PLANTING NARROW-ROW SOYBEAN LEADS TO INCREASED YIELD AND FARM PROFITABILITY UNDER CONVENTIONAL TILLAGE IN THE NORTHEAST

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By

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Abstract

Growers can plant soybean [*Glycine max(* L.) Merr.] with a grain drill or row crop planter, which can affect seed and weed control costs and yield. Farmers planted soybean with a grain drill in 0.19 m rows and a row crop planter in 0.38 and 0.76 m rows at recommended (420,000 seeds ha^{-1}) and reduced (321,000 seeds ha^{-1}) seeding rates in two field-scale studies in New York to obtain agronomic information and conduct partial budget analyses to aid growers in future planter purchase decisions. Soybean intercepted more light in 0.19 (65-70%) compared with 0.76 m rows (50-55%) at flowering, despite lower early plant establishment (~70 and ~85%, respectively) at both locations. At the no-till location, soybean in 0.76 m rows compared with narrower rows had greater weed density at full pod stage (19.7 vs. 6.3 and 5.1 plants m^{-2}) and biomass at harvest (13.7 vs. 6.6 and 7.3 g m^{-2}), but similar yield (~3.30 Mg ha^{-1}). At the chisel tillage location, soybean in 0.19 m rows at 420,000 seeds ha^{-1} yielded more (4.27 Mg ha^{-1}) than other row spacing by seeding rate combinations (4.15 to 4.01 Mg ha^{-1}). Partial budget analyses indicated that soybean in 0.19 m rows at 420,000 seeds ha^{-1} had ~$30 ha^{-1} increased profit compared with 0.76 m rows at 321,000 seeds ha^{-1}. Partial budget analyses indicated that for farms without a grain drill the 4% yield advantage offsets costs of purchasing and owning a grain drill and added seed costs at present market and seed price.

BIOGRAPHICAL SKETCH

The author grew up on a small farm in Perth, NY. His family raised chickens and beef cows and owned a feed store that sold grain to local farmers. The author grew up around farming and so decided to attend Cornell University to study agriculture. At Cornell he was part of the first freshman class in the Agricultural Sciences major and also majored in Natural Resources.

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INTRODUCTION

Soybean production has increased steadily and wheat (*Triticum aestivum* L.) production remains constant (New York Agricultural Statistics, 2011) so grain drills are widely available in the Northeastern United States. Consequently, growers in this region have the option of using a grain drill to seed soybean in 0.19 m rows or a row crop planter to seed soybean in 0.38 m rows (with inter-units) or 0.76 m rows. The yield advantage of planting soybean in 0.19 vs. 0.76 m rows is fairly consistent in northern latitudes but less consistent south of latitude 43N (Lee, 2006). Also, planting soybean in 0.19 compared with 0.76 m rows usually results in less late-season weed densities, which may allow for lower weed control costs for drilled soybean (Bradley, 2006). Row crop planters compared with grain drills, however, provide more uniform seed depth and seed spacing resulting in improved emergence and more uniform stands, which may allow for lower seeding rates and seed costs (Bertram and Pedersen, 2004). Furthermore, soybean in 0.19 or 0.38 m rows compared with 0.76 m rows can incur significant wheel-traffic damage and yield reductions from the increasing use of post-emergence fungicide applications during reproductive development (Holshouser and Taylor, 2008; Hanna et al., 2008). Consequently, planting soybean with a grain drill in 0.19 m rows or with a row crop planter in 0.38 or 0.76 m rows can affect not only yield but also weed control costs, seed costs, and wheel-traffic damage to soybean. Northeast soybean producers can benefit greatly from farmer-participatory studies with field-scale equipment that compare the agronomics and economics of planting glyphosate-resistant soybean at recommended seeding rates with a grain drill in 0.19 m rows and recommended seeding rates with a row crop planter in 0.38 or 0.76 m rows.

Lambert and Lowenberg- DeBoer (2003) summarized the results of numerous soybean row spacing studies in northern latitudes and reported a 4.8% yield advantage for drilled (<0.25) compared to 0.38 m rows and a 15.9% yield advantage compared to 0.76 m rows. Bertram and Pedersen (2004) reported that soybean planted in 0.19 and 0.38 m rows yielded between 5% and 9.6% more than in 0.76 m rows in three regions of Wisconsin in a 3 year study. Bertram and Pedersen (2004) also reported that soybean in 0.38 m rows yielded 4.8% more than in 0.19 m rows in southern Wisconsin, but the same in northern and central Wisconsin. Janovieck et al. (2006) found that soybean drilled in 0.19 m rows compared with 0.76 m rows yielded 13% more under moldboard plow and no-tillage systems in Ontario, Canada. In this same study, however, soybean in 0.19 m rows yielded 4% greater than soybean in 0.38 m rows under moldboard tillage and similarly under no-till conditions. Cox and Cherney (2011) reported that drilled soybean in 0.19 m rows yielded 7.5% more than soybean planted with a row crop planter in 0.38 m rows and 15% more than in 0.76 m rows in New York. In a 3- year study at three locations in Indiana, soybean planted in 0.19 m and 0.38 m rows yielded 9% more than in 0.76 m rows in the absence of post-emergence wheel traffic damage (Hanna et al, 2008). Post-emergence wheel traffic damage from fungicide application, however, erased this yield advantage.

Some studies have reported row spacing by seeding rate interactions with soybean responding more positively to higher seeding rates in narrow vs. wide rows (Weber et al. 1966, Oplinger and Philbrook, 1992). Other studies in Ohio (Beurelein, 1988) and Canada (Ablett et al. 1991) have reported similar optimum seeding rates in 0.18 vs. 0.36 m or 0.25 vs. 50 m rows, respectively. Kratochvil et al. (2004) also reported that soybean in 0.19 and 0.38 m rows responded similarly to seeding rate. A recent study by Cox and Cherney (2011) in New York also found no interaction between row spacing and seeding rate with soybean in all three row spacings having maximum yield at 420,000 seeds ha^{-1}.

Most cited row spacing studies used small plot research methods, at times planting all row spacings with the same planter or at different seeding rates, while eliminating potential yield differences associated with plant establishment, weed control, and post emergent wheel traffic damage. While these studies have yielded valuable information, field-scale studies with growers performing actual production practices with field-scale equipment can provide realistic information on how row spacing affects the agronomics of soybean, especially when post emergent wheel traffic is employed. The first objective of this study was to obtain agronomic information on how soybean row spacing affects soybean establishment, weed establishment and control, lodging, seed moisture, seed mass, seed density, and seed yield at 420,000 and 321,000 seeds ha^{-1}. The second objective was to use the agronomic information to conduct partial budget analyses to aid soybean growers in the Northeast USA who practice either a corn-soybean-wheat rotation or an exclusive corn-soybean rotation in their future purchase decisions on soybean planters.

MATERIALS AND METHODS

Farmer-researcher partnerships were formed to conduct field-scale studies in 2010 and 2011 at two farms in New York. One site was in Cayuga County, New York (42°44’ N, 76° 40’ W). The predominant soil types at this site were Honeoye silt loam (fine-loamy, mixed, active, mesic, Glossic Hapludalfs) and Lima silt loam (fine-loamy, mixed, semiactive, mesic, Oxyaquic Hapludalfs). The other site was located in Livingston County, New York (42°53’ N, 77° 36’ W) with predominant soil types of Cazenovia silt loam (fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs) and Odessa silt loam (fine, illitic, mesic, Aeric Endoaqualfs). The preceding crop was corn (*Zea mays* L.) at both locations in each year. Soil test in the spring of both years indicated high P and K values (Mehlich test).

Farmers or farm staff performed all field operations including tillage, planting, pesticide application, and harvesting. The Livingston Co. site was chisel plowed and disc-harrowed just prior to planting and the Cayuga Co. site was planted no-till in 2010 and 2011. In both years at Livingston Co. a pre-emergence application of a co-pack mix of thifensulfuron methyl (methyl 3-(4-methoxy-6-methyl-1,3,5-triazin-2-ylcarbamoylsulfamoyl)thiophene-2-carboxylate), chlorimuron-ethyl(ethyl 2-(4-chloro-6-methoxypyrimidin-2-ylcarbamoylsulfamoyl)benzoate and flumioxazin (: 2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propynyl)-2H-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1H-isoindole-1,3(2H)-dione) (Enlite ®) was applied. A pre-plant burndown application of tribenuron (2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)methylamino]carbonyl]amino]sulfonyl]benzoic acid) was applied at the Cayuga Co. site in 2010. In 2011 a burndown application of glyphosate ((N-(phosphonomethyl)glycine) was used. Planting dates were 5 May at Cayuga Co. and 24 May at Livingston Co. in 2010. Wet soil conditions delayed planting in 2011 until 25 May at Cayuga Co. and 15 June in Livingston Co. in 2011. Glyphosate was applied post emergence with a 12 m wide sprayer at Cayuga Co at the 2nd node (V2) stage (Fehr and Caviness, 1977) in both years and with a 27 m wide sprayer at the V5 stage at Livingston Co. in 2011.

The experiment was in a randomized split-plot design with three replications at both locations with three row spacings (0.19, 0.38 and 0.76 m) as main plots and two seeding rates (~321,000 and ~ 420,000 seeds ha^{-1}) as sub-plots. The recommended seeding rate is 420,000 seeds ha^{-1} for drilled soybean and 321,000 seeds ha^{-1} in 0.76 m rows planted with a row crop planter in New York. At the Cayuga Co site, the main plots measured about 200 m in length and

6.6 m in width. Soybean was planted in 0.19 m rows with a 3.3 m wide John Deere (Moline, IL) 1590 no-till grain drill. Soybean in 0.38 and 0.76 m rows were planted with a 7- row, 3.3 m White split-row planter (Coldwater, Ohio) with inter-units engaged or disengaged depending upon row spacing. At the Livingston Co. site, main plots measured about 250 m in length and 9.9 m in width. Soybean was planted in 0.19 rows with a 9 m wide Great Plains (Salina, KS) no-till grain drill and in 0.38 and 0.76 m rows with a 9.9 m wide Kinze (Williamsburg, IA) row crop planter with or without engaged inter-units depending upon row spacing. Asgrow brand, AG 2002, an early Maturity Group II soybean variety was planted at both sites in both years. The variety was inoculated with *Bradyrhizobium japonicum* on the day of planting. Seed size ranged from 6400 to 6700 seeds kg^{-1} in both years so we calibrated the grain drill at each location at 6600 seeds kg^{-1} for both targeted seeding rates (within ~5,000 seeds ha^{1} because of the relatively wide range in seeding rates between contiguous drill settings).

Early plant densities were determined at the V2 stage in mid to late June by counting the total number of plants in six areas measuring 1.52 m^2 (8 rows in 0.19 m rows, 4 rows in 0.38 m rows, and 2 rows in 0.76 m rows). Weed densities were determined at Cayuga Co. one day prior to post-emergent glyphosate application and at the full plod (R4) stage, about 5 weeks after glyphosate application, in both years. Weed densities were determined by recording the number of each weed species in four quadrats measuring 0.5 m^2 in each sub plot. Weed densities were not determined at the Livingston Co. in either year because of an almost complete absence of weeds at this site.

Light interception measurements were initiated at both sites at the beginning of the flowering (R1) stage. Ambient light intensity was measured above the canopy using a LI-COR LI-1400 (Lincoln, NB) data logger and one meter light bar in late morning or early afternoon hours. The light bar was immediately placed on the ground in the same position beneath the canopy and the light intensity again measured. The ratio of below canopy to ambient light was subtracted from 1 and multiplied by 100 to determine the percentage of light intercepted by the soybean canopy. This process was repeated four times in each sub plot. Light interception measurements were taken at beginning flower (R1) and R4 stages in 2010 in coordination with weed measurements. Light interception measurements were taken at R1, full flowering (R2), beginning pod (R3), R4, beginning seed (R5), and full seed (R6) stages in 2011 or until soybean in all row spacings intercepted 95% available light.

Weed biomass measurements were taken at the R8 stage (full maturity), a few days before soybean harvest at the Cayuga Co. location. All weeds were clipped in four 0.5 m^2 quadrats in each sub plot. The weeds were oven-dried until constant moisture and then weighed to determine weed biomass. Final soybean densities were taken at this time using the method previously described for early season estimates at the V2 stage. Plant heights and lodging ratings (1-5 scale, Boquet, 1990) were taken in six regions of each sub plot on the morning of harvest.

The growers harvested the entire length and partial widths of each sub plot in both Cayuga Co. (Case IH Model 2144 with a 4.5 m head Racine, IL) and Livingston Co. (Gleaner R52 with a 6 m head, Hesston, KS) in mid to late October of both years. Although both combines were equipped with yield monitors, each sub-plot was weighed with a calibrated weigh wagon (Brent 150 Model, Des Moines, IA) at all locations to avoid any calibration errors with yield monitors. Two harvested seed samples were taken from each sub plot and moistures were determined in the field using a seed moisture meter. Seed yield was adjusted to 130 g kg^{-1} moisture. Seed mass was determined by weighing each moisture sample (~1500 seeds) and then counting the number of seeds that comprised each sample with a seed counter (Old Mill Co., Savage, MD). Seed density (seeds m $^{-2}$) was determined by dividing the seed yield by seed mass.

Statistical analysis was performed using the JMP 9.0.2 statistical package (SAS institute, 2010). Levene's test indicated that variances of most measurements were not similar across locations, probably because of different planting dates in both growing seasons. In addition, different tillage practices as well as herbicide programs were used so locations were analyzed separately. Levene's test indicated that variances for all measurements were similar across years, so combined analyses for all measurements (except for light interception measurement because of different growth stages across years) was used within each location. Row spacing and seeding rates were considered fixed effects and year and replications were random effects in the ANOVA for each location. An LSD comparison (P=0.05) was used to separate row spacing means, if significant, and standard errors of the mean (P=0.05) were used to determine differences between seeding rates, if significant, because there were only two comparisons within this fixed effect. If row spacing by seeding rate interactions were significant, pre-planned orthogonal contrasts were used to separate means (Saville and Rowarth, 2008) of 0.19 m rows at its recommended seeding rate (420,000 seeds ha^{-1}) with 0.76 m rows at its recommended seeding rate (321,000 seeds ha^{-1}) because a major objective of the study was to determine whether to use a new grain drill in a future year instead of using the existing corn planter to plant soybean. We also used a pre-planned orthogonal contrast to compare 0.76 m vs. 0.38 m rows to provide economic information to growers on whether to purchase a new 0.76 m corn planter or to purchase a split-row planter with inter-units in a future year. The two pre-planned contrasts were conducted using LS means contrasts (JMP 9.0.2). Significance was determined at the *P*=0.05 level.

A partial budget approach was used, if row spacing had a significant effect on yield, to estimate the expected change in annual profit for an average future year to determine the most profitable equipment complement for soybean production based on crop rotation. The first rotation considered was a corn-soybean-wheat rotation where it was assumed that a row crop planter was owned (to plant the corn in 0.76 m rows) as well as a grain drill to seed wheat in 0.19 m rows. The other rotation considered was a corn-soybean rotation where it was assumed that only a 0.76 m row crop planter was owned (no drill is required because wheat is not in the rotation). Partial budgets were created for farms that produce 250 and 500 ha of soybeans as part of their rotations.

The analysis accounted for added annual fixed costs of purchasing a new piece of equipment. Depreciation was calculated using the straight line methods assuming a salvage value of 40% of purchase price (PP) and a useful life of 7 years. We used manufacturer's list prices for base model equipment obtained from local equipment dealers to estimate ownership and operating costs of a new 6 m John Deere (Model 1520 Moline, IL) Integral Grain Drill (list price $25 500) to plant 250 ha of soybean and a new 9 m John Deere (Model 445 Moline, IL) Conventional Drill ($46 000 list price) to plant 500 ha of soybean in a timely manner. Likewise, ownership and operating costs were estimated for a new John Deere 1790 23 row split-row planter ((list price $121 000)) to plant 250 ha of soybean and a new John Deere 1790 31 row split-row planter (list price $169 000) to plant 500 ha of soybean in a timely manner. It was assumed that all of the other equipment was already part of the farm business's current operation.

Interest to reflect the opportunity cost of capital was calculated at a real rate of 5%. Fixed costs such as insurance (0.85%) and shelter (1.5%) as well as variable repair costs (4%) were calculated as a percentage of the purchase price of the new equipment (ASABE, 2010). Other variable costs seed cost associated with different seeding rates and harvest and hauling charges (ASABE, 2010). Seed costs were specified at \$2.20 kg^{-1}(New York Agric. Stat. Service, 2011), or \$.0003 $seed^{-1}$ (seed size of 6600 seeds kg^{-1}), harvesting costs at \$0.018 $kg^{-1}$and hauling costs at \$0.007 kg^{-1} (Pennsylvania Custom Rates Costs, 2011). No drying costs were incurred either growing season because the soybean was harvested below the moisture necessary for safe storage.

Expected changes in annual net farm income were generated from average soybean yields for each row spacing by seeding rate combination and the average soybean price (\$0.42 kg^{-1}) in New York for the 2010 and 2011 growing seasons (New York Agric. Stat. Service, 2011). All dollar values for income and cost items are expressed in real terms as current 2012 dollars. The expected changes in profit reflected differences in total net income (increases or decreases) and differences in costs (increases and decreases) for the two farms in this study for a future average year. Also, a sensitivity analysis was performed at different seed costs and average soybean prices to account for the volatility in seed costs and soybean prices in recent years.

RESULTS AND DISCUSSION

Weather conditions differed markedly between growing seasons (Table 1). The 2010 growing season had favorable conditions for soybean growth. Somewhat dry conditions (49 to 56 mm of precipitation) in May allowed for timely planting at both locations. Temperatures averaged 21.0-21.5 ^{0}C from June through August, which allowed soybean to attain the R8 stage in early September at both locations. Monthly rainfall exceeded 90 mm in June, July and August at both

Table 1. Monthly precipitation (Precip.) and average temperature (Temp.), measured at the nearest weather stations, for studies in Cayuga and Livingston Counties, NY during the 2010 and 2011 growing seasons.

Year/Month	Cayuga		Livingston	
	Precip.	Temp.	Precip.	Temp.
	mm	° C	mm	° C
2010				
May	56	16.0	49	15.7
June	133	19.5	121	19.8
July	108	22.5	118	22.8
August	148	21.2	92	21.4
September	65	16.7	65	16.4
Total	511	19.2	446	19.2
2011				
May	90	14.8	114	14.8
June	71	19.5	83	20.2
July	22	23.0	19	23.4
August	106	20.5	118	21.0
September	150	17.7	64	17.9
Total	439	19.1	398	19.5

locations so soybean experienced no drought stress in 2010. The 2011 growing season was characterized by a wet spring that delayed planting at both locations, followed by a dry June and July with rainfall totaling only 93 to 102 mm during the 2-month period at both locations (Table 1). Because of the delayed planting, soybean did not attain the R3 growth stage, the beginning of the critical growth stage for yield, until early August when precipitation was no longer limiting. Consequently, despite the delayed planting date and dry June through July period in 2011, average yields compared to 2010 were only 15% lower at the Cayuga Co. site (3.02 vs. 3.54 Mg ha^{-1}) and only 4.5% lower at the Livingston Co. site (4.04 vs. 4.21 Mg ha^{-1}, respectively).

Cayuga Co.

When averaged across years, early plant densities at the V2 stage showed a significant response to row spacing and seeding rate with no row spacing by seeding rate interaction (Table 2). Soybean in 0.76 m rows averaged about 84% early plant establishment (30.9 plants m^{-2}), compared to about 71% soybean establishment in 0.19 and 0.38 m rows. Oplinger and Philbrook (1992) also reported much greater early soybean establishment under no-till conditions in 0.76 m rows (95%) compared with drilled 0.20 m rows (76.5%). Despite 3.3% plant mortality in 0.76 rows (as indicated by the decrease from 30.9 plants m^{-2} at the V2 stage to 29.9 plants m^{-2} at the R8 stage), soybean in 0.76 m rows compared with 0.19 m rows also had greater final plant densities at the R8 stage (Table 2). Final plant establishment in this field-scale study averaged 72 to 81% across row spacings (26.5-29.9 plants m^{-2}) and 75-76% across seeding rates, similar to the final plant establishment range in numerous small-plot research trials (Ethredge et al., 1989; DeBruin and Pedersen, 2008; Lee et al., 2008; Walker et al., 2010; Cox and Cherney, 2011). Row crop planters compared with drills have more uniform seeding depth and placement in the

Table 2. Early plant densities at the 2nd node stage (V2), weed density before glyphosate application (PRE), final plant densities at full maturity (R8), weed density after glyphosate application at the full pod stage (R4), and weed biomass at harvest for soybean planted at three row spacings and two seeding rates at a cooperator farm in Cayuga County, NY, averaged across the 2010 and 2011 growing seasons.

Seeding rates	Row spacing 0.19 m	0.38 m	0.76 m	Avg.
Early stands-V2, plants m^{-2}				
321,000	23.5	22.1	25.9	23.8
420,000	29.4	29.5	35.8	31.5
Avg.	26.5	25.8	30.9	
Weed density-V2, plants m^{-2}				
321,000	69.0	68.3	78.2	71.8
420,000	47.7	56.3	67.9	57.3
Avg.	58.4	62.3	73.1	
Final stands- R8, plants m^{-2}				
321,000	23.4	23.3	25.3	24.0
420,000	29.6	31.5	34.5	31.9
Avg.	26.5	27.4	29.9	
POST Weed density-R4, plants m^{-2}				
321,000	5.6	7.9	23.2	12.2
420,000	4.6	4.7	16.1	8.5
Avg.	5.1	6.3	19.7	
Weed biomass, g m^{-2}				
321,000	10.2	7.3	16.4	11.3
420,000	4.3	5.9	11.0	7.1
Avg.	7.3	6.6	13.7	

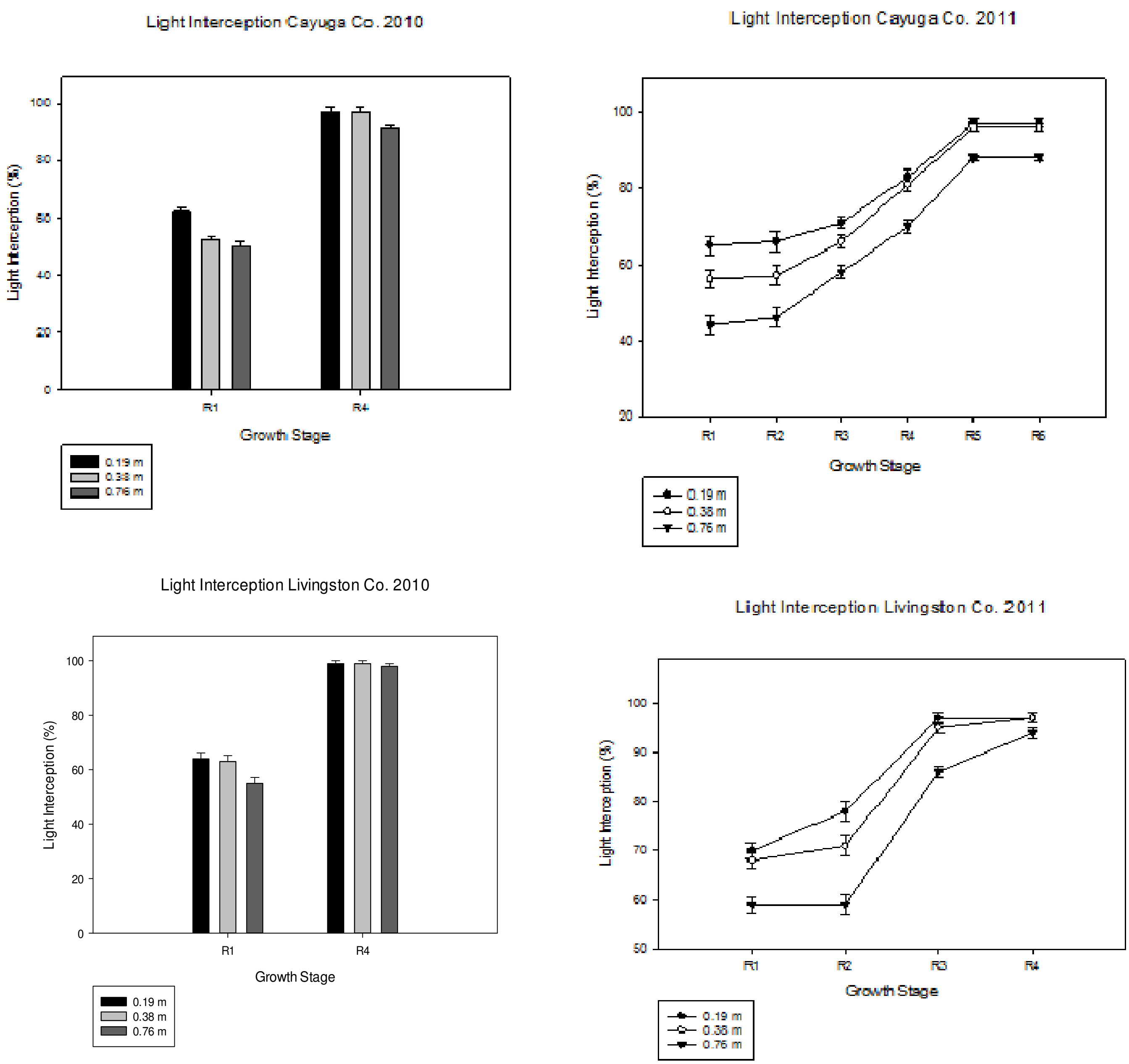
Significance (P values)	Early stands	PRE weeds	Final stands	POST weeds	Weed biomass
Row Spacing	0.001	0.19	0.03	<0.0001	0.006
Seeding Rate	<0.0001	0.03	<0.0001	0.04	0.002
Row spacing x seeding rate	0.47	0.76	0.49	0.38	0.48

row (Bertram and Pedersen,2004), which probably contributed to greater plant establishment in 0.76 m rows under no-till into high-reside corn conditions at this location.

Weed densities, which averaged a moderately high 64.6 weeds m^{-2} (Knezevic et al., 2003) before glyphosate application at the V2 stage, did not show a response to row spacing at this time (Table 2). This indicates that weeds (predominantly *Setaria virdis* L.-green foxtail-in 2010 and *Taraxacum officinale* L.-dandelion-in 2011) established evenly from planting until the V2 stage, regardless of row spacing. Seeding rate, however, affected weed establishment as indicated by greater weed density at the lower seeding rate (Table 2). Growers who use a row crop planter typically plant at the lower seeding rate, which could affect weed control decisions as indicated by 78.2 weeds m^{-2} in 0.76 m rows at a seeding rate of 321,000 seeds ha^{-1} compared with 47.7 weeds m^{-2} in 0.19 rows at a seeding rate of 420,000 seeds ha^{-1}.

When weed densities were determined at the R4 stage, 5-6 weeks after glyphosate application, responses to both row spacing and seeding rate were observed and there was no row spacing by seeding rate interaction (Table 2). The 0.76 m rows averaged about 3.5 times as many weeds (19.7 weeds m^{-2}, predominantly foxtail in 2010 and dandelion in 2011) as the 0.38 m and 0.19 m rows. Weed biomass at harvest also showed a significant response to row spacing with 0.76 m rows having about twice the biomass (13.7 g m^{-2}) compared with weed biomass in narrower rows. Small-plot studies with the use of primary and secondary tillage (Mickleson and Renner, 1997; Dalley et al., 2004, Hock et al, 2006; Harder et al., 2007) have also shown that soybean planted in 0.76 m rows had greater weed densities and biomass from the R4-R6 stage than soybean in 0.19 or 0.38 m rows. The lower seeding rate of 321,000 seeds ha^{-1} compared with 420,000 seeds ha^{-1} also had greater weed densities at the R4 stage and weed biomass at

Fig. 1. Percent light interception of soybean at beginning flowering (R1) and full pod (R4) stages in 2010 and at R1, full flowering (R2), beginning pod (R3), R4, beginning seed (R5), and full seed (R6) stages in 2011 or until soybean intercepted 95% available light in 2011 at three row spacings averaged across two seeding rates at studies in Cayuga Co and Livingston Co., NY.



harvest. The plant establishment and weed data indicate that growers who no-till soybean into high-residue corn conditions with a row crop planter in 0.76 m rows at 321,000 seeds ha^{-1} instead of with a grain drill at a seeding rate of 420,000 seeds ha^{-1} can save on seed costs but may incur greater weed costs during the growing season or in a future year.

Differences among row spacings in weed density at the R4 stage and weed biomass at the R8 stage can be explained by light interception differences from the R1 to R4 stage and time to canopy closure. Row spacing and seeding rate affected light interception on all measurement dates in both years but there was no row spacing by seeding rate interaction so results have been averaged across seeding rates (Fig.1). In both years, soybean in 0.19 m and 0.38 m rows compared with 0.76 m rows intercepted more light at the R1 and R4 stages. Also, soybean in 0.19 and 0.38 m rows attained canopy closure (>95 light interception) at the R4 stage in 2010 and R5 stage in 2011, whereas soybean in 0.76 m rows intercepted only 90% of the light at the R4 stage in 2010 and 87% of the light at the R5 and R6 stages in 2011. Increased light penetration into the canopy and slower time to canopy closure typically results in greater weed establishment in soybean (Bradley, 2006). Dalley et al. (2004) also reported that soybean in 0.19 and 0.38 m rows attained > 98% canopy closure in 3 years of a 4-year study, whereas soybean in 0.76 m rows attained a maximum of only 84% in all 4 years.

Despite differences in weed density at the R4 stage and weed biomass at the R8 stage, row spacing did not affect seed yield (3.24-3.30 Mg ha^{-1}), seed density (2293-2331 seeds m^{-2}) or seed mass (143-147 mg) and there was no row spacing by seeding rate interaction for any of these measurements (Table 3). Halford et al. (2001) reported that under no-till conditions, post-emergent herbicide applied between 21 and 44 days after emergence avoided yield loss in soybean from weed interference. Glyphosate was applied at the V2 stage, 31 days after

Table 3. Seed density (seeds m^{-2}), seed mass and seed yield for soybean planted in three row spacings and two seeding rates at a cooperator farm in Cayuga County, NY averaged across the 2010 and 2011 growing seasons.

Seeding	Row spacing			
rates	0.19 m	0.38 m	0.76 m	Avg.
Seeds m^{-2}, no.				
321,000	2263	2322	2235	2273
420,000	2382	2339	2351	2357
Avg.	2323	2331	2293	
Seed mass, mg $seed^{-1}$				
321,000	142	143	145	143
420,000	143	146	149	146
Avg.	143	145	147	
Seed yield, Mg ha^{-1}				
321,000	3.17	3.26	3.16	3.20
420,000	3.30	3.34	3.44	3.36
Avg.	3.24	3.30	3.30	
Significance (P values)	Seeds m^{-2}	Seed mass	Seed yield	
Row Spacing	0.87	0.06	0.82	
Seeding Rate	0.18	0.08	0.11	
Row spacing x seeding rate	0.74	0.31	0.71	
0.19H v. 0.76L	0.17	0.33	0.43	
0.38H v. 0.76H	0.9	0.14	0.57	

emergence in 2010 and 30 days after emergence in 2011, indicating that weeds may have been removed before the critical stage for yield loss. Knesevic et al (2003), however, indicated that the critical period for weed control in soybean was at the V1 stage in 0.76 m rows, the V2 stage in 0.38 m rows and the V3 stage in 0.19 m rows in the presence of moderately high weed densities (~30 to 100 weeds m-2). This would suggest that weed control in 0.76 m rows occurred after the critical period given the weed densities (64.6) at the V2 stage at this location. On the other hand, the pre-plant burn-down herbicide delayed weed emergence until the V1 stage, reducing competitiveness compared with weeds emerging at planting time (Hock et al., 2003). Furthermore, grassy weeds, the predominant weed species at harvest in 2010, are less competitive with soybean than broadleaf weeds (Hock et al., 2003), reducing the impact of weed competition on yield loss. Also, soybean received ample rainfall from the R3-R6 stages in both years, which greatly reduces the deleterious effect of increased weed competition on soybean yield (Bradley, 2006). Apparently, the combined effects of delayed weed emergence, less competitive weeds as the dominant species, and ample rainfall during the critical R3-R6 growth stage negated any impact of increased weed density and biomass in 0.76 m rows on soybean yield.

Nevertheless, the 0.76 m rows intercepted less light at the R1 and R4 stages in 2010 and from the R1 through R6 stage in 2011 (Fig.1) so it is surprising that yields did not vary among row spacings. Other researchers have reported yield advantages for narrow rows because of increased light interception (Shibles and Weber, 1965, Board, 2000; Lee et al., 2006, Harder et al. 2007). Furthermore, in small-plot research near this site, soybean in 0.19 m rows yielded 15% greater than soybean in 0.76 m rows and 7.5% greater than soybean in 0.38 m rows (Cox and

Cherney, 2011) so it is not clear why row spacing did not affect yield at this location. Janovieck et al. (2006) did report that soybean in 0.19 m rows yielded 4% greater than soybean in 0.38 m rows under moldboard tillage but similar under no-till conditions so perhaps the no-till conditions somehow lessened the yield advantage for soybean in 0.19 m rows. Also, Piper et al. (1989) projected yield losses of 9% in 0.19 m rows from mechanical wheel damage with a single post-emergent application of herbicide at 6 weeks after planting (V7 stage) and 1% at 4 weeks after planting (V2 stage) with the 12 m boom width used in this study, which may have further reduced the yield advantage for soybean in 0.19 m rows.

Seeding rate also did not affect yield, which again contradicts a small-plot study close to this site in which a seeding rate of 420,000 seeds ha^{-1} had a 6.8% yield advantage compared with 321,000 seeds ha^{-1} (Cox and Cherney, 2011). Apparently final stands of about 23.5 plants m^{-2} in the narrower rows and 25.3 plants m^{-2} in 0.76 m rows at the seeding rate of 321,000 seeds ha^{-1} were adequate for optimum yield at this location. Other researchers (DeBruin and Pedersen,2008; Lee et al., 2008; Walker et al., 2010) have also reported that similar final plant densities can provide close to optimum yield in 0.38 or 0.76 m rows. Based on the results of this study, the grower at this location, who practices a corn-soybean-wheat rotation, can use either a no-till grain drill or row crop planter to plant soybean at a seeding rate of 321,000 seeds ha^{-1} into high-residue corn conditions. If the grower switches to an exclusive corn-soybean rotation, the grower can continue to use the grain drill but not purchase a new drill once it requires replacement. Instead, the grower should only maintain a row crop planter without interunits and plant corn and soybean in 0.76 m rows.

Livingston Co.

Early plant densities at the V2 stage showed a significant response to row spacing and seeding rate (Table 4). Soybean in 0.38 and 0.76 m rows averaged 81-86%% early plant establishment (29.9 -31.9 plants m^{-2}), compared to 69% soybean establishment in 0.19 m rows. Final plant densities also differed among row spacings with about 86% final plant establishment in 0.38 and 0.76 m rows compared with down to 62% final plant establishment in 0.19 m rows because of plant mortality, but there was a row spacing by seeding rate interaction. The pre-planned orthogonal contrast indicates similar final plant densities between soybean in 0.19 m rows at a seeding rate of 420,000 seeds ha^{-1} compared with soybean in 0.76 m rows at 321,000 seeds ha^{-1} (Table 4). Similar to the no-till location, plant establishment data at this chisel tillage location corroborate the recommendation of the lower seeding rate of 321,000 seeds ha^{-1} when planting soybean with a row crop planter compared with a grain drill, as suggested by other researchers (Bertram and Pedersen, ,2004; Epler and Staggenborg 2008).

A row spacing by seeding rate interaction was observed for lodging at harvest. The pre-planned orthogonal contrast indicates more lodging for soybean in 0.76 m rows at 321,000 seeds ha^{-1} compared with 0.19 m rows at 420,000 seeds ha^{-1}(Table 4). It is unclear why soybean in 0.76 m rows at 321,000 seeds ha^{-1} showed more lodging because row spacing and seeding rate did not affect plant height and there was no row spacing by seeding rate interaction for plant height (Table 4). Also, Oplinger and Philbrook (1992) reported no difference in lodging for soybean in 0.2 m rows at higher seeding rates compared with soybean in 0.76 m rows at lower seeding rate. Furthermore, Bertram and Pedersen (2004) reported more lodging for soybean in

0.19 m rows at higher seeding rates compared with soybean in 0.38 or 0.76 m rows at a lower seeding rate.

Table 4. Early plant densities at the 2nd node stage (V2), final plant densities at full maturity (R8), plant height, and lodging (1= no lodging, 5=complete lodging) for soybean planted at three row spacings and two seeding at a cooperator farm in Livingston County, NY, averaged across the 2010 and 2011 growing seasons. H= 420,000 seeds ha^{-1} and L= 321,000 seeds ha^{-1}.

Seeding rates	Row spacing 0.19m	0.38m	0.76m	Avg.
Early stands-V2, plants m^{-2}				
321,000	22.6	29.2	26.1	25.9
420,000	28.6	34.6	33.7	32.3
Avg.	25.6	31.9	29.9	
Final stands-R8, plants m^{-2}				
321,000	20.2	27.1	27.0	24.8
420,000	25.5	36.5	37.3	33.1
Avg.	22.8	31.8	32.1	
Plant height, cm				
321,000	90.8	93.1	91.8	91.9
420,000	92.8	94.6	94.5	94.0
Avg.	91.8	93.9	93.2	
Lodging, rating 1-5 scale				
321,000	1.9	1.8	2.1	1.9
420,000	1.6	1.6	2.5	1.9
Avg.	1.7	1.7	2.3	
Significance (P values)	Early Stands	Final Stands	Lodging	Plant height
Row Spacing	0.0001	<0.0001	0.004	0.37
Seeding Rate	<0.0001	<0.0001	0.96	0.08
Row spacing x seeding rate	0.69	0.0062	0.03	0.93
0.19H v 0.76L	0.18	0.15	0.04	0.62
0.38H v 0.76H	0.61	0.5	<0.0001	0.9

Row spacing had a significant effect on soybean yield and seed density but there were row spacing by seeding rate interactions (Table 5). The pre-planned orthogonal contrast indicated that soybean in 0.19 m rows at a seeding rate of 420,000 seeds ha^{-1} had a 4% greater yield (4.27 Mg ha^{-1}) compared with 0.76 m rows at 321,000 (Table 5). Soybean in 0.19 m rows at a seeding rate of 420,000 seeds ha^{-1} also had 7% greater seed density (2852 seeds m^{-2}) compared with 0.76 m rows at 321,000 (Table 5). Cox and Cherney (2011) also reported that seed density was the yield component most responsible for optimum yield for 0.19 m rows at a seeding rate of 420,000 seeds ha^{-1}. The final yield advantage for 0.19 m rows at 420,000 seeds ha^{-1} compared with 0.76 m rows at 321,000 seeds ha^{-1}, however, was only 4% instead of 7% because of lower seed mass in 0.19 m rows (152.0 mg) compared with 0.76 m rows (156.3 mg). Apparently, the response of seed mass to row spacing is inconsistent as previous studies indicated either no difference among the three row spacings (Cox and Cherney, 2011), higher seed mass for 0.76 m rows (156 mg) compared with 0.25 m rows (150 mg, Ethredge et al., 1989), or higher seed mass for 0.76 m rows (141 mg) compared with 0.38 m rows (136 mg) in one location but similar at two other locations (DeBruin and Pedersen, 2008)

Soybean intercepted more light in 0.19 vs.0.76 m rows at the R1 stage in 2010 and more light than both 0.38 and 0.76 m rows from the R1 through the R3 stage in 2011 (Fig.1). Similar light interception during the seed-filling period but fewer seeds $plant^{-1}$ (seed density divided by final plant density) probably allowed for yield component compensation, contributing to the greater seed mass in soybean in 0.76 compared with 0.19 m rows. Nevertheless, greater seed mass in 0.76 m rows could not compensate for the lower seed density because less light interception during most of the R1 to R5 period (Fig.1) results in lower soybean yield (Lee et al., 2008).

Table 5. Seed density (seeds m $^{-2}$), seed mass, seed yield, and seed moisture for soybean planted at three row spacings and two seeding rates at a cooperator farm in Livingston County, NY averaged across the 2010 and 2011 growing seasons. H= 420,000 seeds ha^{-1} and L= 321,000 seeds ha^{-1}.

Seeding rates	Row spacing 0.19m	0.38m	0.76m	Avg.
Seed yield, Mg ha $^{-1}$				
321,000	4.11	4.01		4.07
420,000	4.27	4.10	4.15	4.17
Avg.	4.19	4.05	4.13	
Seeds m $^{-2}$, no.				
321,000	2725	2655	2673	2684
420,000	2852	2637	2664	2717
Avg.	2789	2646	2668	
Seeds mass, mg seed $^{-1}$				
321,000	152.4	155.3	155.1	154.2
420,000	151.7	154.9	157.5	154.7
Avg.	152.0	155.1	156.3	
Significance (P values)	Seed yield	Seeds m^{-2}	Seed mass	
Row Spacing	0.03	0.011	0.03	
Seeding Rate	0.15	0.28	0.74	
Row spacing x seeding rate	0.16	0.11	0.57	
0.19H v 0.76L	0.02	0.0018	0.14	
0.38H v 0.76H	0.11	0.61	0.26	

Economic Analysis-Livingston Co.

For the purposes of this analysis it was specified that growers utilizing a corn-soybean-wheat rotation would own a 0.76 m row crop planter (to seed corn) as well as a 0.19 m grain drill (to seed wheat) to plant all crops in a timely manner, given the size of the farm. Therefore, the decision to plant soybean in 0.76 vs. 0.19 m rows would require no additional financial investment in new equipment. Instead, the decision would primarily be based on function-added revenue associated with the significant yield advantage for soybean in 0.19 m rows at 420,000 seeds ha^{-1} vs. soybean in 0.76 m rows at 321,000 seeds ha^{-1} (4.27 Mg ha^{-1} vs. 4.11 Mg ha^{-1}) minus the additional cost of planting soybean with a drill in 0.19 m rows at the higher seeding rate (Table 5).

Table 6 shows the expected annual change in net farm income per hectare at multiple seed costs and soybean market prices. Values in the table are determined by multiplying the market price by the yield advantage for planting soybean in 0.19 m rows at 420,000 seeds ha^{-1} vs. soybean in 0.76 m rows at 321,000 seeds ha^{-1} (160 kg ha^{-1}) and subtracting the product of the seed cost and the additional seed (99,000 seeds ha^{-1}/6600 seeds kg^{-1}=15 kg ha^{-1}) for soybean in 0.19 m rows at the higher seeding rate. For example, in 2010 and 2011, the average market price in NY was \$0.42 kg^{-1} and average seed cost was \$2.20 kg^{-1} (New York Agricultural Statistics Service, 2011). An increase in annual net farm income of \$34.20 ha^{-1} would have been realized before hauling costs in those years by planting soybeans in 0.19 m rows at 420,000 seeds ha^{-1} vs. 0.76 m rows at 321,000 seeds ha^{-1} [(\$0.42 kg^{-1} x 160 kg ha^{-1}) – (\$2.20 kg^{-1} x 15 kg ha^{-1})]. Consequently, the farmer at Livingston Co. who owns a grain drill and practices a corn-soybean-wheat rotation would have realized an additional \$29.81 ha^{-1} (~\$4 additional harvesting and hauling costs associated with the 160 kg ha^{-1} yield advantage) in annual net farm income by

Table 6. The expected change in net farm income ha^{-1} at multiple market prices and seed costs of planting soybean in 0.19 m rows at 420,000 seeds ha^{-1} vs. 0.76 m rows at 321,000 seeds ha^{-1}. Values in the table are determined by multiplying the market price by the yield advantage (160 kg ha^{-1}) and subtracting the product of the seed cost and additional seed (15 kg ha^{-1}) needed for the higher seeding rate for the 0.19 m soybeans.

		Seed cost (\$ kg^{-1})								
		1.76	1.98	2.20	2.42	2.65	2.87	3.09	3.31	3.53
	0.36	31.20	27.90	24.60	21.30	17.85	14.55	11.25	7.95	4.65
	0.38	34.40	31.10	27.80	24.50	21.05	17.75	14.45	11.15	7.85
Market	0.40	37.60	34.30	31.00	27.70	24.25	20.95	17.65	14.35	11.05
Price	0.42	40.80	37.50	34.20	30.90	27.45	24.15	20.85	17.55	14.25
(\$ kg^{-1})	0.44	44.00	40.70	37.40	34.10	30.65	27.35	24.05	20.75	17.45
	0.46	47.20	43.90	40.60	37.30	33.85	30.55	27.25	23.95	20.65
	0.48	50.40	47.10	43.80	40.50	37.05	33.75	30.45	27.15	23.85

Expected change in net farm income (\$ ha^{-1})

drilling soybean in 0.19 m rows. However, the economic advantage of planting soybean with a grain drill lessens when market prices decrease and seed costs increase because drilled soybean requires higher seeding rates at this location (Table 6). Since 2006, soybean market prices in NY have varied from a low of \$0.23 kg^{-1} to a high of \$0.48 kg^{-1} (New York Agricultural Statistics Service, 2011). Seed costs, on the other hand, have consistently increased during that same time period, indicating that the future profitability of drilling soybean in 0.19 m rows on this farm should be evaluated periodically.

Some neighboring growers in Livingston Co., however, practice a 50-50 corn-soybean rotation on their farm and only own a 0.76 m row crop planter. In order to plant soybean in narrower rows, these growers would need to either buy a grain drill to seed at 0.19 m rows, or replace their current 0.76 m row crop planter with a similarly sized 0.38 m split-row planter. The 0.38 m split-row planter would be able to plant soybean in 0.38 m rows as well as to plant corn in 0.76 m rows by disengaging the appropriate inter-units on the planter.

Table 7 shows partial budget analyses, based on the yield data at the Livingston Co. location and market prices in New York in 2010 and 2011, for neighboring farms switching from seeding soybean in 0.76 m rows to either 0.19 or 0.38 m rows at two farm sizes in a 50-50 corn-soybean rotation (250 and 500 ha of soybean annually). Greater annual fixed costs for switching to 0.19 m rows are associated with the purchase of a new grain drill. Greater variable costs for switching to 0.19 m rows included additional repair costs for the drill, additional seed costs, based on 2010 and 2011 seed prices, and greater harvesting and hauling costs, based on the 160 kg ha^{-1} greater yield.

Table 7. Partial budget analyses for farms that produce 250 ha (6 m Grain Drill) and 500 ha (9 m Grain Drill) of soybean annually in a corn-soybean rotation, based on added fixed (ownership) and variable (operating) costs of switching planting soybean from 0.76 m rows to either 0.19 m or 0.38 m rows, mean soybean market price for the 2010 and 2011 growing seasons ($0.42 kg^{-1}), estimated soybean seed cost ($2.20 kg^{-1}) and differential soybean production (yield) from switching to 0.19 or 0.38 m rows from 0.76 m rows.

	0.76 to 0.19		0.76 to 0.38	
Partial Budget	250 ha	500 ha	250 ha	500 ha
Annual added income				
Value of annual revenue difference	17 600	35 200	0	0
Reduced annual equipment costs	0	0	19 125	23 707
Annual new equipment costs				
Annual fixed costs				
Depreciation	2 186	3 942	10 414	14 486
Interest	1 275	2 300	6 075	8 450
Insurance	217	391	1 033	1 437
Shelter	383	690	1 823	2 535
Annual variable costs				
Repairs	1 020	1 840	4 860	6 760
Seed cost	8 250	16 500	0	0
Harvest	717	1 435	0	0
Hauling	292	584	0	0
Total annual new equipment costs	14 340	27 682	24 205	33 668
Expected change in annual net profit	3 260	7 518	-5 080	-9 961

Switching from planting soybean in 0.76 m rows at 321,000 seeds ha^{-1} to 0.19 m rows at 420,000 seeds ha^{-1} resulted in an increase in net farm profitability of $3260 for 250 ha ($13.04 ha^{-1}) and $7518 for 500 ha ($15.03 ha^{-1}) of soybean production. The 160 kg ha^{-1} yield advantage of soybean in 0.19 m rows at a selling price of $0.42 kg^{-1} offset the costs of purchasing and owning a grain drill and the added seed cost associated with planting at the higher seeding rate. This increase is somewhat greater than the $8.48 ha^{-1} advantage reported by Lambert and Lowenberg-DeBoer (2003) for a corn-soybean rotation in which soybean was planted in 0.25 m rows and the corn was planted in 0.76 m rows compared to seeding both corn and soybean in 0.76 m rows.

Table 7 shows partial budget analyses, based on the yield data at the Livingston Co. location and market prices in New York in 2010 and 2011, for neighboring farms switching from seeding soybean in 0.76 m rows to planting soybean in 0.38 m rows at two farm sizes in a 50-50 corn-soybean rotation (250 and 500 ha of soybean annually). By replacing the 0.76 m planter with a 0.38 m planter, a farm would no longer incur the cost of owning the 0.76 m planter, so we considered these savings as added income change for the purposes of these analyses (Table 7). There were no yield differences between soybean in 0.38 and 0.76 m rows at both the high and low seeding rates so switching from planting soybean in 0.76 m rows to 0.38 m rows at 321,000 seeds ha^{-1} provided no additional revenue. Although the farm would no longer incur the ownership and operating costs associated with the 0.76 m planter, the lack of yield increase coupled with the greater ownership and operating costs of the 0.38 m planter led to a decrease in net farm profitability. The lack of economic advantage for the 0.38 m rows vs. the 0.76 m rows differs from previous research. Lambert and Lowenberg-DeBoer (2003) reported a $6.56 ha^{-1} advantage in net returns for soybean planted in 0.38 rows compared to soybean planted in 0.76 m rows. DeBruin and Pedersen (2008) found that planting soybean in 0.38 m rows increased farm profitability by $74 ha^{-1} on farms planting 288 ha of soybean in a 50-50 corn-soybean rotation. The main reason for the increase in net returns for these studies was a significant yield advantage for 0.38 vs. 0.76 m rows, an advantage that was not observed at either location in this study.

CONCLUSION

Field-scale studies on soybean row spacing showed inconsistent and lower yield increases to narrow rows compared to previous small-plot research in northern latitudes. For example, row spacing and seeding rate did not affect seed yield under no-till conditions in a location close to a small-plot research study where soybean yielded 15% more in 0.19 vs. 0.76 m rows. Narrow row soybean (0.38 and 0.19 m), however, did suppress weed resurgence after post-emergence glyphosate application better than soybean in 0.76 m rows, which may have future weed control consequences. Nevertheless, results indicate that the grower at the no-till location should not purchase a new grain drill in the future to plant soybean in 0.19 m rows, if in a corn-soybean rotation exclusively, but instead should plant corn and soybean with a row crop planter in 0.76 m rows.

Soybean planted in 0.19 m rows at a seeding rate of 420,000 seeds ha^{-1} yielded 4% more than soybean in 0.76 m rows at a seeding rate of 321,000 seeds ha^{-1} at a location where chisel tillage and secondary tillage were used. Partial budget analyses indicated that planting soybean with a grain drill in 0.19 m rows at 420,000 seeds ha^{-1} would have increased profit by about $30 ha^{-1} compared with 0.76 m rows at 321,000 seeds ha^{-1} in 2010 and 2011. Market prices for soybean, however, fluctuate, whereas seed costs have steadily increased. Consequently, the grower at this location, who practices a corn-soybean-wheat rotation, may wish to reconsider planting with a grain drill in years when the expected market price for soybean is low but seed costs are high.

Soybean growers close to the chisel tillage location with similar soils who practice an exclusive corn-soybean rotation may wish to consider adding a grain drill to their equipment complement to plant soybean, especially if soybean prices remain high. The 4% yield advantage of soybean in 0.19 m rows offsets both the costs of purchasing and owning a grain drill and the added seed cost associated with planting at the higher seeding rate at 2010 and 2011 prices. If soybean prices decrease, however, the 4% yield advantage may not offset the added fixed and variable costs for planting soybean with a grain drill.

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