (seed size)

Kinston 2008			
Dependent variable	p value	R^2	predicted equation
leaflet width	0.0005	0.27	Y=3.2 + 0.09 (seed size)
leaflet length	NS		
petiolule length	NS		
petiole length	NS		
node count	NS		
early height (3 WAE)	< .0001	0.65	Y=3.9 + 0.24 (seed size)
late height (7 WAE)	< .0001	0.31	Y=29.2 + 0.38 (seed size)
early stand density (1 WAE)	NS		
late stand density (2 WAE)	0.10	0.07	Y=40.3 - 0.22 (seed size)

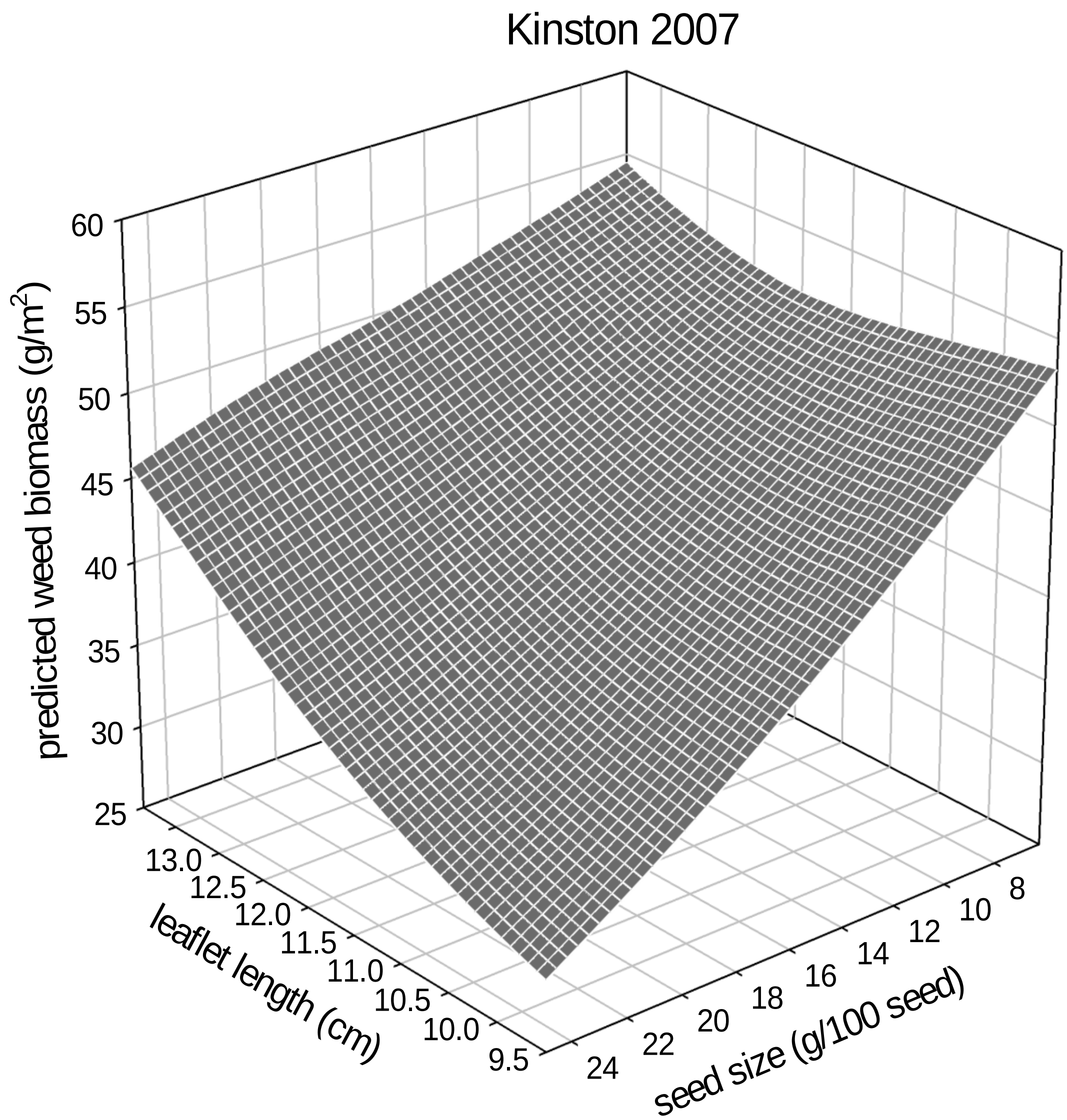

Figure 1. Seed size and leaflet length effect on model predicted weed biomass for Kinston 2007. Model $R^2 = 0.37$. The model predicted weed biomass (g/m^2) = 0.29 + 0.01(leaflet length (cm)) – 0.003 (seed size (g/100 seed)).

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Chapter 4

Effects of Soybean Seed Size on Weed Competition

Introduction

The acreage of organic soybean is increasing as the organic milk, beef and egg markets grow each year (Dimitri 2008; Paulson 2006). Farmers making the transition to organic soybean production cite weed management as their top challenge (Cavigelli et al. 2008; Walz 1999). Without the use of herbicides as a management option, organic producers must rely on a variety of tactics to reduce weed pressures (Liebman and Gallandt 1997). Increasing soybean competitiveness is one such supplemental weed management tactic. Competitiveness of soybean can be increased with cultural practices such as: later planting date (Gunsolus 1990), narrow row spacing (Nice et al. 2001; Reddy 2002), increased seeding rate (Norsworthy & Shipe 2006; Place et al. 2009), and cultivar selection (Rose et al. 1984). Larger seed size may also increase the competitiveness of soybean.

The influence of seed size within a genotype has been demonstrated in various crop species. Germination rate and seedling vigor increased with the increase of seed size in rice cultivars (Roy et al. 1996). Minor differences in germination time and percentage due to seed size were shown within cultivar in oat (Willenborg et al. 2005). Wheat plants derived from larger seed were shown to produce more biomass and yield (Stougaard & Xue 2004).

Sorghum plants derived from larger seed had increased height, leaf area, biomass and yield compared to plants from smaller seed (Rao et al. 1999).

Previous research indicates that increased soybean seed size positively affects various growth parameters. Larger soybean seed resulted in a larger embryo (Burris et al. 1971) and cotyledonary area increases (Burris et al. 1973). Larger seed were also found to produce seedlings with greater heights than small seed seedlings, with the trend lasting up to 6 weeks after emergence (WAE) (Burris et al. 1973). Large soybean seed were superior to smaller seed in seedling shoot and root mass (Longer et al. 1986). Larger soybean seed at planting also resulted in more seed yield and branches at maturity (Fontes and Ohlrogge 1972). Soybean progeny from large seed produced more yield than those from small seed when both seed sizes were planted in the same row (Smith and Camper 1975). All of these studies were conducted in the absence of weeds. No research has been conducted to investigate the effect of within soybean genotype seed size on competitive ability with weeds.

The influence of seed size at planting on the competitiveness of a subsequent soybean canopy must arise through a change in plant morphology. Canopy traits that impart weed competitiveness for soybean may include: height (Jannink et al. 2000), leaf area (Jordan 1993), and various leaf characteristics (Guneyli et al., 1969). The relation of such traits to competitive ability is likely to be very dependent on the growth stage. Traits of interest for increased competitiveness with weeds should be investigated early in the season when plants are establishing competitive dominance. The critical period for weed competition is defined as the interval in the life cycle of the crop when it must be kept weed free to prevent yield loss (Zimdahl 1980; Van Acker et al., 1993). This period for soybean is variable depending on environmental conditions (Van Acker et al., 1993) but has been estimated between the stages V2 and V8 (Eyherabide et al., 2002) which occur at approximately 2 and 7 weeks after emergence. To study the competitive outcome between soybean and weeds, the first 7 weeks are critical. Pigweed (*Amaranthus retroflexus* L.) is particularly competitive with soybean with an average soybean seed yield reduction of 22% at a pigweed density of 16 plants per 10 m of row (Shurtleff and Coble 1985).

The objectives of this study were to evaluate how soybean seed size affects canopy traits during the critical period for weed competition. Additionally, this study investigated whether the changes in soybean canopies would increase competitiveness with weeds. The weed competitiveness effect of seed size was tested within three popular conventional soybean cultivars: 'Hutcheson', 'NC-Roy' and 'NC-Raleigh' of maturity group (MG) V, VI, and VII, respectively (Burton et al., 2005, 2006; Buss et al., 1998). We hypothesized that larger seed would result in changes in early soybean canopy traits that would reduce pigweed growth and increase soybean biomass.

Materials and Methods

Soybean seed classes were separated for the cultivars Hutcheson, NC-Roy, and NC-Raleigh by passing 68 kg of unsorted seed for each cultivar through 7.15 mm, 6.75 mm, 6.35 mm, 5.95 mm, 5.55 mm and finally 5.15 mm screens. Soybean remaining on the screen surface were grouped into a size class (Table 1). Three random subsamples of 100 seed for each size class of each cultivar were collected, weighed and tested for germination by wrapping equally spaced soybean seed in moist germination paper and placing in humidity chambers set at 30˚ C for one week (Table 1).

Soybean were planted at the Kinston Research Station in Kinston, NC on May 22, 2007 on a Kenansville Loamy Sand (siliceous, subactive, thermic Arenic Hapludults) and on May 21, 2008 on a Pocalla Loamy Sand (siliceous, subactive, thermic Arenic Plinthic Paleudults). Planting at the Tidewater Research Station in Plymouth, NC occurred on May 23, 2008 on a Cape Fear Loam. Experimental plots consisted of 3 rows 3.96 m long with 96.5 cm between rows. A John Deere MaxEmerge planter with rotating cones above each planting unit was utilized to achieve a uniform seeding rate of 39 live seed m^{-1} based on germination tests. Testing at this higher seeding rate was conducted based on recommendations for improved weed control in organic soybean production (Place et al. 2009)

Weedy plots were overseeded with redroot pigweed (*Amaranthus retroflexus* L.) seed immediately after soybean planting to increase weed pressure uniformity. Weed free plots were treated with alachlor at 5.84 L ai ha^{-1} immediately following soybean planting and maintained weed free with weekly hand weeding. Between row weeds for both weedy and weed free plots were destroyed with a Sukup 9400 cultivator (Sukup Manufacturing Company; Sheffield, Iowa) at 4 and 7 weeks after emergence (WAE), leaving only the weeds within 10 cm of the crop row in the weedy plots. At 1 and 4 WAE, sethoxydim with crop oil adjuvant was sprayed over the entire trial at 1.75 L ai ha^{-1} to limit weed presence to broadleaf weeds for more uniform weed pressures.

The following measurements were taken in the weed free plots over the 7 week period following soybean emergence to quantify canopy characteristics. Stand counts were taken at 1 and 3 WAE. Soybean height was measured at 3 and 7 WAE in 2007 and 3, 4, 5, 6, and 7 WAE in 2008 in weed free plots on 4 randomly selected soybean plants plot^{-1}. At 3 WAE (early) and 5 WAE (late), percent ground cover was estimated in weed free plots using digital photography images and pixel analysis. Photos were taken with a Canon PowerShot A360 Digital Camera (8.0 mega pixels) using a custom built camera stand which was centered over the middle row of each weed free plot. Plots were shaded during photography to avoid shadow effects in image processing. The digital image size was 1.37 m wide and 1.87 m of the row, capturing approximately 70 plants. In 2007, images were processed with Adobe Photoshop 5.0 to convert soybean canopy to black pixels and visible ground to white pixels. A Javascript pixel counting software as described by Stewart et al. (2007) was then utilized to estimate the percent canopy coverage from the ratio of black pixels to the total number of black and white pixels. In 2008, images were processed utilizing SigmaScan Pro with a macro language software for batch analysis as described by Karcher and Richardson (2005) with the hue settings from 47 to 107 and the saturation setting from 10-100. Leaf petiole length, leaflet length and leaflet width were measured on the 3rd most fully expanded leaf at 4 WAE. At 7 WAE node number was measured.

At 7 WAE, an area 0.36 m wide and 3.05 m long of the center row of each weedy and weed free plot was harvested using a Haldrup forage plot harvester. Weeds and soybean plants were separated by hand in weedy plots. Fresh weight biomass was taken for the entire harvest area. Biomass was sub-sampled, dried and weighed to estimate biomass moisture percentage.

Experimental design consisted of soybean cultivar and weed management as stripped main plot factors and seed size as the sub-plot factor. Main plots were randomized within blocks and subplots were randomized within main plots. Each soybean cultivar consisted of four or five seed classes. Each seed class consisted of two levels of weed management, weedy and weed free, which were stripped across the block to allow for consistent herbicide application and weed seed overseeding. One location was planted in 2007 and two locations were planted in 2008, with 9 replications at each location.

Statistical analysis was conducted using SAS 9.1 with Kinston 2007, Kinston 2008, and Plymouth 2008 treated as 3 separate environments. Environmental effects were significant for soybean biomass (Table 2) and weed biomass (Table 3), thus biomass and canopy coverage results are reported by separate environments. Linear regression of mean soybean and weed biomass and soybean canopy coverage values on soybean seed sizes was conducted for each environment. Leaf petiole length, leaflet width, leaflet length, and node count were pooled over all three environments. Soybean height data was pooled over Kinston 2008 and Plymouth 2008 (weekly interval measurements did not occur in 2007). Square root transformation was utilized for analysis of weed biomass data, while all other dependent variables met model assumptions. Least squares mean values were utilized for reporting of treatment means. Linear, quadratic and lack of fit contrasts were done to test the effect of seed size on all dependent variables.

Results and Discussion

Stand densities were slightly affected by seed size (data not shown) even though seeding rates for each seed size class were adjusted to 39 live seed m^{-1} based on germination tests. However, detected effects showed that neither the smallest nor largest size class resulted in an emergence advantage. Burris et al. (1971) found that larger soybean seed resulted in a larger embryo, however, their results suggested that smaller seed may result in greater emergence and shoot growth. Similarly, smaller soybean seed were shown to have faster emergence and greater root development than larger seed (Edwards and Hartwig 1971). Edwards and Hartwig hypothesized that such a rapid emergence would result in a more uniform stand, a critical quality for crop competitiveness. However, Johnson and Luedders (1974) found no seed size effect on soybean emergence. Our results did not detect an emergence advantage for smaller seed.

Early canopy percent ground cover estimation from the overhead imaging was affected by seed size in all three environments (Figure 1). This digital imaging technique was previously found by Stewart et al. to have a strong relationship ($R^2 = 0.74$) with measured leaf area index (LAI). Early images were taken between V1 and V2 growth stages of the soybean and were a good indication of early seedling vigor. The importance of early vigor in competitive ability has been previously shown (Callaway 1992; Caton et al. 2003; Guneyli et al., 1969; Zao et al. 2006). The effect of seed size on soybean canopy coverage was stronger at 3 weeks after emergence (R^2=0.69, R^2=0.50 and R^2=0.70 in Kinston 2007, Kinston 2008, and Plymouth 2008 respectively) than at 5 weeks after emergence (R^2=0.42, R^2=0.23 and R^2=0.37 in Kinston 2007, Kinston 2008, and Plymouth 2008 respectively). (Figure 2).

The influence of seed size on measured leaf traits was only detected for petiole length. The linear relationship of larger seed class and longer petiole (Table 4) showed a 7% petiole length advantage for the largest seed class compared to the smallest seed class across all environments and cultivars. A previous study found larger seed classes in soybean were positively correlated (correlation coefficient = 0.69) with petiole diameter (Oexemann 1942). This may be one contributing effect to the larger percent of canopy ground cover and weed suppression.

Larger seed sizes also resulted in taller soybean canopies. Repeated measures analysis on soybean height data in Kinston and Plymouth 2008 showed that height curves over 5 weeks differed between seed size classes and cultivars (Table 5). Figure 3 shows the increasing slope of height growth as seed size increases across cultivars and environments in 2008. In Kinston 2008, the percent height advantage for the larger seed class compared to the smallest seed class was greatest for Hutcheson, NC-Roy, and NC-Raleigh at the earliest measurement (26% taller, 36% taller and 33% taller, respectively) and dissipated with each subsequent measurement (15% and 9% taller for NC-Roy and NC-Raleigh at 7 WAE; while no seed size effect was detected at this growth stage for Hutcheson). In Plymouth 2008, the largest height advantage from increased seed size was measured at 3 WAE (37% taller), 5 WAE (36% taller), and 4 WAE (35% taller) for Hutcheson, NC-Roy, and NC-Raleigh respectively. At 7 WAE, the largest seed class for Hutcheson, NC-Roy, and NC-Raleigh had a canopy 17%, 18%, and 19% taller, respectively, than the smallest seeded soybean canopy.

In one of the only other investigations of seed size class influences on soybean height, seed size was well correlated with soybean height. Oexemann (1942) showed the correlation was strongest at 2, 3, and 4 WAE (correlation coefficients = 0.662, 0.494, and 0.576 respectively), dissipated at 5 and 6 WAE (correlation coefficients = 0.45 and 0.24 respectively) and disappeared at 7 WAE (correlation coefficients = -0.17) (Oexemann 1942). Our results and previous findings show that the influence of seed size may be strongest during the critical period for weed competition but dissipates following canopy closure. However, even at initiation of canopy closure (7 WAE), the effect of seed size on height was detected in most cases. In competition with weeds for light, height is a critical trait (Begonia et al. 1991). Reduction of weed biomass has been demonstrated to be directly related to soybean height (Shilling et al. 1995). Bussan et al. (1997) found no relationship between soybean height and weed biomass but the poor relationships were due to large variation in trial weed density. Jannink et al. (2000) found soybean height at 7 WAE to be a good indicator of weed competitiveness.

A significant influence of seed size on weed free soybean biomass was detected in two of the three environments (Figure 4). The largest seed class in Hutcheson resulted in a dry soybean biomass advantage of 6%, 6% and 24% compared to the smallest seed class in Kinston 2007, Kinston 2008 and Plymouth 2008 respectively. The seed class advantage for soybean NC-Roy in the presence of weeds was 9%, 12% and 18% compared to the smallest seed class in Kinston 2007, Kinston 2008 and Plymouth 2008 respectively. NC-Raleigh biomass advantage was 26%, 19% and 21% in Kinston 2007, Kinston 2008 and Plymouth 2008 respectively.

The influence of seed size on soybean biomass was stronger with the presence of weed competition (Figure 5). The linear relationship of increased soybean biomass in weedy conditions with larger seed size was significant in all environments. The largest seed class in Hutcheson resulted in a dry soybean biomass advantage of 9%, 36% and 27% compared to the smallest seed class in Kinston 2007, Kinston 2008 and Plymouth 2008 respectively. The seed class advantage for soybean NC-Roy in the presence of weeds was 23%, 20% and 18% compared to the smallest seed class in Kinston 2007, Kinston 2008 and Plymouth 2008 respectively. NC-Raleigh biomass advantage was 58%, 21% and 19% in Kinston 2007, Kinston 2008 and Plymouth 2008 respectively.

Weed biomass reductions due to larger soybean seed were also detected. Significant linear relationship of decreased weed biomass in soybean grown from larger soybean seed size was detected in the Kinston 2007 and 2008 environments where pigweed populations were most dense and vigorous. Pigweed populations in Plymouth 2008 were sparse, resulting in the absence of an effect of soybean seed size on weed biomass. The largest seed class in Hutcheson resulted in a weed biomass reduction of 22% and 37% compared to the smallest seed class in Kinston 2007 and Kinston 2008 respectively (Figure 6). The seed class advantage for soybean NC-Roy resulted in a weed biomass reduction of 15% compared to the smallest seed class in both Kinston 2007 and Kinston 2008. NC-Raleigh resulted in a weed biomass reduction of 16% and 27% in Kinston 2007 and Kinston 2008 respectively. Although previous research in soybean seed size effects on competitiveness with weeds is lacking, the competitive effect of seed size classes within wheat varieties has been investigated. Xue and Stougaard (2006) showed that wild oat density and biomass decreased when spring wheat was established from large seed compared to small seed. It was also shown that larger seed in the spring wheat varieties resulted in more crop spikes, biomass and yield (Stougard and Xue 2004). Large seeded winter wheat was shown to reduce jointed goatgrass biomass compared to small seeded wheat from the same genotype (Yenish and Young 2004).

Photosynthetic advantage from greater ground cover combined with increased soybean height may explain the soybean biomass advantage imparted by larger seed even in the absence of weed competition. Increased soybean height and leaf area was shown to be significantly associated with interception of photosynthetically active radiation during vegetative growth (Wells et al. 1993; Wells 1991). With dense weed pressures, larger soybean seed size resulted in less weed biomass. Our results suggest that the larger seed size competitive advantage may be due to the increases in early canopy coverage, height and petiole length. Because these effects dissipate later in the season they may not be of interest for producers without strong weed competition.

For soybean producers relying on integrated weed management and contending with difficult weed infestations, these results suggest that seed size sorting may serve as another weed management tactic. Several organic soybean producers save their own seed, thus such a sieving process may be cost effective. However, it has been shown that seed size-grading can result in more cracked seed (Illipronti et al. 2000). Further research is needed to ascertain if large scale soybean seed sieving would result in increased damage to seed.

Sources of Materials

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

Table 1. Soybean seed classes and germination rates for soybean cultivars Hutcheson, NC-Roy, and NC-Raleigh in 2007 and 2008.

Size Class (1-5)	Hutcheson	NC-Roy	NC-Raleigh	Hutcheson	NC-Roy	NC-Raleigh	Hutcheson	NC-Roy	NC-Raleigh
2007									
	g/100 seed			% of total seed lot			germination %		
1	11.2	10.8	10.7	5.0	13.4	10.7	92.0	100.0	97.0
2	14.2	13.1	13.6	14.0	33.5	29.7	98.0	98.0	100.0
3	17.2	15.4	16.1	44.5	38.0	49.7	98.0	98.0	100.0
4	20.2	18.1	18.9	25.4	15.0	10.0	100.0	99.0	98.0
2008									
	Hutcheson	NC-Roy	NC-Raleigh	Hutcheson	NC-Roy	NC-Raleigh	Hutcheson	NC-Roy	NC-Raleigh
	g/100 seed			% of total seed lot			germination %		
1	9.4	7.5	9.4	6.7	5.4	3.2	73.5	81.5	81.5
2	11.5	9.4	12.4	27.4	7.6	14.5	74.5	76.5	82.0
3	13.7	11.3	13.3	32.6	34.5	41.7	72.0	79.0	74.5
4	15.9	13.1	16.3	26.8	30.3	31.2	82.0	76.5	80.0
5	18.6	15.3	19.1	6.5	22.2	9.4	81.5	80.0	69.0

Table 2. Analysis of variance (ANOVA) on the dependent variable soybean biomass done with SAS general linear model to generate variance source degrees of freedom (DF), type three sums of squares (Type III), mean squares, F test values, and p value associated with the F test. Environment and experimental replications (rep) were tested as random factors. Soybean cultivar (cultivar), weediness and seed size class (class) were treated as fixed factors. The factor environment included Kinston 2007, Kinston 2008, and Plymouth 2008. Class was nested within environment due to differing seed size classes in 2007 and 2008.

Source	DF	Type III	Mean Square	F value	p value
environment	2	6.16	3.08	721.0	<.0001
rep(environment)	24	1.85	0.08	18.0	<.0001
cultivar	2	0.10	0.05	11.5	<.0001
environment*cultivar	4	0.04	0.01	2.4	0.0548
rep*cultivar(environment)	48	0.95	0.02	4.6	<.0001
weediness	1	1.64	1.64	383.8	<.0001
environment*weediness	2	1.36	0.68	158.5	<.0001
rep*weediness(environment)	24	0.16	0.01	1.6	0.0394
class(environment)	11	0.49	0.04	10.4	<.0001
cultivar*class(environment)	22	0.21	0.01	2.2	0.0016
rep*class(environment*cultivar)	252	1.70	0.01	1.6	<.0001
cultivar*weediness	2	0.00	0.00	0.2	0.8208
environment*cultivar*weediness	4	0.00	0.00	0.1	0.9818
weediness *class(environment)	11	0.04	0.00	0.9	0.4996
cultivar* weediness *class(environment)	22	0.04	0.00	0.5	0.9804

Table 3. Analysis of variance (ANOVA) on the dependent variable weed biomass done with SAS general linear model to generate variance source degrees of freedom (DF), type three sums of squares (Type III), mean squares, F test values, and p value associated with the F test. Environment and experimental replications (rep) were tested as random factors. Soybean cultivar (cultivar), and seed size class (class) were treated as fixed factors. The factor environment included Kinston 2007, Kinston 2008, and Plymouth 2008. Class was nested within environment due to differing seed size classes in 2007 and 2008.

Source	DF	Type III	Mean Square	F value	p value
environment	2	0.89	0.45	2228.0	0.0004
rep(environment)	24	0.22	0.01	46.7	0.0212
cultivar	2	0.00	0.00	1.1	0.4882
environment*cultivar	4	0.01	0.00	13.3	0.0714
rep*cultivar(environment)	48	0.21	0.00	21.5	0.0454
class(environment)	11	0.09	0.01	38.8	0.0254
cultivar*class(environment)	22	0.03	0.00	6.8	0.1361
rep*class(environment*cultivar)	245	0.39	0.00	8.0	0.1176

Table 4. Linear (L), quadratic (Q), and lack of fit (LOF) response of petiole length, leaflet width, and leaflet length characteristics measured at 4 weeks after emergence (WAE) and response of node count measured at 6 WAE to soybean seed size. Least squares mean values are pooled over environment and cultivar. NS = non significant effects.

Size Class (1-5)	Node Count	Petiole Length	Leaflet Width	Leaflet length
		— cm —	— cm —	— cm —
1	8.3	12.5	5.4	8.1
2	8.0	12.8	5.3	7.6
3	8.2	13.2	5.4	7.7
4	8.3	13.2	5.5	7.8
5	8.6	13.4	5.5	7.9
p value	NS	0.05 (L)	NS	NS

Table 5. Repeated measures analysis on dependent variable soybean height done with SAS mixed procedure to generate numerator degrees of freedom (Num DF), denominator degrees of freedom (Den DF), F test values, and p values associated with the F test. Sources of variance included: soybean cultivar (cultivar), seed size class (class), and weekly measurement intervals (time). The factor time represented the weekly height measurements from 3 to 7 weeks after emergence. Analysis conducted on data pooled from Kinston and Plymouth in 2008.

Source	Num DF	Den DF	F value	p value
cultivar	2	34	2.6	0.0874
class	4	197	33.6	<.0001
cultivar*class	8	197	1.7	0.1034
time	4	5	11.5	0.0100
cultivar*time	8	992	18.0	<.0001
class*time	16	992	2.6	0.0005
cultivar*class*time	32	992	0.7	0.9290

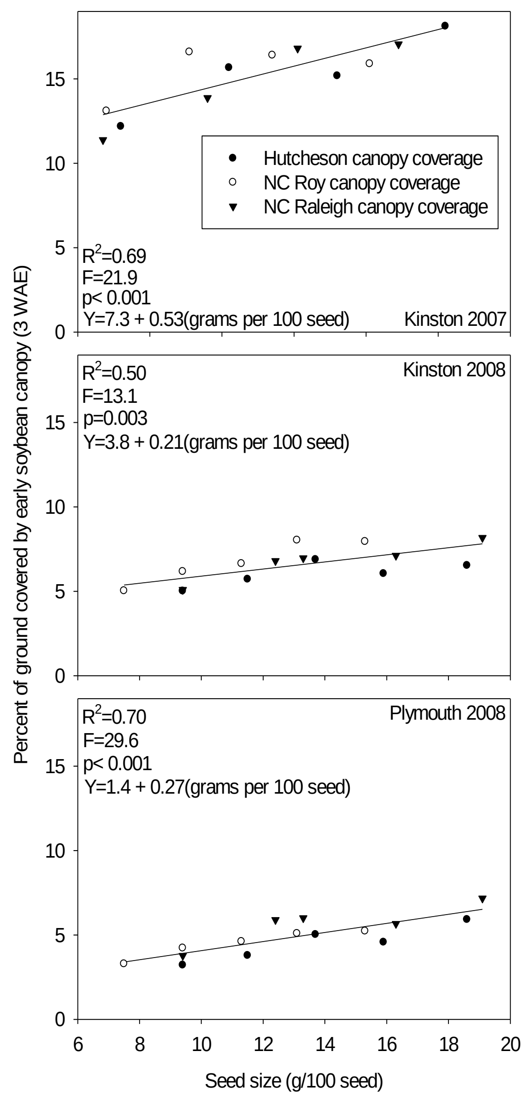

Figure 1: Linear regression of mean percent ground covered by early soybean canopy at three weeks after emergence (3 WAE) as affected by soybean seed size (g/100 seed) for the environments Kinston 2007, Kinston 2008, and Plymouth 2008. Each data point represents a mean value for nine replications.

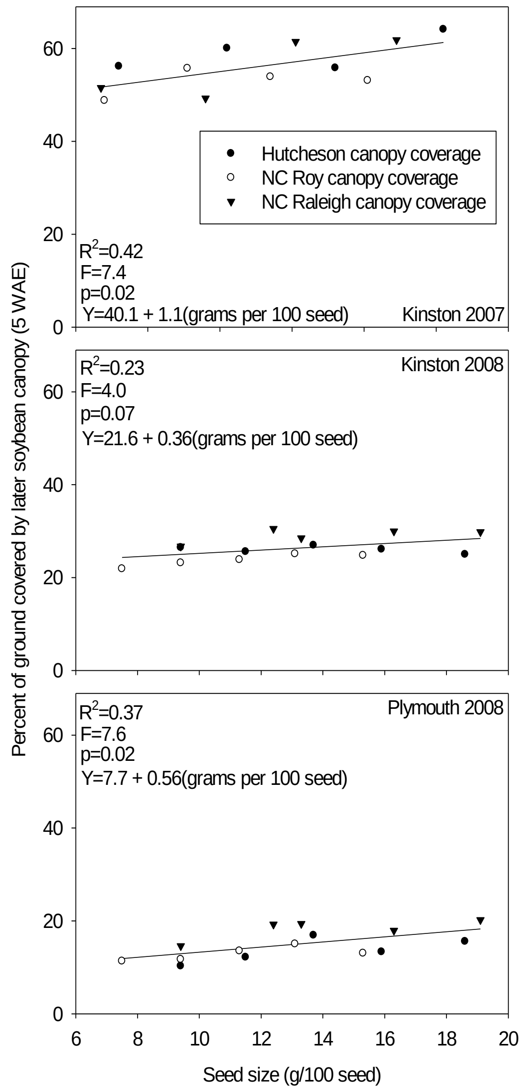

Figure 2: Linear regression of mean percent ground covered by later soybean canopy at five weeks after emergence (5 WAE) as affected by soybean seed size (g/100 seed) for the environments Kinston 2007, Kinston 2008, and Plymouth 2008. Each data point represents a mean value for nine replications.

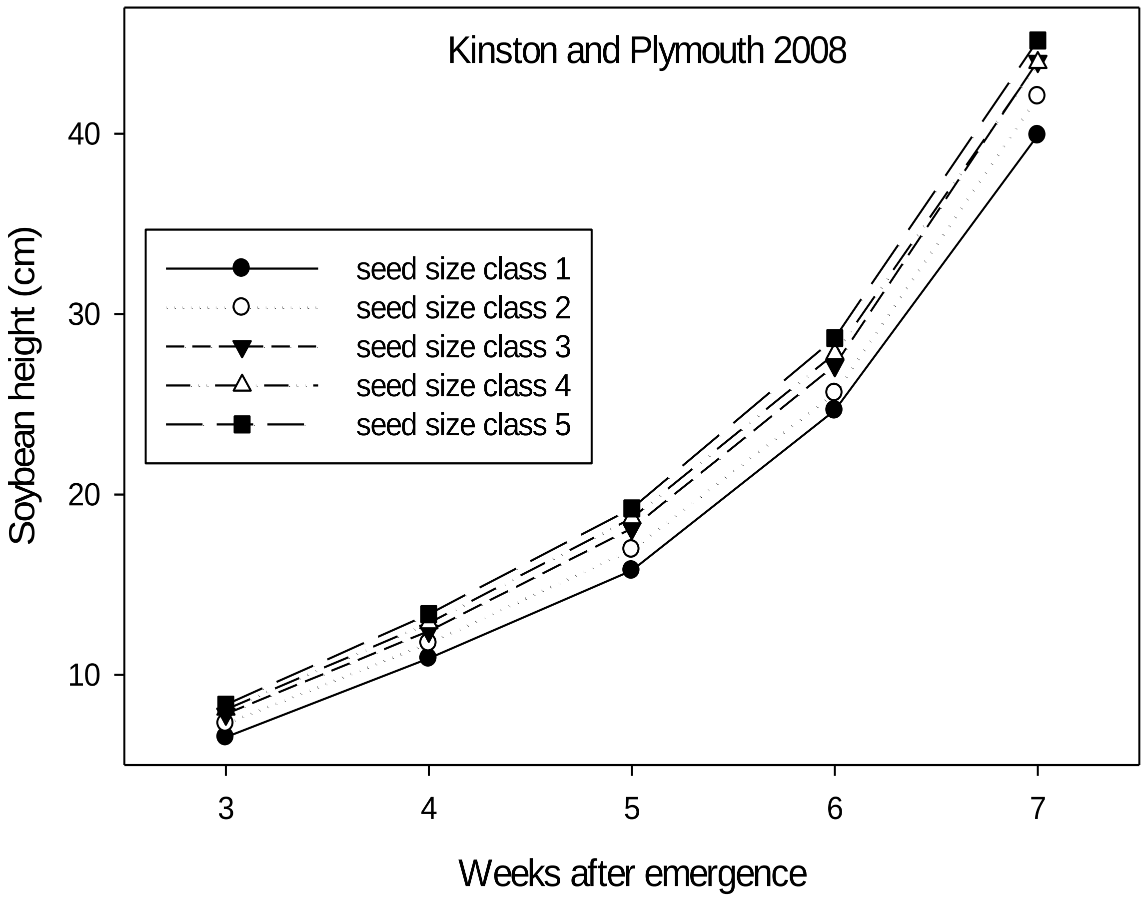

Figure 3: Soybean height change over 5 weeks for soybean seed size class 1 (9.4, 7.5, and 9.4 g/100 seed for Hutcheson, NC Roy, and NC Raleigh respectively), class 2 (11.5, 9.4, and 12.4 g/100 seed for Hutcheson, NC Roy, and NC Raleigh respectively), class 3 (13.7, 11.3, and 13.3 g/100 seed for Hutcheson, NC Roy, and NC Raleigh respectively), class 4 (15.9, 13.1, and 16.3 g/100 seed for Hutcheson, NC Roy, and NC Raleigh respectively), class 5 (18.6, 15.3, and 19.1 g/100 seed for Hutcheson, NC Roy, and NC Raleigh respectively),. Data are pooled over cultivar and two locations in 2008.

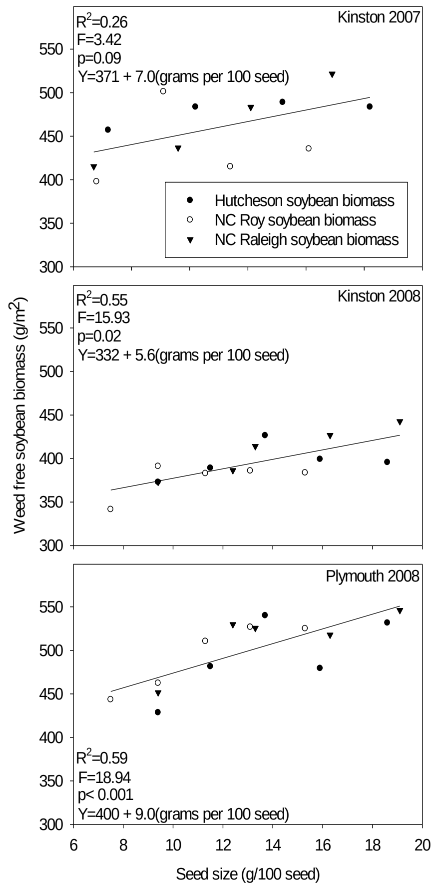

Figure 4: Linear regression of mean soybean biomass (g/m^2) at 7 weeks after emergence (WAE) in weed free conditions as affected by soybean seed size (g/100 seed) for the environments Kinston 2007, Kinston 2008, and Plymouth 2008. Each data point represents a mean value for nine replications.

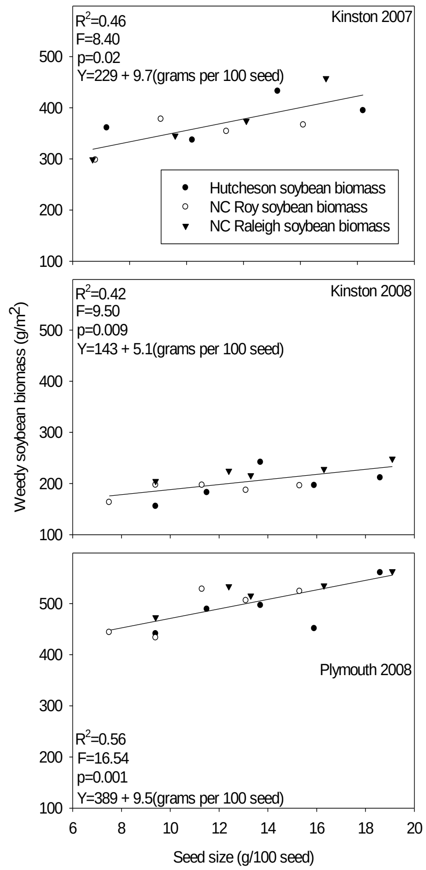

Figure 5: Linear regression of mean soybean biomass (g/m^2) at 7 weeks after emergence (WAE) in weedy conditions as affected by soybean seed size (g/100 seed) for the environments Kinston 2007, Kinston 2008, and Plymouth 2008. Each data point represents a mean value for nine replications.

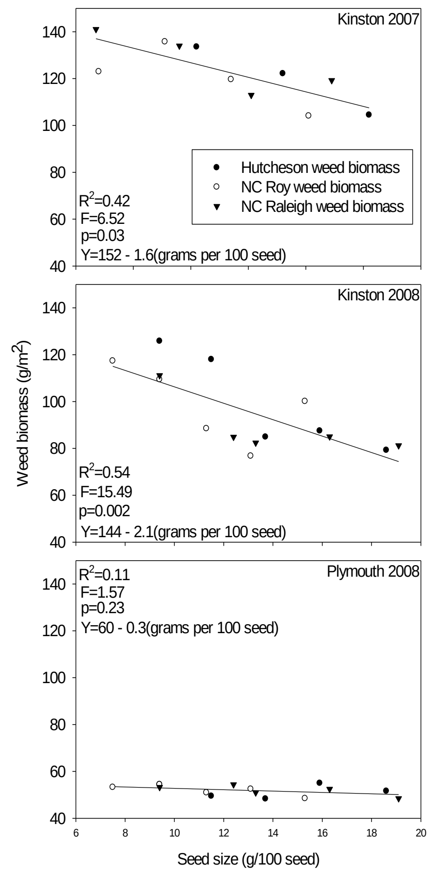

Figure 6: Linear regression of mean weed biomass (g/m^2) growing with soybean at 7 weeks after soybean emergence as affected by soybean seed size (g/100 seed) for the environments Kinston 2007, Kinston 2008, and Plymouth 2008. Each data point represents a mean value for nine replications.

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Chapter 5

Interaction of Planting Pattern, Weed Management Tactics and Cultivar in Peanut

Introduction

Peanut production in the Southeastern United States traditionally relies on PPI, PRE, and POST applied herbicides for weed management (Wilcut et al. 1995). Reliance on herbicide weed management systems can be costly and can lead to herbicide resistance concerns, while herbicide use is often recommended for maximum economic returns (Wilcut et al. 1995). Changes in federal farm legislation in recent years has led to peanut price fluctuations based on supply and demand pressures. Additionally, peanut farmers are interested in pest management strategies that are less expensive. Interest in marketing peanut organically has increased in recent years (Lamb 2007; Parker 2007). Peanut producers interested in reducing herbicide inputs or marketing organic peanut will require a greater reliance on non-herbicidal alternatives for weed management.

Low input weed management must rely on a multi-tactic approach (Liebman and Gallandt 1997). This approach includes optimal row spacing and plant population, mechanical weed control, hand weeding, and cultivar selection. Planting peanut in rows

spaced 20 cm apart improved weed control and increased yield by 20 to 50% compared to peanut planted in rows 81
cm apart (Buchanan and Hauser 1980). Buchanan and Hauser (1980) demonstrated that the yield advantage of rows spaced 20 cm compared to 81 cm apart increased with higher weed density. Johnson et al. (2005) demonstrated a 25% decrease in total weeds and 12% higher pod yield with peanut planted in rows spaced 30 cm apart compared with rows spaced 91 cm apart. Twin rows spaced 19 cm apart on 76 cm centers improved weed control of several weeds resulting in higher pod yield compared with single rows spaced 76 cm apart at equivalent per hectare seeding rate (Brecke and Stephenson 2006). Other research demonstrated (Besler et al. 2008; Lanier et al. 2004b) increased pod yield for peanut planted in twin row pattern compared to standard single rows. Planting peanut in narrow row spacings may be advantageous in low input or organic production systems.

Genotypic differences in the competitiveness with weeds have been identified for corn (*Zea mays* L) (Woolley and Smith 1986), cowpea (*Vigna unguiculata* L.) (Remison 1978), rice (*Oryza sativa* L.) (Haefele et al., 2004), soybean (*Glycine max* L.) (Jannink et al. 2000; Rose et al. 1984), wheat (*Triticum aestivum* L.) (Ramsel and Wicks 1988), and several other crops (Callaway 1992). Cultivar selection in combination with other tactics may improve weed control in peanut, especially in absence of herbicides.

Peanut grown for the organic market cannot be treated with seed treatments with fungicides to enhance seedling emergence and growth or insecticide to minimize damage from thrips. Optimum seed emergence and rapid early season seedling growth is important in minimizing weed interference and optimizing yield. Utilization of an appropriate combination of tactics that overcome these limitations in early season stand establishment will be important in developing strategies for organic peanut production.

Experiments were conducted in North Carolina to define interactions of peanut planting pattern, weed management system, and peanut cultivars on weed control, peanut yield, and estimated economic return.

Materials and Methods

Experiments were conducted in North Carolina from 2007 to 2009 at the Peanut Belt Research Station located near Lewiston-Woodville on a Norfolk sandy loam soil (fine-loamy, siliceous, thermic Typic Plaeudults) with pH 5.8 to 6.1 and 1.5 to 2.3% organic matter. Peanut was planted in early to mid-May on flat ground in a conventionally tilled seedbed. Plot size was 2 by 9 m with two non-treated border rows (91-cm spacing) separating each plot.

Treatments consisted of three levels of planting pattern (single rows spaced 91 cm apart, standard twin rows 18 cm apart on 91-cm centers, and narrow twin rows 18 cm apart on 46-cm centers), three levels of weed management (clethodim[1] applied postemergence, cultivation and hand removal of weeds, and clethodim with appropriate broadleaf herbicides applied postemergence), and two levels of cultivar (NC 12C and VA 98R). The cultivar NC 12C (Isleib et al. 1997), has an above-ground growth habit intermediate between bunch and runner habits. The cultivar VA 98R (Mozingo et al. 2000) has an above-ground runner growth habit. Insecticide was not applied to control tobacco thrips in this experiment.

Herbicide treatments varied considerably for each year. In 2007 and 2008 Field 1 the entire field (all treatments) was treated with a PPI application of pendimethalin[2]. No such blanket application was applied to the fields in 2008 Field 2 and in 2009 to allow treatment comparisons in higher grass weed densities. In 2007, conventional herbicide treatments included paraquat[3] plus bentazon[4] in early June followed by lactofen[5] plus 2,4-DB[6] two weeks later. In 2008 in Field 1, conventional herbicide treatments included bentazon plus acifluorfen[7] plus lactofen applied at mid June. In 2008 in Field 2, conventional herbicide treatments included imazapic[8] followed by clethodim applied POST in mid June. In 2009, conventional herbicide treatments included a PRE application of metolachlor[9] and POST applications of imazapic followed by clethodim applied in early June followed by lactofen applied in late June. Acifluorfen plus bentazon, bentazon, clethodim, imazapic, lactofen, metolachlor, paraquat, and pendimethalin were applied at 0.38 kg ai ha^{-1} + 0.56 kg ai ha^{-1}, 1.1 kg ha^{-1}, 0.14 kg ai ha^{-1}, 70 g ai ha^{-1}, 0.22 kg ai ha^{-1}, 1.7 kg ai ha^{-1}, 1.1 kg ai ha^{-1}, 0.14 kg ai ha^{-1}, and 1.1 kg ai ha^{-1} respectively. Acifluorfen plus bentazon was applied with nonionic surfactant[10] at 0.25% (v/v). Paraquat plus bentazon was applied with nonionic surfactant at 0.125% (v/v). Clethodim, imazapic, and lactofen were applied with crop oil concentrate[11] at 1.0% (v/v). Adjuvant was not utilized with metolachlor and pendimethalin. Herbicides were applied in 145 L ha^{-1} using regular flatfan nozzles[12] at 214 kPa.

Peanut was cultivated twice with a spring harrow cultivator on 91-cm centers in late May and early June in the planting patterns when POST herbicides were not included (referred to as the low input herbicide program). Although all plots in 2007 and Field 1 in 2008 received pendimethalin for general weed control, the plots that did not receive further herbicide treatments will be referred to as the low input treatment and plots that only received an additional treatment of clethodim will be referred to as the graminicide only treatment. Low input (single row and

standard twin row) plots were cultivated twice with a spring harrow cultivator in late May and early June. The low input managed narrow twin row plots were cultivated on 182-cm centers. Timed hand weeding in low input plots was implemented in late July 2007, Field 1 in 2008, and 2009. No hand weeding was conducted in 2008 Field 2 due to its ineffectiveness with a Texas panicum infestation. The graminicide only plots were treated with clethodim in early June as described previously. In 2008, Field 2 was treated with a second application of clethodim in mid July. With the exception of weed management practices and insecticide for tobacco thrips, all other production and pest management inputs were common across each test site and were based on North Carolina Cooperative Extension Service recommendations (Brandenburg 2009; Jordan 2009a 2009b; Shew 2009).

Percent ground cover was visually estimated for the most prevalent weeds 10 weeks after planting using a scale of 0 to 100 where 0 = weed not present and 100 = entire plot covered by each weed. In the 2007 location and the 2008 Field 1 location, dominant weeds were common lambsquarters, eclipta, and nodding spurge at a density of 1 to 3 plants m^{-2}, 1 to 8 plants m^{-2} , and 1 to 5 plants m^{-2}, respectively. In the 2008 Field 2, the dominant weeds were common lambsquarters, common ragweed, eclipta, nodding spurge, and Texas panicum at a density of 0 to 2 plants m^{-2}, 1 to 10 plants m^{-2} , 0 to 1 plants m^{-2}, 0 to 3 plants m^{-2} , and 0 to 40 plants m^{-2}, respectively. In the 2009 location, the dominant weeds were common lambsquarters, pitted morningglory, Texas panicum, and yellow nutsedge at a density of 0 to 3 plants m^{-2}, 1 to 10 plants m^{-2}, 0 to 15 plants m^{-2}, and 0 to 12 plants m^{-2} respectively.

Peanut was dug and vines inverted in late September or early October based on pod mesocarp color to optimize yield and market grade characteristics (Williams and Drexler 1981).

To effectively dig the narrow twin row pattern, a two row digger was modified by attaching a steel bar to both blades so that the entire plot width could be dug. Yield was adjusted to a final moisture of 8%.

Fixed and variable costs for production (Table 1) were estimated at $445 and $1202 per ha respectively (Brown 2009). Seed cost varied due to cultivar selection and planting pattern. When NC 12C was planted, seed costs in single rows, standard twin rows, and narrow twin rows were \$312 ha^{-1}, \$356 ha^{-1}, and \$534 ha^{-1} respectively. When VA 98R was planted, seeding costs for these respective planting patterns were \$249 ha^{-1}, \$296 ha^{-1}, and \$445 ha^{-1} respectively. Cultivation cost was \$39 ha^{-1} regardless of cultivar or planting pattern. Hand weeding costs varied by year and fields within year (Table 1). No hand weeding was conducted in 2008 Field 2 due to its ineffectiveness with a Texas panicum infestation. Hand weeding labor costs were estimated at $10 per hour with an overall average cost of \$121 ha^{-1}, \$264 ha^{-1}, \$0 ha^{-1}, and \$42 ha^{-1} in the 2007 site, 2008 Field 1, 2008 Field 2, and the 2009 site respectively. The graminicide only treatment (including a pendimethalin application in 2007 and 2008 Field 1) cost \$68 ha^{-1} in 2007 and Field 1 in 2008. Two applications of clethodim were required in the Field 2 2008 site making the cost

$106 ha^{-1}. One application of clethodim was applied in 2009 for a cost of $53 ha^{-1}. Conventional weed management costs were $116 ha^{-1}, $93 ha^{-1}, $117 ha^{-1} , and $116 ha^{-1} in the 2007 site, 2008 Field 1, 2008 Field 2, and 2009 site respectively. The low input weed management system (including a pendimethalin application in 2007 and 2008 Field 1) without handweeding costs were $104 ha^{-1}, in 2007 and Field 1 2008. The low input weed management for Field 2 in 2008 and the 2009 site required one clethodim spraying for a total cost of $132 ha^{-1}. Each herbicide application cost $9.88 ha^{-1}. Crop oil adjuvant additions were calculated as

$2.47 ha^{-1}. Peanut selling price was estimated at $0.60 kg^{-1}. Economic return was calculated for each treatment as: ($0.60 kg^{-1}) * (pod yield kg ha^{-1}) – (fixed + variable costs) – (seed and weed management costs).

The experimental design was a split plot treatment arrangement with 4 replications. Main plots consisted of cultivars and sub-plots included nine randomly positioned combinations of weed management and planting pattern.

Data for percent cover for individual weed species, low input management hand weeding times, peanut pod yield, and estimated economic return were subjected to analysis of variance by experiment for a two (cultivar) by three (weed management tactic) by three (planting pattern) factorial treatment arrangement using SAS[13]. Analysis by experiment was conducted due to the diversity in weed population and differences in PPI herbicides among experiments. The square root of visual estimates of percent ground coverage were arc sine transformed to meet analysis assumptions. All other data were analyzed without transformation. Means of significant main effects and interactions were separated using Fisher's Protected LSD test at $p \leq 0.05$.

Results and Discussion

Weed Control. Significant weed management effects were demonstrated in the percent cover by the dominant weed species in all cases except for eclipta in Field 2 in 2008 (Table 2). In 11 out of 15 of specific weed coverage effects, the low input and conventional weed management systems were not different in weed control. The low input weed management system was less effective than the conventional herbicide system in controlling eclipta in 2007 and pitted morningglory in 2009 but still more effective than the system with no broadleaf weed control (Table 3). Texas panicum was a dominant weed in Field 2 in 2008 and in 2009. Low input weed management was entirely ineffective in controlling this grass infestation in both cases.

Planting pattern main effects on weed control were detected for 4 of the 15 dominant weeds (Table 3). No differences were detected between twin and narrow twin row planting pattern in weed control. The narrow twin row planting pattern was superior to single row in eclipta control in 2008 Field 1 and pitted morningglory control in 2009. The standard twin row pattern was superior to single row planting pattern in nodding spurge control in 2008 Field 1 and Texas panicum control in the 2008 Field 2 site.

The only cultivar effect on weed control detected was on eclipta control in 2007 (Table 4). VA 98R plots on average had 25% cover by eclipta while NC 12C plots had only 14% cover by eclipta. VA 98R has a runner growth habit while NC 12C is an intermediate cultivar between a runner and bunch type growth habit with excessive vine growth (Jordan 2009). No interactions were detected for cultivar and weed management system or planting pattern regardless of weed species.

A significant interaction of weed management by planting pattern effect on percent common ragweed cover at the 2008 Field 2 site (Table 5) demonstrates an important difference between low input and conventional weed management systems. In conventional weed management, closer row spacing often results in more rapid canopy closure and less weed interference (Buchanan and Hauser 1980). Low input weed management often relies on secondary tillage. However, between row cultivation is limited in narrow twin rows; potentially reducing weed control and pod yield. These results suggest that in a low input weed management system for peanut, more rapid canopy closure from the narrow twin row planting pattern does not effectively compensate for the restricted cultivation. Lanier et al. (2004) concluded that twin row planting can improve weed control compared to single row planting but did not eliminate the need for herbicides to protect pod yield when sicklepod, *Senna obtusifolia* L., was the primary weed. The standard twin planting pattern may offer the optimal spacing for low input peanut weed control by allowing for a more competitive canopy while permitting cultivation. Although plot hand weeding time differences were not detected in the low input management, mean weeding time values also suggest a standard twin row advantage in 2007 and 2008 (Table 6).

Pod Yield. No weed management effects on pod yield were detected in 2007, 2008 Field 1 site, or 2009 (Table 7). Weed management main effects on pod yield were detected in the 2008 Field 2 site (Table 7) where conventional weed management resulted in 37% and 71% greater pod yield than the graminicide only and low input systems respectively (Table 8). The graminicide only treatment resulted in 54% greater pod yield than the low input system. As previously discussed, the reduced pod yield in the low input weed management system was due to the inability of mechanical cultivation to manage the Texas panicum infestation. Texas panicum can often become sod forming with a single plant producing over 800 tillers and covering a square meter in area (Wehtje et al. 1986). With such a spreading growth, Texas panicum was not killed by cultivation passes.

No differences were detected between standard twin row and narrow twin row planting patterns for pod yield in any of the sites (Table 8). Equivalent yield for peanut in narrow twin row and standard twin row concurs with previous investigations (Lanier et al. 2004). Yield differences due to planting pattern main effects were only detected in the 2008 Field 2 site (Table 7). With a dense Texas panicum infestation, both the standard and narrow twin row planting patterns, pooled across cultivar and weed management system, yielded higher than the single row pattern. The advantage of standard twin row in the low input weed management system was seen in the Texas panicum infested 2008 Field 2 site. A significant interaction of weed management system by row spacing effect on pod yield (Table 7) again demonstrated the importance of cultivation, which was inhibited by the narrow twin row planting pattern, for low input weed management. Although not statistically different, with low input weed management, twin row mean yield was 358% and 100% greater than the narrow twin and single row pod yield respectively (data not shown).

No difference between varieties was detected for yield (Table 7). Marois and Wright (2003) reported a differential pod yield between cultivars but the effect was not consistent. No interactions of weed management or planting pattern with cultivar selection were detected on pod yield. Other studies have shown management interactions with cultivar in pod yield (Culpepper et al. 1997; Jordan et al. 2003).

Economic analysis. In 2007 and 2009, no differences in economic return were detected between treatments (Table 9). In 2008 Field 1, the interaction of cultivar, row spacing and weed management on economic return showed the two profitable treatments to be the VA 98R graminicide treatment and the NC12C conventional herbicide treatment with both treatments planted in standard twin rows (Table 10). The low input weed management treatments resulted in the least profitability due to the high cost of hand weeding (Table 10). In Field 2 of 2008, main effects of variety, planting pattern, weed management, and a planting pattern by weed management interaction were detected for economic return (Table 9). In Field 2, conventional herbicide use was the most profitable weed management system (Table 11). The standard twin row was the most profitable planting pattern (Table 11). Cultivar VA 98R was the more profitable cultivar selection (Table 11). The planting pattern by weed management interaction showed that conventional weed management with use of standard twin rows was the most profitable system in Field 2 in 2008 (Table 12).

General conclusions from this investigation include the following: low input weed management in peanut can result in broadleaf weed control and yield similar to conventional weed management systems. However, handweeding costs in low input systems are not economically feasible in most cases. Further research is needed to investigate whether handweeding could be replaced by rotary hoeing, flex tine harrowing or another broadcast secondary tillage tactic. No weed control differences were detected between the standard twin row and narrow twin row planting pattern. Standard twin row planting pattern may often result in an economic advantage over the narrow twin row planting pattern due to reduced seeding costs. Standard twin row spacing is also advantageous in systems utilizing cultivation. Few differences were seen with cultivar selection, thus growers can focus on overall yield potential, insect and disease reaction, and market appeal rather than considering possible benefits of cultivars with respect to weed control.

Sources of Materials

[1]Select 2EC herbicide®. Valent USA Corporation, Walnut Creek, CA 94596.

[2]Prowl 3.3 herbicide®. BASF Corporation, Research Triangle Park, NC 27709.

[3]Gramoxone Inteon herbicide®. Syngenta Crop Protection, Greensboro, NC 27419.

[4]Basagran herbicide®. BASF Corporation, Research Triangle Park, NC 27709.

[5]Cobra 2EC herbicide®. Valent USA Corporation, Walnut Creek, CA 94596.

[6]Butyrac 200 herbicide®. Albaugh Inc., Ankeny, IW 50021.

[7]Storm herbicide®. BASF Corporation, Research Triangle Park, NC 27709.

[8]Cadre herbicide ®. BASF Corporation, Research Triangle Park, NC 27709.

[9]Dual Magnum herbicide®. Syngenta Crop Protection, Greensboro, NC 27419.

[10]Induce® nonionic surfactant. Proprietary blend of alkyl aryl polyoxyalkane ethers, free fatty acids, and dimothyl polysiloxane, 90%. Helena Chemical Company, Collierville, TN 38107.

[11]Agri-Dex® spray adjuvant. Proprietary blend of alkyl aryl polyoxyalkane ethers, free fatty acids, and dimothyl polysiloxane, 90%. Helena Chemical Company, Collierville, TN 38107.

[12]8002 Spray nozzles. Spraying Systems Company, Wheaton, IL 60189-7900.

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

Table 1. Production costs associated with weed management system, planting pattern, and cultivar selection.

Weed Management[a]	Planting Pattern[b]	Cultivar	Hand Weeding Costs[c] 2007	Hand Weeding Costs[c] 2008 Field 1	Hand Weeding Costs[c] 2008 Field 2	Hand Weeding Costs[c] 2009	Herbicide Program Costs[de] 2007	Herbicide Program Costs[de] 2008 Field 1	Herbicide Program Costs[de] 2008 Field 2	Herbicide Program Costs[de] 2009	Total Costs 2007	Total Costs 2008 Field 1	Total Costs 2008 Field 2	Total Costs 2009
			$\$ha^{-1}$											
Graminicide Only	Single Row	NC 12C	0	0	0	0	78	78	106	53	2037	2037	2065	2012
Graminicide Only	Single Row	VA 98R	0	0	0	0	78	78	106	53	1973	1973	2001	1949
Graminicide Only	Twin Row	NC 12C	0	0	0	0	78	78	106	53	2080	2080	2108	2055
Graminicide Only	Twin Row	VA 98R	0	0	0	0	78	78	106	53	2021	2021	2049	1996
Graminicide Only	Narrow Twin Row	NC 12C	0	0	0	0	78	78	106	53	2258	2258	2286	2233
Graminicide Only	Narrow Twin Row	VA 98R	0	0	0	0	78	78	106	53	2169	2169	2197	2144
Conventional	Single Row	NC 12C	0	0	0	0	116	93	117	116	2075	2052	2076	2075
Conventional	Single Row	VA 98R	0	0	0	0	116	93	117	116	2012	1989	2013	2012
Conventional	Twin Row	NC 12C	0	0	0	0	116	93	117	116	2119	2095	2120	2118
Conventional	Twin Row	VA 98R	0	0	0	0	116	93	117	116	2059	2036	2060	2059
Conventional	Narrow Twin Row	NC 12C	0	0	0	0	116	93	117	116	2296	2273	2297	2296
Conventional	Narrow Twin Row	VA 98R	0	0	0	0	116	93	117	116	2207	2184	2209	2207
Low Input	Single Row	NC 12C	143	223	0	40	25	25	53	53	2023	2023	2051	2051
Low Input	Single Row	VA 98R	45	416	0	51	25	25	53	53	1960	1960	1988	1988
Low Input	Twin Row	NC 12C	75	97	0	44	25	25	53	53	2067	2067	2095	2095
Low Input	Twin Row	VA 98R	158	252	0	36	25	25	53	53	2007	2007	2036	2036
Low Input	Narrow Twin Row	NC 12C	121	256	0	49	25	25	53	53	2245	2245	2273	2273
Low Input	Narrow Twin Row	VA 98R	185	338	0	31	25	25	53	53	2156	2156	2184	2184

[a]Low input weed management included cultivation and hand removal of weeds. Graminicide only treatment included a POST application of clethodim. Conventional weed management included POST applications of paraquat, bentazon, lactofen, and 2,4-DB in 2007; bentazon, acifluorfen and lactofen in Field 1 2008; imazapic and clethodim in Field 2 2008; and imazapic, clethodim, and lactofen in 2009.

[b]Single rows were spaced 91 cm apart, standard twin rows were spaced 20 cm apart on 91-cm centers, narrow twin row pattern including twin rows were spaced 20 cm apart on 46-cm centers.

[c]Handweeding labor costs were calculated as $10.00 hour^{-1}.

[d]Each herbicide application cost was estimated at $9.88 ha^{-1}.

[e]Crop oil adjuvant additions were calculated as $2.47 ha^{-1}.

Table 2. ANOVA F values on arc sine of the square root of weed percent coverage of eclipta, nodding spurge, common lambsquarters, common ragweed, Texas panicum, yellow nutsedge, and pitted morningglory.

	Eclipta			Nodding Spurge			Common Lambsquarters				Ragweed	Texas Panicum		Yellow Nutsedge	Pitted Morningglory
	2007	2008	2008	2007	2008	2008	2007	2008	2008	2009	2008	2008	2009	2009	2009
ANOVA Effects		Field 1	Field 2		Field 1	Field 2		Field 1	Field 2		Field 2	Field 2			
Cultivar	10.9*	1.3	0.4	0.1	0.7	0.0	0.5	0.6	0.4	1.0	0.1	0.5	0.8	2.3	1
Planting Pattern[a]	0.1	4.8**	0.0	0.4	5.2**	0.5	0.3	0.8	0.1	6.0	2.0	3.9*	0.2	2.2	6.0**
Weed Management[b]	29.2**	9.1**	1.4	4.4*	3.9*	5.2**	7.6**	3.1*	10.5**	22.1**	88.4**	160.4**	53.2**	16.9**	22.1**
Cultivar * Planting Pattern	1.3	0.2	1.3	0.1	1.4	0.2	0.0	0.9	0.9	0.5	1.1	0.5	0.6	0	0.5
Cultivar * Weed Management	0.8	1.2	2.6	0.9	1.7	0.3	1.6	1.3	0.4	1.2	2.4	0.6	2.4	0.5	1.2
Planting Pattern * Weed Management	2.4	2.0	1.0	0.3	1.1	0.2	0.8	0.7	0.6	1.2	2.6*	1.8	0.4	2.1	1.2
Cultivar * Planting Pattern * Weed Management	1.6	0.1	0.4	0.4	0.1	0.3	0.6	0.2	1.5	0.9	0.5	0.6	0.7	0.2	0.9
Coefficent of Variation (%)	56.0	136.8	470.3	70.0	78.9	192.2	167.7	165.5	125.7	83.3	49.8	58.7	85.0	146	83.3

[a]Single rows were spaced 91 cm apart, standard twin rows were spaced 20 cm apart on 91-cm centers, narrow twin row pattern including twin rows were spaced 20 cm apart on 46-cm centers.

[b]Low input weed management included cultivation and hand removal of weeds. Graminicide only treatment included a POST application of clethodim. Conventional weed management included POST applications of paraquat, bentazon, lactofen, and 2,4-DB in 2007; bentazon, acifluorfen and lactofen in Field 1 2008; imazapic and clethodim in Field 2 2008; and imazapic, clethodim, and lactofen in 2009.

* is significant at $p < 0.05$

** is significant at $p < 0.01$

Table 3. Mean values separated by Fisher protected LSD for yield and percent weed cover of eclipta, nodding spurge, common lambsquarters, common ragweed, Texas panicum, yellow nutsedge, and pitted morningglory.[a]

	Eclipta			Nodding Spurge			Common Lambsquarters				Common Ragweed	Texas Panicum		Yellow Nutsedge	Pitted Morningglory
Weed Management[b]	2007	2008 Field 1	2008 Field 2	2007	2008 Field 1	2008 Field 2	2007	2008 Field 1	2008 Field 2	2009	2008 Field 2	2008 Field 2	2009	2009	2009
	%														
Low Input	23 b	5 ab	0 a	26 ab	7 b	2 b	2 b	1 b	1 b	5 b	5 b	79 a	25 a	3 b	25 b
Graminicide Only	33 a	8 a	1 a	37 a	16 a	10 a	19 a	8 a	8 a	12 a	59 a	0 b	1 b	11 a	36 a
Conventional	4 c	0 b	0 a	13 b	6 b	1 b	2 b	5 ab	2 b	0 b	6 b	7 b	5 b	0 b	4 c
Planting Pattern[c]															
Single Row	20 a	8 a	0 a	23 a	15 a	3 a	8 a	6 a	3 a	7 a	29 a	36 a	10 a	7 a	30 a
Twin Row	18 a	4 ab	0 a	25 a	6 b	6 a	10 a	3 a	4 a	5 a	21 a	22 b	9 a	5 a	22 ab
Narrow Twin Row	21 a	2 b	0 a	29 a	8 ab	4 a	5 a	5 a	4 a	6 a	20 a	28 ab	11 a	3 a	13 b

[a]Means within a weed species and year followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p \leq 0.05$. Data are pooled over cultivar.

[b]Low input weed management included cultivation and hand removal of weeds. Graminicide only treatment included a POST application of clethodim. Conventional weed management included POST applications of paraquat, bentazon, lactofen, and 2,4-DB in 2007; bentazon, acifluorfen and lactofen in Field 1 2008; imazapic and clethodim in Field 2 2008; and imazapic, clethodim, and lactofen in 2009.

[c]Single rows were spaced 91 cm apart, standard twin rows were spaced 20 cm apart on 91-cm centers, narrow twin row pattern including twin rows were spaced 20 cm apart on 46-cm centers.

Table 4. Mean values and Fisher protected LSD for cultivar effect on eclipta percent weed cover. [a]

2007	Eclipta
	%
VA98R	25 a
NC12C	14 b

[a]Means within eclipta percent weed cover followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p < 0.05$.
Data are pooled over weed management and planting pattern.

Table 5. Mean values and Fisher protected LSD for common ragweed percent weed cover and yield.[a]

2008 Field 2	Common Ragweed			Yield		
	Single Row[b]	Twin Row[b]	Narrow Twin Row[b]	Single Row	Twin Row	Narrow Twin Row
	%			$kg\ ha^{-1}$		
Low Input[c]	3 c	4 b	9 b	790 ab	1580 bc	340 c
Graminicide Only[c]	73 a	56 a	48 a	1820 a	1860 b	2250 b
Conventional[c]	11 c	3 b	3 b	1770 a	3870 a	3710 a

[a]Means within common ragweed percent weed cover or yield followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p < 0.05$. Data are pooled over cultivar.

[b]Single rows were spaced 91 cm apart, standard twin rows were spaced 20 cm apart on 91-cm centers, narrow twin row pattern including twin rows were spaced 20 cm apart on 46-cm centers.

[c]Low input weed management included cultivation and hand removal of weeds. Graminicide only treatment included a POST application of clethodim. Conventional weed management included POST applications of imazapic and clethodim in Field 2 2008.

Table 6. Cultivar and row pattern main effect on mean hours ha^{-1} of hand weeding in low input weed management plots. [a]

Cultivar	2007	2008	2009
		hour ha^{-1}	
NC 12C	11.3 a	19.2 a	4.4 a
VA 98R	12.9 a	33.5 a	4.1 a
Planting Pattern[b]			
Single Row	9.4 a	31.9 a	4.5 a
Twin Row	11.6 a	17.4 a	4.2 a
Narrow Twin Row	15.3 a	29.7 a	4.0 a

[a]Means within a cultivar or planting pattern and year followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p < 0.05$.

Data are pooled over weed management.

[b]Single rows were spaced 91 cm apart, standard twin rows were spaced 20 cm apart on 91-cm centers, narrow twin row pattern including twin rows were spaced 20 cm apart on 46-cm centers.

Table 7. ANOVA F values on the effect of listed ANOVA sources on pod yield.

ANOVA Effects	Peanut Yield 2007	2008 Field 1	2008 Field 2	2009
Cultivar	0.1	0.3	3.1	1.9
Planting Pattern[a]	0.6	2.5	5.4**	1.4
Weed Management[b]	2.3	1.0	27.0**	2.9
Cultivar * Planting Pattern	0.0	0.8	0.2	0.5
Cultivar * Weed Management	0.4	1.2	1.1	1.6
Planting Pattern * Weed Management	0.9	0.5	3.9**	1.9
Cultivar * Planting Pattern * Weed Management	0.1	3.3	0.6	0.4
Coefficent of Variation (%)	23.1	40.8	52.2	32.8

[a]Single rows were spaced 91 cm apart, standard twin rows were spaced 20 cm apart on 91-cm centers, narrow twin row pattern including twin rows were spaced 20 cm apart on 46-cm centers.

[b]Low input weed management included cultivation and hand removal of weeds. Graminicide only treatment included a POST application of clethodim. Conventional weed management included POST applications of paraquat, bentazon, lactofen, and 2,4-DB in 2007; bentazon, acifluorfen and lactofen in Field 1 2008; imazapic and clethodim in Field 2 2008; and imazapic, clethodim, and lactofen in 2009.

* is significant at p< 0.05

** is significant at p< 0.01

Table 8. Mean values separated by Fisher protected LSD for yield.

Weed Management[b]	Yield 2007		2008 Field 1		2008 Field 2		2009	
	kg ha^{-1}							
Low Input	3310	a	2680	a	900	c	1810	a
Graminicide Only	2940	a	2500	a	1980	b	1850	a
Conventional	3360	a	2940	a	3120	a	2180	a
Planting Pattern[c]								
Single Row	3270	a	2320	a	1460	b	1790	a
Twin Row	3070	a	3010	a	2430	a	1970	a
Narrow Twin Row	3270	a	2800	a	2100	a	2080	a

[a]Means within yield followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p < 0.05$. Data are pooled over cultivar.

[b]Low input weed management included cultivation and hand removal of weeds. Graminicide only treatment included a POST application of clethodim. Conventional weed management included POST applications of paraquat, bentazon, lactofen, and 2,4-DB in 2007; bentazon, acifluorfen and lactofen in Field 1 2008; imazapic and clethodim in Field 2 2008; and imazapic, clethodim, and lactofen in 2009.

[c]Single rows were spaced 91 cm apart, standard twin rows were spaced 20 cm apart on 91-cm centers, narrow twin row pattern including twin rows were spaced 20 cm apart on 46-cm centers.

Table 9. ANOVA F values on economic return.

ANOVA Effects	Return			
	2007	2008 Field 1	2008 Field 2	2009
Cultivar	0.5	0.3	4.1*	2.7
Planting Pattern[a]	1.6	2.3	4.8*	0.2
Weed Management[b]	1.2	1.9	26.7**	2.8
Cultivar * Planting Pattern	0.0	0.7	0.3	0.6
Cultivar * Weed Management	0.3	0.0	1.1	1.6
Planting Pattern * Weed Management	0.8	0.5	4.1*	1.9
Cultivar * Planting Pattern * Weed Management	0.1	2.9*	0.6	0.4
Coefficent of Variation (%)				

[a]Single rows were spaced 91 cm apart, standard twin rows were spaced 20 cm apart on 91-cm centers, narrow twin row pattern including twin rows were spaced 20 cm apart on 46-cm centers.

[b]Low input weed management included cultivation and hand removal of weeds. Graminicide only treatment included a POST application of clethodim. Conventional weed management included POST applications of paraquat, bentazon, lactofen, and 2,4-DB in 2007; bentazon, acifluorfen and lactofen in Field 1 2008; imazapic and clethodim in Field 2 2008; and imazapic, clethodim and lactofen in 2009.

* is significant at $p < 0.05$

** is significant at $p < 0.01$

Table 10. Mean values and Fisher protected LSD for cultivar x planting pattern x weed management on economic return. [a]

2008 Field 1	VA 98R			NC12C		
	Single Row[b]	Twin Row[b]	Narrow Twin Row[b]	Single Row	Twin Row	Narrow Twin Row
	$\$ ha^{-1}$					
Low Input[c]	-1080 c	-230 abc	-450 abc	-780 abc	-640 abc	-1230 c
Graminicide Only[c]	-950 bc	160 abc	-780 abc	-170 abc	-990 bc	-820 abc
Conventional[c]	-390 abc	-380 abc	-480 abc	-980 bc	230 a	-70 abc

[a]Means within a cultivar followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p < 0.05$.

[b]Single rows were spaced 91 cm apart, standard twin rows were spaced 20 cm apart on 91-cm centers, narrow twin row pattern including twin rows were spaced 20 cm apart on 46-cm centers.

[c]Low input weed management included cultivation and hand removal of weeds. Graminicide only treatment included a POST application of clethodim. Conventional weed management included POST applications of bentazon, acifluorfen and lactofen in Field 1 2008.

Table 11. Main effect economic return.[a]

Weed Management[b]	Economic Return For 2008 Field 2
	$\$ \, ha^{-1}$
Low Input	-1570 c
Graminicide Only	-940 b
Conventional	-270 a
Planting Pattern[c]	
single row	-1160 b
twin row	-630 a
narrow twin row	-990 b
Cultivar	
VA98R	-780 a
NC12C	-1070 b

[a]Means within a weed species or yield followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p < 0.05$. Data are pooled over each of the three main effects.

[b]Single rows were spaced 91 cm apart, standard twin rows were spaced 20 cm apart on 91-cm centers, narrow twin row pattern including twin rows were spaced 20 cm apart on 46-cm centers.

[c]Low input weed management included cultivation and hand removal of weeds. Graminicide only treatment included a POST application of clethodim. Conventional weed management included POST applications of imazapic and clethodim in Field 2 2008.

Table 12. Mean values and Fisher protected LSD for economic return for 2008 Field 2. [a]

2008 Field 2	Single Row[b]	Twin Row[b]	Narrow Twin Row[b]
		$ ha -1	
Low Input[c]	-1550 cd	-1130 bc	-2020 d
Graminicide Only[c]	-950 bc	-970 bc	-900 b
Conventional[c]	-990 bc	210 a	-40 a

[a]Means within planting pattern and weed management followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p < 0.05$. Data are pooled over cultivar.

[b]Single rows were spaced 91 cm apart, standard twin rows were spaced 20 cm apart on 91-cm centers, narrow twin row pattern including twin rows were spaced 20 cm apart on 46-cm centers.

[c]Low input weed management included cultivation and hand removal of weeds. Graminicide only treatment included a POST application of clethodim. Conventional weed management included POST applications of imazapic and clethodim in Field 2 2008.

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Chapter 6

Influence of Genotype on Peanut Response to Weed Interference

Introduction

The organic industry is a rapidly expanding market, providing economic opportunities for some producers. The most rapidly expanding sector of the U.S. peanut industry is the organic peanut market (Lamb 2007; Parker 2007). In North Carolina, organic peanut buyers paid a price premium of \$1.76 to \$3.30 kg^{-1}, more than twice the price for conventional peanut (Guerena and Adam 2008). The organic peanut buyers in North Carolina obtained most of their organic peanut from New Mexico peanut producers (Guerena and Adam 2008). Peanut producers are unable to meet the demand for organic peanut. In 2005, there was an unmet need for almost 4000 metric tons of organic peanut in the U.S. (Culbreath 2005). One of the biggest challenges to organic peanut production is weed control (Organic Farming Research Foundation 2001).

Without herbicides as a management option, organic producers must rely on a diversity of tactics to reduce weed pressures (Liebman and Gallandt 1997). Utilization of more competitive peanut cultivars may improve weed management in addition to tactics such as cultivation and plant population. Cultivar selection is a strong component of disease (Shew 2009; Wynne et al. 1991a) and insect (Sharma et al. 2003) management programs in both organic (Branch and Culbreath 2008) and conventional systems (Shew 2009). A more competitive peanut cultivar could also be useful for conventional peanut producers interested in reducing reliance on herbicides.

Genotypic differences in competitiveness for weeds have been identified for several crops including corn (*Zea mays* L.) (Wooley and Smith 1986), cowpea (*Vigna unguiculata* L.) (Remison 1978), rice (*Oryza sativa* L.) (Haefele et al. 2004), wheat (*Triticum aestivum* L.) (Ramsel and Wicks 1988), and several others (Callaway 1992). Genetic differences have been found to exist between peanut genotypes in tolerance to weed interference (Agostinho et al. 2006; Hiremath et al. 1997) and ability to suppress weed growth (Fiebig et al. 1991). However, peanut genotype differences in competitiveness with weeds have rarely been investigated within virginia market type peanut genotypes grown in the mid-Atlantic U.S.

The objectives of this investigation were to determine if genetic differences exist between peanut genotypes in early season canopy ground cover, reduction of weed biomass, reduction of peanut biomass due to weeds, and reduction of peanut pod yield due to weeds.

Materials and Methods

Experiments were conducted in North Carolina during 2007 and 2008 at the Upper Coastal Plain Research Station located near Rocky Mount on a Goldsboro sandy loam soil (fine-loamy, siliceous, thermic Aquic Paleudults). Peanut was planted in mid-May in conventionally-tilled raised seedbeds in single rows spaced 91 cm apart at a seeding rate designed to achieve an in-row population of 4 plants m^{-1}. Plot length was 6 m. Two non-treated peanut rows separated plots. Aldicarb[1] was applied at 1.1 kg ai ha^{-1} in the seed furrow to control thrips (*Frankliniella spp.*). With the exception of weed control treatments, other management practices common for the region were utilized (Brandenburg 2009; Jordan 2009a 2009b; Shew 2009).

Eight peanut genotypes including the cultivars NC 10C (Wynne et al. 1991b), NC-V 11 (Wynne et al. 1991c), NC 12C (Isleib et al. 1997), Phillips (Isleib et al. 2006), and VA 98R (Mozingo et al. 2000) and the breeding lines N99027L (T. G. Isleib, personal communication), N01013T (T. G. Isleib, personal communication), and N02020J (T. G. Isleib, personal communication) (Table 1) were compared under weedy and weed-free conditions. Weed-free subplots were maintained with an early postemergence application of paraquat[2] at 0.14 kg ai ha^{-1} plus diclosulam[3] at 24 g ai ha^{-1} plus metolachlor[4] at 1.42 kg ai ha^{-1} plus nonionic surfactant[5] at 0.125% (v/v) 8 days after planting followed by clethodim[6] at 0.14 kg ai ha^{-1} plus crop oil concentrates[7] at 1.0% (v/v) in mid June. Additionally, weed escapes were removed by hand throughout the season. Natural weed infestations were left unmanaged in weedy subplots where weed and peanut biomass was determined. Weedy plots where peanut pod yield was determined were treated with clethodim at 0.14 kg ha^{-1} plus crop oil concentrates at 1.0% (v/v) in mid June to remove annual grasses. In all experiments, weed-free and weedy plots received a postemergence application of clethodim at 0.14 kg ha^{-1} plus crop oil concentrate at 1.0% (v/v) in mid June to limit natural weed infestations to broadleaf weeds. Herbicides were applied using a CO_2–pressurized backpack sprayer calibrated to deliver 145 L ha^{-1} using regular flatfan nozzles[11] at 214 kPa.

Estimations of canopy cover were recorded with overhead photography 4 and 8 weeks after planting (WAP) in weed-free plots. Images were recorded with a Canon PowerShot A360 Digital Camera[12] (8.0 mega pixels) using a custom built camera stand to center and level the camera 2 m above the middle row of each weed-free plot. Plots were shaded during photography to avoid excessive shadow effects in image processing. The digital image size was 1.37 m wide and 1.87 m of the row, capturing approximately 70 plants in the center row only. The digital images were processed with Adobe Photoshop 5.0[13] to convert soybean canopy to black pixels and visible ground to white pixels. A Javascript pixel[14] counting software as described by Stewart et al. (2007) was then utilized to estimate the percent canopy coverage from the ratio of black pixels to the total number of black and white pixels. Weedy peanut biomass, weed-free peanut biomass, and weed biomass were harvested by hand at 10 WAP. Fresh weight was determined, subsampled and oven dried at 70˚ C for 5 days to determine total dry biomass. Differences in weed biomass between genotypes was measured with the hypothesis that less weed biomass indicated a more competitive peanut genotype. Weed species density data were recorded 12 WAP in weedy yield subplots. Predicted percent yield loss due to weeds was estimated using the Herbicide Application Decision Support System[15] (HADSS). HADSS predicted yield loss is based on the population density and competitive index of the weed specie (Table 2).

Peanut were dug and vines inverted in early October for all test sites. Peanut were dug based on mesocarp color (Williams and Drexler 1981). The entire subplot width was dug and inverted. Peanut pods and vines air dried for approximately 1 week before threshing. Final pod yield was adjusted to 8% moisture. The HADSS yield loss estimation was compared with actual percent yield loss for each genotype. Differences between estimated yield loss and actual yield loss were determined with the hypothesis that a genotype resulting in less actual yield loss than predicted was indicative of a genotype with a greater tolerance to weed interference.

The experimental design was a split plot arrangement in a randomized complete block with eight replications. Main plots were peanut genotype and subplots consisted of weed-free yield (6.1 m of 2 rows), weedy yield (6.1 m of 2 rows), weed-free biomass (3.05 m of 1 row), and weedy biomass (3.05 m of 1 row).

Statistical analyses were carried out using the SAS[16] statistical analysis software package. Results were reported separately for 2007 and 2008 for canopy cover at 4 and 8 WAP, HADSS predicted yield loss due to weed species and density, weed free peanut biomass, weedy peanut biomass, weed biomass, peanut biomass reduction by weeds, weedy peanut yield, weed-free peanut yield, percent of weed-free yield reduced by weeds, and the difference in actual yield loss and HADSS predicted yield loss due to weeds. Separate year reporting was due to several significant year by genotype interaction effects on analyzed measurements (Table 3). Estimations of percent ground canopy cover at 4 and 8 WAP, HADSS predicted yield loss due to weeds, weedy and weed-free peanut biomass, weed biomass, peanut pod yield in weedy and weed-free conditions, actual percent of yield loss due to weeds, and differences in HADSS predicted losses vs. actual percent yield losses due to weeds were factors measured only in weed-free or weedy conditions and therefore only analyzed for the effect of year, genotype and year by genotype interactions (Table 3). Peanut biomass (Table 4) and peanut pod yield (Table 5) were measured in both weedy and weed free conditions and were additionally analyzed for the effect of management (weedy and weed-free conditions) and interactions of year and genotype with management. Means of significant main effects and interactions were separated using Fisher's Protected LSD test at $p \leq 0.05$.

Results and Discussion

Commercially available cultivars and breeding lines. Differences between genotypes were detected with overhead photography estimations of percent ground cover by canopy coverage at both 4 and 8 WAP (Table 6). Stewart et al. (2007) found that overhead photography was well correlated with leaf area index ($R^2 = 0.74$), a critical canopy characteristic for light competition (Gibson et al. 2003). However, increased canopy cover did not translate to improved weed suppression. The significant positive correlation between individual canopy coverage estimations and weed biomass suggests that weed biomass was increasing with more canopy coverage (Table 7). However, no significant correlation was detected between genotype mean values for canopy cover and weed biomass (data not shown), suggesting the individual values correlation may be spurious. Furthermore, no differences in weed biomass were detected between the genotypes (Table 8) and there was no significant interaction between genotype and management (weedy and weed-free conditions) (Table 4). The only indication of some variance between genotypes in tolerance to weed interference was in the difference between weedy and weed free biomass in 2008 (Table 8). The genotypes N01013T, N02020J, NC 10C, and Phillips showed differences in weed biomass due to weed presence, while the genotypes N99027L, NC 12C, NC-V 11, and VA 98R did not have a detectable difference between peanut biomass with and without weed interference. These findings could be interpreted as a possible variability within genotypes in tolerance to weed interference, but these differences were not consistently detected.

No differences were detected for the densities of the dominant weeds associated with the genotypes (Table 9). The presence of other weeds was variable across each location (data not shown), thus HADSS was utilized to estimate a yield percent loss due to overall weed interference associated with each genotype. No significant interaction was detected between genotype and management (weedy and weed-free conditions) for peanut pod yield (Table 5), suggesting little do no differences between the genotypes in yield response to weed interference. However, the differences between weed-free and weedy peanut pod yield were variable between genotypes. In 2007, NC 10C showed no significant difference in yield due to weeds (Table 10) and in 2008, N01013T, NC 10C, NC 12C, Phillips, and VA 98R showed no significant difference in yield due to weeds. Genotypes did not differ in the presence of weeds as shown by no differences in the HADSS predicted yield loss due to weeds associated with the genotypes (Table 10). Similarly, when comparing the yield loss percentage between genotypes, no differences were detected between the genotypes. The difference between the actual percent yield loss was compared with HADSS predicted yield loss percentage with the hypothesis that a larger difference between the predicted and actual yield loss might indicate a genotype more tolerant of weed interference. No such weed tolerant genotypes were detected (Table 8).

In the discussion of a competitive genotype, the term competition itself must be addressed. Competition can be examined from two perspectives: suppressiveness and tolerance. Suppressiveness is the ability of a plant to reduce the biomass and/or reproductive production of plants in close proximity to a greater than expected extent. Tolerance is the ability of a plant to endure the close proximity of other plants and have a less than expected decrease in biomass and/or reproductive production. In this series of experiments, it was hypothesized that an increased canopy percent ground cover would indicate an advantage in competition for solar radiation and result in a reduction in weed biomass. While some differences existed between cultivars and breeding lines in the ground canopy cover, there were no differences in weed biomass. It was also hypothesized that less than expected peanut yield loss due to weeds would indicate a peanut genotype tolerant to weed interference. The HADSS predicted percent yield loss due to weed species competitive indices and densities measured was consistently greater than the actual percent yield loss in weed-free and weedy comparisons. Yield loss prediction models have been demonstrated to overestimate yield loss due to weeds in some cases (Willis et al. 2006). This discrepancy was the same for all peanut genotypes tested, indicating no differences in weed tolerance.

Previous studies have suggested differences between peanut genotypes in their tolerance to weed competition. A research group in India reported differences in cultivar tolerance to weed competition. It was reported that the highest yielding peanut genotype in weed-free conditions yielded much less than other genotypes in weedy conditions (Hiremath et al. 1997). A Brazilian investigation showed weed tolerance differences between peanut cultivars in relation to the reduction of seed weight due to weeds (Agostinho et al. 2006). In another study, some peanut genotypes were better able to avoid reductions of dry matter caused by cocklebur (*Xanthium strumarium* L.) (Fiebig et al. 1991). The researchers concluded that late maturity seemed to increase the weed tolerance ability of a peanut genotype but that such a characteristic was not preferable for many peanut producers. Contrary to previous studies, results from our research suggest very little difference between genotypes in weed competitive ability. These results indicate that peanut cultivar selection does not seem to be a promising weed management tactic by itself.

Sources of Materials

[1]Temik 15G®. Bayer CropScience LP, Research Triangle Park, NC 27709.

[2]Gramoxone INTEON herbicide®. Syngenta Crop Protection, Greensboro, NC 27419.

[3]Strongarm Herbicide®. Dow AgroSciences, Indianapolis, IN 46268.

[4]Dual Magnum Herbicide®. Syngenta Crop Protection, Greensboro, NC 27419.

[5]Induce® nonionic surfactant. Proprietary blend of alkyl aryl polyoxyalkane ethers, free fatty acids, and dimothyl polysiloxane, 90%. Helena Chemical Company, Collierville, TN 38107.

[6]Select 2EC herbicide®. Valent USA Corporation, Walnut Creek, CA 94596.

[7]Agri-Dex® spray adjuvant. Proprietary blend of alkyl aryl polyoxyalkane ethers, free fatty acids, and dimothyl polysiloxane, 90%. Helena Chemical Company, Collierville, TN 38107.

[8]Prowl H_20 herbicide®. BASF Ag Products, Research Triangle Park, NC 27709-3528.

[9]Valor SX herbicide®. Valent USA Corporation, Walnut Creek, CA 94596.

[10]Cadre ®. BASF Corporation, Research Triangle Park, NC 27709.

[11]8002 Spray nozzles. Spraying Systems Company, Wheaton, IL 60189-7900.

[12]Canon PowerShot A360 Digital Camera (8.0 mega pixels), Canon 30-2, Shimomaruko 3-chome, Ohta-ku, Tokyo, 146-8501, Japan.

[13]Adobe Photoshop 5.0, Adobe Systems Incorporated, 345 Park Avenue, San Jose, CA 95110.

[14]PixelCounter 1.0, a Javascript software developed at North Carolina State University, Raleigh, NC 27695.

[15]HADSS™, "Herbicide Application Decision Support System," is a trademark of North Carolina State University and is distributed by AgRenaissance Software LLC, P.O. Box 68007, Raleigh, NC 27613, www.AgRenaissance.com.

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

Table 1. Characteristics of cultivars and breeding lines evaluated under weedy and weed free conditions.

Genotype	Market type	Growth habit	Seed weight
			—g 100 seed^{-1}—
N01013T	Virginia	bunch-runner	89
N02020J	Virginia	bunch-runner	98
N99027L	Virginia	bunch	86
NC 10C	Virginia	runner	80
NC 12C	Virginia	semi-runner	87
NC-V 11	Virginia	runner	83
Phillips	Virginia	semi-runner	85
VA 98R	Virginia	runner	86

Table 2. HADSS[a] individual competitive indices (CI) for dominant weeds counted at 12 weeks after planting.

Weed Species		
Common name	Latin binomial and authority	Competitive Index[b]
Redroot pigweed	*Amaranthus retroflexus* L.	4.0
Common lambsquarters	*Chenopodium album* L.	3.8
Common ragweed	*Ambrosia artemisiifolia* L.	5.2
Upright spurge	*Euphorbia serrulata* L.	1.2
Yellow nutsedge	*Cyperus esculentus* L.	0.3
Ivyleaf morningglory	*Ipomoea hederacea* L.	3.2
Pitted morningglory	*Ipomoea lacunosa* L.	3.6
Horsenettle	*Solanum carolinense* L.	1.1
Prickly sida	*Sida spinosa* L.	1.2
Eclipta	*Eclipta prostrata* L.	1.8
Sicklepod	*Senna obtusifolia* L.	3.6
Broadleaf signalgrass	*Urochloa platyphylla* L.	1.8
Large crabgrass	*Digitaria sanguinalis* L.	0.2

[a]HADSS™, "Herbicide Application Decision Support System," is a trademark of North Carolina State University and is distributed by AgRenaissance Software LLC, P.O. Box 68007, Raleigh, NC 27613, www.AgRenaissance.com.

[b] Competitive index scale ranges from 0.1 (least competitive) to 10.0 (most competitive) in estimating percent yield loss.

Table 3. Analysis of variance for the effect of year, genotype, and year x genotype on peanut canopy cover, peanut biomass, HADSS estimated yield loss due to weeds, peanut biomass, weed biomass, peanut yield in weedy and weed-free conditions, percent of weed-free peanut yield reduced by weeds, and difference in actual peanut yield loss and HADSS predicted yield loss at Rocky Mt., NC during 2007 and 2008. Analysis dependent variable genotype includes the cultivars and genetic lines N01013T, N02020J, N99027L, NC 10C, NC 12C, NC-V 11, Phillips, VA 98R.

	year		genotype		year x genotype	
ANOVA source	F-value	p-value	F-value	p-value	F-value	p-value
Canopy cover at 4 WAP	1787.17	<0.0001	12.69	<0.0001	12.57	<0.0001
Canopy cover at 8 WAP	6494.09	<0.0001	4.00	<0.0007	3.97	<0.0007
HADSS[1] predicted yield loss due to weed species and density	16.58	<0.0001	1.01	0.4312	0.45	0.8684
Weed-free peanut biomass	191.22	<0.0001	1.31	0.2553	1.15	0.3411
Weedy peanut biomass	5.71	0.0188	1.23	0.2963	0.92	0.4962
Weed biomass	75.16	<0.0001	1.63	0.1372	2.48	0.0222
Peanut biomass reduction by weeds	128.56	<0.0001	1.28	0.2694	1.38	0.2215
Weedy peanut yield	6.34	0.0134	5.15	<0.0001	1.20	0.3129
Weed-free peanut yield	1.28	0.2603	5.22	<0.0001	3.32	0.0033
Percent of weed-free yield reduced by weeds	8.95	0.0035	1.11	0.3637	2.04	0.0572
Difference in actual yield loss and HADSS predicted yield loss	1.12	0.2930	1.09	0.3735	2.51	0.0205

[1]HADSS™, "Herbicide Application Decision Support System," is a trademark of North Carolina State University and is distributed by AgRenaissance Software LLC, P.O. Box 68007, Raleigh, NC 27613, www.AgRenaissance.com.

Table 4. Analysis of variance for peanut biomass harvested at 10 weeks after planting at Rocky Mt., NC during 2007 and 2008. Analysis dependent variable genotype includes the cultivars and genetic lines N01013T, N02020J, N99027L, NC 10C, NC 12C, NC-V 11, Phillips, VA 98R. Management includes weedy and weed-free conditions.

	genotype	
ANOVA source	F-value	p-value
Year	141.72	< .0001
Genotype	1.56	0.1476
Year x Genotype	1.03	0.4114
Management	243.14	< .0001
Genotype x Management	0.88	0.5219
Year x Management	89.37	< .0001
Year x Genotype x Management	0.93	0.4859

Table 5. Analysis of variance for peanut pod yield at Rocky Mt., NC during 2007 and 2008. Analysis dependent variable genotype includes the cultivars and genetic lines N01013T, N02020J, N99027L, NC 10C, NC 12C, NC-V 11, Phillips, VA 98R. Management includes weedy and weed-free conditions.

	genotype	
ANOVA source	F-value	p-value
Year	0.92	0.3388
Genotype	9.28	< .0001
Year x Genotype	2.23	0.0332
Management	99.71	< .0001
Genotype x Management	0.81	0.5838
Year x Management	6.86	0.0095
Year x Genotype x Management	1.85	0.0786

Table 6. Digital imaging estimations of peanut canopy cover in weed-free conditions at 4 weeks after planting (WAP) and 8 WAP. [a]

	Peanut Canopy Cover			
	4 WAP		8 WAP	
Genotype	2007	2008	2007	2008
	% ground cover			
N01013T	10.5 a	6.5 a	62.4 bc	15.5 bc
N02020J	11.0 a	6.5 a	70.0 a	16.0 ab
N99027L	10.5 a	7.1 a	58.0 c	13.5 cd
NC 10C	12.7 a	7.5 a	70.5 a	15.0 bc
NC 12C	4.7 b	5.5 a	65.8 ab	12.0 d
NC-V 11	10.2 a	8.0 a	67.1 ab	17.3 ab
Phillips	11.4 a	8.4 a	68.2 ab	18.3 a
VA 98R	12.4 a	6.7 a	72.2 a	15.5 ab
CV	18.8	29.7	9.9	22.5

[a]Means within a year and measurement period followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p \leq 0.05$.

Table 7. Pearson correlation coefficients for digital image estimations of peanut canopy cover in weed-free conditions at 4 weeks after planting (WAP) and 8 WAP, weedy peanut biomass, weed-free peanut biomass, weed biomass, weedy peanut pod yield, and weed-free peanut pod yield. Each correlation coefficient is calculated from 128 variable comparisons (pooled across 8 genotypes, 8 reps, and 2 years).

	Image (4 WAP)	Image (8 WAP)	Weedy peanut biomass	Weed-free peanut biomass	Weed biomass	Weedy peanut yield	Weed-free peanut yield
Image (4 WAP)	1	0.9227 ***	0.2045 *	0.7663 ***	0.5466 ***	-0.1414	0.1186
Image (8 WAP)		1	0.2480 **	0.7852 ***	0.5844 ***	-0.1744 *	0.0903
Weedy peanut biomass			1	0.2892 **	-0.1611	0.1843 *	0.0995
Weed-free peanut biomass				1	0.6537 ***	-0.2255 *	0.1939 *
Weed biomass					1	-0.2361 **	0.2948 ***
Weedy peanut yield						1	0.2551 **
Weed-free peanut yield							1

*Correlation between two variables is significant with $0.01 < p \leq 0.05$.

**Correlation between two variables is significant with $0.001 < p \leq 0.01$.

***Correlation between two variables is significant with $p \leq 0.001$.

Table 8. Comparison of peanut biomass under weedy and weed-free conditions and weed biomass.[a]

	Peanut biomass				Weed biomass	
	2007		2008			
Genotype	Weed-free	Weedy	Weed-free	Weedy	2007	2008
	kg m^{-2}					
N01013T	0.84	0.44 ***	0.42	0.28 *	0.27 a	0.19 a
N02020J	0.75	0.34 **	0.39	0.25 ***	0.66 a	0.23 a
N99027L	0.74	0.39 ***	0.41	0.32	0.40 a	0.17 a
NC 10C	0.95	0.36 **	0.46	0.34 **	0.54 a	0.15 a
NC 12C	0.90	0.34 ***	0.42	0.31	0.74 a	0.15 a
NC-V 11	0.75	0.28 **	0.45	0.32	0.45 a	0.22 a
Phillips	0.98	0.35 ***	0.41	0.33 *	0.70 a	0.09 a
VA 98R	0.86	0.30 ***	0.40	0.23	0.50 a	0.19 a
CV					56.7	74.6

[a]Means within a year and measurement period followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p \leq 0.05$.

*Difference between weed-free peanut biomass and weedy peanut biomass is significant with $0.01 < p \leq 0.05$.

**Difference between weed-free peanut biomass and weedy peanut biomass is significant with $0.001 < p \leq 0.01$.

***Difference between weed-free peanut biomass and weedy peanut biomass is significant with $p \leq 0.001$.

Table 9. Weed species mean density associated with selected peanut cultivars and lines in 2007 and 2008 at Rocky Mt., NC. [a] Data are pooled over years.

Genotype	Redroot pigweed	Common lambsquarters	Jimsonweed	Ivyleaf morningglory
	species density 10 m^{-2}			
N01013T	27.6 a	7.9 a	5.8 a	7.6 a
N02020J	15.8 a	12.6 a	20.8 a	9.1 a
N99027L	6.9 a	9.5 a	4.3 a	8.0 a
NC 10C	27.0 a	13.0 a	4.4 a	9.5 a
NC 12C	35.7 a	14.1 a	5.3 a	8.4 a
NC-V 11	21.9 a	19.6 a	4.0 a	8.1 a
Phillips	12.4 a	5.8 a	4.4 a	7.8 a
VA 98R	17.3 a	17.1 a	5.2 a	8.1 a
CV	127.1	117.4	64.7	57.6

[a]Means within both years and measurement period followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p \leq 0.05$.

Table 10. Pod yield of selected cultivars and breeding lines under weed-free and weedy conditions in 2007 and 2008 at Rocky Mt., NC. HADSS[a] predicted percent yield loss is calculated based on the competitive index of each weed specie and its density associated with each peanut genotype. Yield % loss is calculated as [(weed-free peanut yield) - (weedy peanut yield)]/(weed-free peanut yield) * 100%. Difference between HADSS predicted yield loss and actual loss denote the difference between the HADSS predicted percent yield loss due to weeds and actual percent yield loss due to weeds.[b] HADSS differences denote the difference between the actual yield loss due to weeds and the yield loss predicted by HADSS.[a,b] Yield % loss is calculated as [(weed-free peanut yield) - (weedy peanut yield)]/(weed-free peanut yield) * 100%.

	Peanut yield				HADSS predicted yield loss		Yield % loss		HADSS difference	
	2007		2008							
Genotype	Weed-free	Weedy	Weed-free	Weedy	2007	2008	2007	2008	2007	2008
	yield kg ha^{-1}				%					
N01013T	3010	2320 **	2960	2610	67.2 a	63.3 a	21.6 a	10.6 a	45.6 a	52.7 bc
N02020J	2810	2000 *	3260	2540 *	68.6 a	58.6 a	27.3 a	21.1 a	41.3 a	37.5 ab
N99027L	3230	2640 **	3180	2470 ***	62.8 a	46.3 a	17.3 a	22.0 a	45.5 a	24.3 a
NC 10C	2620	2020	2780	2300	67.3 a	50.1 a	18.6 a	13.7 a	48.7 a	36.4 ab
NC 12C	2930	1930 ***	2320	2290	68.3 a	57.2 a	33.8 a	0.1 a	34.5 a	57.1 c
NC-V 11	3120	2730 **	3270	2670 **	65.7 a	57.6 a	12.2 a	18.6 a	53.5 a	39.0 abc
Phillips	3360	2670 **	2930	3000	65.8 a	40.5 a	19.3 a	-5.4 a	46.5 a	45.9 bc
VA 98R	3060	2460 *	2740	2440	65.5 a	51.6 a	19.0 a	8.5 a	46.5 a	43.1 bc
CV					13.5	45.2	68.4	202.1	35.5	43.9

[a]HADSS™, "Herbicide Application Decision Support System," is a trademark of North Carolina State University and is distributed by AgRenaissance Software LLC, P.O. Box 68007, Raleigh, NC 27613, www.AgRenaissance.com.

[b]Means within a year and measurement period followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p \leq 0.05$.

*Difference between weed-free peanut yield and weedy peanut yield is significant with $0.01 < p \leq 0.05$.

**Difference between weed-free peanut yield and weedy peanut yield is significant with $0.001 < p \leq 0.01$.

***Difference between weed-free peanut yield and weedy peanut yield is significant with $p \leq 0.001$.

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