OPTIMAL ROW WIDTH FOR CORN AND SOYBEAN

by

Dayton M. Lambert
and
Jess Lowenberg-Deboer

Staff Paper # 01-10

October 2001

Dept. of Agricultural Economics
Purdue University

Optimal Row Width for Corn-Soybean Production
Dayton M. Lambert and J. Lowenberg-DeBoer

Introduction

Soybean production in narrow rows is not a novel idea. Wiggans (1939) reported yield advantages of drilled soybeans in narrow rows (8-inches) over soybeans planted in 28-inch rows. However, farmers, consultants, and extension agents face a bewildering array of information regarding optimal row widths intended to maximize return from corn and soybeans during a growing cycle. This information is further complicated by the choices of planting equipment specialized for certain row widths.   That soybeans planted in narrow rows generally out-yield soybean produced in wider rows is well documented. However, what is not clear is which narrow row width consistently and significantly outperforms other widths, yield-wise and return-wise, in which regions (Devlin et al., 1995).

Farmers frequently ask about optimal row width for corn and soybeans because equipment costs can be reduced when both are planted with the same equipment. Hallman and Lowenberg-DeBoer (1999a) addressed the corn part of this question looking at the costs associated with switching from wide to narrow row production of corn. Using mean-variance and stochastic dominance analysis, they found modest returns to narrow row (20-inch) corn in the Northern corn-belt region when no insecticides were required. To answer the row width question for combined corn and soybean systems, it is necessary to also quantify the benefits of narrow rows in soybeans.   In addition to quantifying expected profitability of narrow row soybeans, this study attempts to answer the broader question of what row width is best for combined corn and soybean systems in the Corn Belt Region.

Reported Agronomic and Economic Benefits of Narrow Row Soybean

Agronomic research suggests that soybeans produced in narrow rows generally have superior yields to soybeans planted in wider (30-inch) rows when conditions are favorable. Doster et al. (1997) estimate that soybean yields grown in 14 to 18-inch or 7-inch rows are superior to soybean cultivated in 30-inch rows by 6 to 18%, respectively. Costa et al. (1980) found that soybeans grown in 10-inch rows out-yielded soybeans produced in 30-inch rows by 21%. Leuschen et al (1992) found that yields were 8% to 14% greater for soybean grown in 10-inch rows compared to soybeans grown in 30-inch rows, and Parker et al. (1981) found that soybean cultivated in 18-inch rows out-yielded soybean grown in 30-inch rows by 4%. Over a six-year trial in Illinois, Cooper (1977) found that soybeans produced in 7.5-inch rows out-yielded soybeans grown in 20 and 30-inch rows by 10% to 20%, respectively. Yield increase observed from soybeans grown in narrow rows has been attributed to an increased leaf area index resulting in more efficient interception of sunlight and increased rates of photosynthesis (Shibles and Weber, 1967). However, in stressful conditions where water was a limiting resource, Taylor (1980), Alessi and Power (1982), and Cooper and Jeffers (1984) found no significant differences

1

in yields between soybeans grown in narrow (7- to 10-inch) or wide (30-inch) rows. Devlin et al. (1995) bring to light the fact that though there are many reported yield benefits from narrow row soybean, there are equally as many results that are inconclusive.

Agronomic research also indicates that soybeans produced in narrow rows can suppress weed competition (Yelverton and Coble, 1991), and reduce the amount of herbicide needed to control weed growth. Mickelson and Renner (1997) found that planting soybeans in 7.5-inch rows reduced the frequency of needed herbicide applications and increased crop profitability, concluding that soybeans planted in narrow rows out-compete weeds for space and light. Nelson and Renner (1998, 1999) provide evidence that, in some situations, soybeans produced in narrow rows decrease the amount of herbicide needed, thereby increasing economic benefits to narrow row soybeans.

Although there is ample literature with reference to the yield benefits of narrow row soybeans, relatively few studies have documented economic benefits. Oriade et al. (1997) found estimated net returns for narrow (19-inch) superior to wide row (38-inch) spacings for irrigated and non-irrigated soybeans. They estimated returns to non-irrigated, narrow row soybeans to range between $96 to $189/acre, and net returns to non-irrigated soybean grown in wide rows to range between $57 and $162/acre. Oplinger (1980) found a $32.50/acre increase in net returns with row width reduction from 30 to 10-inches. Combining soybean production data from Illinois, Indiana, Ohio, Iowa, and Nebraska, Paszkiewicz (1998) found that soybeans planted in 7.5 and 15-inch rows yielded 2.8 bu/acre (5.8%) over 30-inch row spacings. In that report, net returns from narrow row soybeans (7.5 and 15-inch) were superior to soybeans produced in 30-inch rows ($300.49, $297.38, and $282.06/acre, respectively).

Reported Agronomic and Economic Benefits of Narrow Row Corn

Agronomic research on corn row width has been going on since at least the early 20th century (Hume et al., 1908), and potential yield benefits of narrow row corn were recognized in the 1940s (Bryan et al., 1940). Paskiewicz (1996) reported that yields of corn grown in narrow rows corn was 3.2% greater than corn produced in wide rows in the Corn Belt region, and in Northern Iowa, corn grown in narrow rows increased yields by 4.2%. However, Nielsen (1996) concluded that corn yield increases due to narrow row spacing are not consistent, and that frequency of stalk breakage increases when corn is planted in narrow rows. Nielsen also suggested that insecticide cost for narrow row corn increase because it is applied on a linear foot basis.

Hallman and Lowenberg-DeBoer (1999a) found that long-term equipment costs increased with narrow row corn by about $6.50/acre. They found that moving from wide (30-inch) to narrow (20-inch) rows increased rootworm insecticide costs by 50%, or $8/acre. For a producer in the Northeast Corn Belt region who had a planter that was used for corn only, they concluded that narrow row corn could generate on average $8.75/acre net returns if rootworm insecticide was not needed. In the Northwestern Corn Belt region, estimated net returns to corn grown in narrow rows was $2/acre greater than

conventional, 30-inch rows. Narrow row corn resulted in lower net returns in the Central and Southern Corn Belt. They estimated that producers who switched from 30-inch row corn and drilled soybeans to a narrow row planter for both crops would reduce equipment costs by as much as $10/acre for soybean and $3.50/acre for corn. They also estimated that a producer who currently uses a 30-inch planter for corn and row splitters for 15-inch row soybeans would incur an extra annual equipment cost of about $6 per acre when moving to 15-inch row corn because of the high cost of custom built 15-inch row corn heads.

Materials and Methods

Most of the data used in this analysis are from publicly available sources, found either in refereed journals or on the World Wide Web. This is the data available to producers, agricultural consultants, and field agronomists who are faced with the practical problems of row width choice. The drawbacks and biases that accompany this type of data are clear. Planting methods used by research institutions vary according to regions, available farm machinery, regional differences in production practices, and the interests of sponsors. Consequently, experimental designs accounting for these sources of variation economize research funding using elaborate split plot and/or randomized block designs. It is still not clear which narrow row width consistently and statistically outperforms other widths, yield-wise and return-wise, in which regions (Devlin et al., 1995). Though it is well-documented that soybean cultivated in narrow rows out-yield soybeans grown in wider rows, yield variation between reports may be in fact due to different experimental designs, and the particular research questions at hand. Another problem complicating the use of publicly available data sources is that there is no general agreement as to what constitutes narrow and wide row cultivation. This study identified 12 soybean row widths reported in the literature. Despite these drawbacks, the publicly available data is the best available to most producers and agribusinesses.

Results based on the public data set were crosschecked with a data set provided by Pioneer Hi-bred International (Pioneer). This data set included yield data collected between 1987 and 1995. Soybean yields from four row classes (10-inch, N=2746; 15-inch, N=1775; 20-inch, N=848; and 30-inches, N=2741) are reported.

This report uses yield data for non-irrigated soybeans and corn. Data for the narrow row soybean analysis includes research conducted in Ohio, Iowa, Illinois, Indiana, Kansas, Michigan, Wisconsin, Minnesota, Ontario, and North Dakota between 1966 and 2000. It should be noted that none of the trials used here explicitly tested row width in environments with strong white mold or other plant disease pressure. Following the economic analysis of soybean grown at different row widths, publicly available data for corn grown at narrow (15 and 20-inch, N = 122, N = sample size) and wide (30-inch, N = 122) rows compiled by Hallman and Lowenberg-DeBoer (1999a) was combined with the soybean dataset to estimate distributions of returns when corn and soybeans are grown in rotation. The corn and soybean data sets scan be downloaded at www.agecon.purdue.edu/research/pub_data.

Narrow row soybean analysis

Data from the states included in this report were pooled (Appendix I, III). Four row width classes were constructed to categorize soybean cultivation at different row widths: <10-inches (N = 233), 10-19.5 inches (N = 78), 19.5-30 inches (N = 95), and widths greater than 30-inches (N = 230; from here, RC-I, II, III, and IV, respectively) based on equipment specifications of planters and drills available to farmers and the categories found in the literature. It was assumed that soybeans planted in row widths less than or equal to 10-inches were sown with a drill. Averaging all of the row widths placed in RC-I yielded a mean row width of 7.5-inches. A mean value of 30-inches was found after taking the average of all row widths subsumed under RC-IV, while mean values for RC-II and III were 13 and 19-inches, respectively.

Unlike the Hallman and Lowenberg-DeBoer (1999a) narrow row corn analysis, no attempt was made to do a regional analysis for soybeans. This was because the number of observations by row width varied widely, with no information in some regions and row width categories (Appendix III). Also, there is no indication in the literature that there is a strong row width response that varies by region. For corn, this regional difference linked to latitude was a prominent hypothesis in previous studies.

None of the trials explicitly include the effects of white mold (Sclerotinia sclerotiorum) or other plant diseases, in spite of the widespread hypothesis that these problems are linked to row width (Edwards et el., 1999; Grau, 1984; Dorrance et al., 1998). However, limited evidence suggests that even when there are moderate yield losses caused by white mold, yields from soybeans produced in narrow rows are still superior to wide row spacings (Butzen, 1998). It should be assumed that the results hold for cases in which these plant diseases are not a problem.

Unlike the costs associated with switching over from wide (>30-inches) row corn to narrow row corn (<20-inches, Hallman and Lowenberg-DeBoer, 1999a), cost of switching from wide to narrow row widths for soybean would be primarily attributable to planting equipment. A switch to drilled narrow row soybeans can cut equipment costs since drills are usually less expensive than planters. Planters designed to plant at 15 or 20-inches are expected to be slightly more expensive than 30-inch planters because there are relatively more moving parts. The difference between RC-II and III lies in narrow row equipment availability, and the options open to farmers who are making the switch from wide row soybean and corn to narrower rows for both crops.

A spreadsheet was developed to calculate expected net returns between treatments for Pioneer and public soybean data sets. Equipment cost estimates used only commercially available machine list prices (Heartland Ag-Business Group, 2001). To avoid the issue of differences in timeliness, all planting equipment was assumed to cover a 40-ft swath. For the 900-acre farm model, all planting equipment was assumed to cover a 20-ft swath. Equipment costs from wide to narrow row widths assumed the purchase of a drill for RC-I, or the purchase of a 40-ft planter capable of planting within the range of RC-II or RC-III widths. Use of a 30-inch row, 40-ft planter for soybean cultivated in RC-

IV was assumed. Per-acre equipment cost estimates assume that planting time is the limiting factor and that a producer plans to complete corn and soybean planting in 10 working days (Doster et al., 1996). For a mixed, 50/50, 1800-acre corn-soybean rotation system, this implies the capacity to finish planting all soybeans in five working days. Assuming use of a 40-ft wide planter (RC-II, III, and IV), or two 20-ft wide 10-inch drills pulled with a dolly hitch (RC-I), an estimated planting rate of 15.3 acres/h (Doster, 1996), and a 12-hour work day, 900 acres of soybean could be planted in five working days days. For the 900-acre farm size, it was assumed that 8 row planters and/or the single drill combination could plant 900-acres (450-acres corn, 450-acres soybeans) in this time period.

Many farmers have a soybean drill for planting rows between 7 and 10-inches wide. Others modify 30-inch planters with row splitters to plant soybeans at widths between 15 and 20-inches. Analyses assumed purchase of a new planter capable of planting either RC-II or III widths. When the producer switches to RC-I, a drill and a dolly hitch to pull two 20-ft wide drills would be required to maintain timeliness. Thus, RC-II and RC-III categories were constructed to identify differences of net returns to soybean planted in either of these row classes.

A sinking fund approach (Hunt, 1995) estimated annual equipment costs with a 10-yr useful lifespan and a 10% discount rate. Insurance and annual property tax was estimated at 0.91%, and repairs were estimated at 4.66% of the list price/150-hour of use for seeding equipment (Doster, 1996). Prices for dolly hitches, planters, and drills were solicited from local equipment dealers in Central Indiana or taken from a bluebook equipment guide (Heartland Ag-Business Group, 2001). To account for the fact that farmers often negotiate equipment prices, actual purchase price was assumed to be 85% of the list price.

Net returns to soybean for the public and Pioneer datasets were determined using the mean of the prices from the states included in the data set between 1988 and 1999 ($5.97/bu, USDA-NASS, 2000). Hauling charges ($0.20/bu) and drying charges ($0.13/bu, Pierce, 2000) were subtracted from the sale price. Seed costs for drilled soybeans were estimated $6.14/acre more than the cost of seeding for all other row classes. This extra cost is based on the assumption that extra seed is needed for drilled soybean to cover seed breakage and misplacement (hence lower germination rates) caused by the inaccurate placement of the seed in rows by the drill. Soybean seed was estimated to cost $4.80/50,000 (Paskeiwicz, 1998), or $13.44/50-lb bag of seed. A seeding rate of 46 to 57-lbs/acre at 2,800 seed/lb was assumed for RC-II, III, and IV, while a seeding rate of 74-lbs/acre at a similar seed count was assumed for drilled soybean (Purdue Crop Diagnostic Training and Research Center, 1999). Glyphosate-resistant soybean seed cost was estimated to be $24.25 for a 50-lb bag of seed (Ohio Enterprise Budgets, 2000).

The soybean production model considered four weed control programs and their expected costs. For RC-IV, program-I assumed herbicide material and application costs with a pre-plant treatment of a chlorimuron ethyl/sulfentrazone co-pack (Canopy XL®) at

$12.12/acre, and 1.5 (half rate) to 2 post-plant applications of fomesafen (Flexstar®) at $15.19/acre. Soybeans grown in widths RC-I, II, and III assumed a pre/post-plant treatment using the same materials, except at a 1:1 ratio pre-/post-plant application rate, assuming narrower rows suppress weed growth. In a sensitivity analysis, an herbicide program was assumed for glyphosate-resistant (GR) soybeans grown in each row class. Herbicide costs for GR soybeans cultivated in RC-IV assumed at least two post-plant applications of glyphosate (2 x $7.09/acre), while GR soybeans grown in the other narrow row class widths received only one post-plant treatment. Hallman and Lowenberg-Deboer (1999a) found no difference between herbicide costs of narrow and wide-row corn, and they are not included in the analysis.

Narrow and wide row corn-soybean

For the combined corn-soybean analysis, of issue is whether the same narrow row equipment used to plant soybeans can be used to plant narrow row corn with little to no modifications. Presently, there is no mass-produced 15-inch row corn head commercially available. The 15-inch corn heads must be custom-built and hence they are relatively high cost. However, 20-inch row heads are commercially available. The approach used to estimate equipment costs and net returns to narrow and wide row corn systems outlined by Hallman and Lowenberg-DeBoer (1999a) was adopted for this study.

A weighted average of the net returns to corn and soybean systems at every level of probability determined the empirical distributions of combined corn-soybean systems (Appendix I). Five corn-soybean rotation systems were compared: corn and soybean both cultivated at 15, 20, or 30-inches (C/S 15, C/S 20, and C/S 30); a corn-soybean system where soybeans were drilled in row widths of 10 inches or less, rotated with corn planted in 30-inch rows (10S + 30C); and a corn-soybean rotation that assumed planting soybean at 15-inches with custom built row splitters, then corn at 30-inches. Because of the lack of robust regional data sets for soybeans, no regional analysis was conducted for the corn-soybean rotation. A sensitivity analysis compares net returns per acre to each technology when a smaller farm size of 900-acres is assumed.

Equipment costs for wide and narrow row (20-inch) corn were determined following Hallman and Lowenberg-DeBoer (1999a). Equipment costs for a custom 15-inch corn head were estimated following Hallman and Lowenberg-DeBoer (1999b). Equipment costs for the 10S + 30C system included the cost of a 10-inch soybean drill plus a dolly hitch, combine and tractor tires, a 30-inch corn head, and a 16 row 30-inch planter. Equipment costs for the C/S 15, 20, and 30-inch systems included the costs of a planter and corn head following each row width specification, and combine and tractor tires following row width specification. When a 900-acre farm size was considered, use of a 20-ft 8 row 30-inch planter, or an 8 row 15-inch/30-inch planter with splitters was assumed. This assumes a 20-ft planting width. For the C/S 20 option, there were no prices available for 8 row planters. Instead, a 12-row 22-inch corn-soybean planter was used in this analysis. The dolly hitch was omitted from drilled soybean costs in the 10S + 30C alternative in the 900-acre farm analysis.

Another sensitivity analysis re-estimated net returns to corn-soybean systems based on recent corn and soybean loan rates (USDA, 2000). Estimated loan rates were based on the mean of the minimum loan rate in a given state included in the analysis. Another sensitivity analysis re-considered the 15-inch corn head price on a cost per-row basis comparable to 20-inch corn head per-row costs. A fourth sensitivity analysis compared net returns per acre for corn-soybean systems where glyphosate-resistant soybeans were produced in place of conventional soybean.

Stochastic dominance analysis

Empirical distributions of net returns to production systems were compared using the mean-variance decision rule (Markowitz, 1952) and stochastic dominance (Hadar and Russel, 1969). The mean-variance rule assumes that the dominant alternative must have either a higher mean for a given variance or a lower variance for a given mean. The stochastic dominance analysis used the spreadsheet approach outlined by Lowenberg-DeBoer et al. (1990) and Hien et al. (1994). Net return per acre was estimated for each data point using the cost and price assumptions outlined above. The analysis assumed that each observation in the dataset had equal probability of occurring. Stochastic dominance compares cumulative distributions of outcomes based on two observations about human nature:

(i)   most people prefer more to less
(ii)   most people prefer to avoid low value outcomes.

Observation (ii) implies that humans are risk averse, but is not the same as saying that individuals avoid variability. Most people enjoy variability so long as they benefit from the outcomes (e.g. higher yields, higher crop prices, higher profits), but are risk averse to downside variability. Those preferring more to less, but who do not seek to avoid variability are characterized as risk neutral.

These observations are quantifiable in terms of empirical distributions using two decision rules that correspond to the two assertions made above regarding human behavior: first-degree stochastic dominance (FDSD) and second-degree stochastic dominance (SDSD) rules. FDSD assumes decision makers prefer more to less, and states that an alternative is preferred over others if it provides a higher outcome at every level of probability. Expressed graphically, the preferred distribution is always to the right of other distributions.

SDSD assumes risk aversion. The area under the empirical distribution is a measure of the propensity of an alternative to have low-value outcomes. An alternative is dominant over others if the area under its empirical density curve is smaller at every outcome level. FDSD is easier to visually identify than SDSD. In the simple case of a cumulative distribution starting to the right of an alternative distribution and crossing over only once, the distribution to the right at the horizontal axis dominates if the area between the distributions below the crossover is greater than the area between the

distributions above the intersection. Anderson (1974) provides discussion and examples of stochastic dominance use in interpreting agronomic research data.

Kolmogorov-Smirnov tests

The Kolmogorov-Smirnov (K-S) test was used to determine the reliability of the stochastic dominance results. The K-S statistic D ("distance") is used to determine whether two datasets as characterized by their empirical distributions are significantly different. The K-S test statistic tests whether the distribution of a variable is the same across different groups by measuring the maximum vertical deviation between two empirical distributions at their maximum distance (SAS, 1996). The alternative hypothesis is that the two estimated distributions belong to the same underlying distribution. That the distributions would diverge from one another by such a distance D is given a probability value. The K-S test is non-parametric in the sense that it makes no assumptions about the underlying distribution of the data. When the calculated probability of the K-S D statistic is at or below the specified Type-I probability level, more reliability can be attributed to FDSD and SDSD test results.

Data resampling and bootstrapping

Results were resampled to estimate the robustness of the original data sets using the non-parametric bootstrap methodology outlined by Efron and Tibshirani (1982). Bootstrap experiments replicated net returns from the Pioneer, public soybean, and combined corn-soybean data sets. Observations from a parent data set were randomly drawn with replacement assuming each observation had an equally likely chance of being selected. This means that in some bootstrap data sets some original observations may be missing or might appear more than once. Bootstrap estimates for means and variances were simulated with:

$$(1) \qquad \hat{\theta} = \sum_{m=1}^{M} \hat{\theta}_n^* \Big/ M$$

$$(2) \qquad \hat{V}_B(\hat{\theta}) = \sum_{m=1}^{M} (\hat{\theta}_m^* - \hat{\theta}^2) \Big/ (M-1)$$

where equation (1) provides the bootstrap estimate of the mean and (2) variance estimate of the parent data set: $\hat{\theta}_1^*, \hat{\theta}_2^*, ..., \hat{\theta}_m^*$ are the bootstrap estimates at each iteration within M (Lohr, 2000). Estimates of median values were also determined using this procedure.

Once the number of randomly drawn observations equaled the sample size of the parent population, the new set was sorted in ascending order, and the process repeated again (for M = 1000 and 2500 cycles). The bootstrap methodology is not a remedy for improving poor data sets. However, the technique is useful for verifying consistency within a data set, hence an additional method whereby dataset reliability can be assessed.

Results and Discussion

Yield and net returns to narrow row soybean

Mean yields for RC-I of the public data set (58.45 ± 1.05 bu/acre, mean ± standard error), were superior to the other row classes (Table 1). Soybeans planted in narrow rows RC-II and III (55.79 ± 1.55 and 55.66 ± 1.47 bu/acre, respectively) yielded more than soybeans planted at wider row widths (50.43 ± 0.96 bu/acre). Yields for soybean planted in row widths less than 10-inches were about 5% greater than RC-II and III, and 16% higher than RC-IV. Soybeans produced in RC-II and III yielded about 10% more than RC-IV. Soybean yield for RC-II was less than 1% higher than yields from RC-III.

In the Pioneer data set, estimated mean yield for soybeans produced in RC-II (47.21 ± 0.25 bu/acre) was slightly superior to the RC-I yield (47.00 ± 0.24 bu/acre, Table 2). Mean yields for soybean grown in RC-III and IV were 46.50 ± 0.48 and 44.58 ± 0.21 bu/acre, respectively. Soybeans produced in RC-II were superior to yields of soybean grown in RC-I, III, and IV by 0.46, 1.5, and 5.57%, respectively.

Herbicide and Soil Fertility costs

Switching from RC-IV to any narrow row strategy decreased herbicide costs. Per acre cost decreased from $38.64 to $31.04/acre for wide row and all narrow row classes, respectively. A sensitivity analysis comparing wide and narrow row glyphosate systems indicated herbicide costs for narrow row soybeans were half as much as costs for soybeans planted in wide rows ($7.09 and $14.18/acre, respectively), since only one herbicide application was assumed for narrow rows.

Following Doster et al. (1996), cost of lime, phosphorous, and potassium removal per soybean rotation were $0.22, 0.12, and 0.01/acre at removal rates of 0.8, 1.4, and 5.1 lbs/acre/cycle per nutrient, respectively. Nitrogen removal was not considered since soybeans are nitrogen-fixing legumes. Soil fertility costs ranged between $20.19 to $21.53/acre for RC-II and III, and I, respectively. The combined soil fertility cost average for RC-II and III was $21.22/acre, whereas costs for RC-IV were $19.00/acre.

Equipment costs for narrow row soybeans

Unlike the shift from wide to narrow-row corn (Hallman and Lowenberg-DeBoer, 1999a), the focus of the narrow row soybean cost discussion centers on planting equipment. Changing soybean row width does not require a change in harvest equipment. Average cost for a 40-foot wide planter with 15-inch spacings was $77,000, whereas average cost for a planter of the same width but with 30-inch spacings was $69,000 (Table 3, MSRP – manufacturer's suggested retail price, Heartland Ag-Business Group, 2001). Twenty-foot wide 10-inch drills were estimated to cost between $13,000 and $45,000 each (MSRP, including a dolly hitch; Heartland Ag-Business Group, 2001).

This range reflects the cost difference between integral and double-disk drill systems. Estimated total cost for the soybean drill-dolly hitch system was $32,155.

The average annualized planting equipment cost at width RC-IV was $13,489, or $14.98/acre (Table 3). Annualized operating expenses for a producer planting soybean at this row width who decides to switch to RC-II or III from RC-IV increases by $1,657 ($1.84/acre) and $2,194 ($2.44/acre), respectively (Table 4). However, when a producer switched over to RC-I from the widest row width, annualized operating costs decrease by $6,896, or $7.66/acre. These results are expected since cost increases when moving from RC-IV to RC-II or III because the same type of equipment is used (i.e. a planter), but with almost twice as many rows, hence almost twice as many moving parts. Cost decreases when moving from RC-IV to I because of the change in equipment from planter to drill. Planters are more complex pieces of machinery, and hence more expensive. Drills are simpler and cheaper, but not as accurate in terms of seed placement. Soybeans are tolerant of irregular seed placement; they compensate, whereas with corn, drills are not appropriate because corn does not compensate very well with irregular seed placement. Including herbicide costs, total costs of soybean production decreased by $3.69, $3.10, and $12.72/acre switching from RC-IV to RC-III, II, and I, respectively.

Equipment costs for narrow row corn-soybean systems

Making the switch from C/S 30 to 10S + 30C was the most expensive ($3.49/total acres, annualized costs) compared to the narrow row corn-soybean systems at the 15 and 20-inch row widths ($3.11 and $2.03/acre, respectively). The total difference in total annualized costs for moving from a C/S 30 system were highest for the 10S + 30C alternative ($6,279) compared to the C/S 15 and 20 systems ($5,590 and $3,658, respectively, Appendix II). Purchase cost estimates increased by $28,831 for the 10S + 30C alternative, whereas the purchase price for equipment increased by $33,410 and $23,559 for the C/S 15 and 20 systems, respectively (Appendix II). Similar to the cost differences observed between the RC-II and III options with soybean only, the switch to narrower rows from a 30-inch row spacing for corn and soybean was more expensive for the narrower row (C/S 15) since there are more moving parts in the planting machine and custom built corn head. The custom-built 15-inch head does not seem more expensive than a commercial 20-inch head on a per-row cost basis. The estimated cost per row for a commercially available 20-inch corn head was $3,129/row. Based on this figure, the estimated MSRP cost for a commercially available 15-inch corn head was $50,072.

When smaller equipment costs were considered with the 900-acre farm size, annualized costs for the 10S + 30C system were less expensive since only one 20-ft drill is purchased, and no dolly hitch is required ($3.49/acre, Appendix III).

Estimated Fertility costs for corn-soybean systems

Nitrogen, phosphorous, and potassium removal rates for corn were estimated to be $0.15, $0.22, and $0.12/lb/bu, and lime removal rates were estimated to cost less than $0.01/acre. Fertility costs for C/S 30 were $71.78/acre, while costs for C/S 15 and C/S

20 alternatives were about $75/acre each. Fertility costs for the 10S + 30C option were $74.32/acre. Herbicide costs estimated in the narrow row soybean analysis were similar to those estimated for the corn-soybean analysis.

Mean variance analysis and stochastic dominance

Narrow row soybean

In the baseline analysis of the public data set (Table 5), the drilled soybeans (RC-I) have the highest average net return per acre ($263.02 ± 5.51/acre). The narrow-row option RC-II had a slightly higher estimated net return ($245.03 ± 8.15) than RC-III (244.98 ± 7.75). Net returns of soybeans grown in width RC-I were about $52/acre more than net returns from soybeans produced in RC-IV ($211.68 ± 5.05/acre). Likewise, net returns of RC-II and III surpassed returns of RC-IV by about $34/acre. The difference in net return per acre between RC-I and RC-II and III was about $18/acre. When the mean variance rule is strictly applied, RC-II is preferred to RC-III and IV, but not RC-I. The mean-variance rule does not allow a ranking of RC-I over RC-II, III, or IV, because RC-I has a higher variance than these options.

Net returns per acre for soybeans grown at different widths followed a similar trend in the Pioneer data set (Table 6). Even though the 20-inch row class had slightly higher yields than the 10-inch row class, net returns were highest for soybeans grown in the 10-inch row class ($201.73 ± 1.33/acre), followed by the 15 and 20-inch row classes ($198.78. ± 1.42/acre and $197.58 ± 2.55/acre, respectively) since RC-I annualized equipment costs are less than equipment costs for RC-II and III (Table 3). Net returns were lowest for soybeans grown in the 30-inch row class ($179.84 ± 1.19/acre).

A Kolmogorov-Smirnov 2-Sample Test indicated that the empirical distributions representing RC-II and RC-III distributions were different at the 5% level (D = 0.2140, P = 0.0395, P = probability), while all other row class comparisons were different at P < 0.001. The results of the K-S test suggest comparison using stochastic dominance analysis is quite reliable for the public dataset.

Row class I stochastically dominates RC-IV according to the first rule, but not RC-II or III since it has a lower minimum value (Table 7, Figure 1). Row class III displayed FDSD over RC-IV. The K-S test for this pairing was significant at P < 0.0001 (D = 0.3007, Table 5, Figure 1). Row class II did not dominate RC-IV as the tails of each distribution crossed before positive net returns were observed. However, net returns from RC-II were superior to RC-IV at all probability levels in the CDF after 3%. Similarly, RC-I was non-dominant when compared with RC-II, but returns from RC-I are superior to RC-II from about the 32nd to the 97th percentile ($240 to $385/acre, respectively, Figure 1a).

The cumulative distributions of RC-III and RC-II are intertwined. Row class II starts to the left with a negative number, but from about the 4th percentile to the 31st percentile it is to the right until the 83rd percentile ($298/acre). In better than average

growing conditions, RC-III appears to be preferable to RC-II as the net returns afforded by RC-III overtake those from RC-II in probability as conditions improve. However, after about the 95% probability level, the respective distributions separate with superior returns belonging to RC-II. The estimated returns of the 15 and 20-inch row widths for corn-soybean systems are almost identical and stochastic dominance cannot rank them. The 30-inch row class (RC-IV) is never the preferred option in any analysis.

Kolomogorov-Smirnov tests for the Pioneer data set indicated that all distributions of net returns per acre were different at P < 0.0001 (Table 8). Stochastic dominance results indicated that the 10-inch row class displayed SDSD over the 30-inch row class (Figure 2). The 15-inch row class was the only other row class displaying stochastic dominance where it was superior to the 30-inch row class following the SDSD order (Figure 2).

Use of the mean-variance criteria assumes some risk aversion. Mean-variance analysis assumes all variability is bad, including upward variability, while stochastic dominance can recognize that upside variability can be positive. Mean-variance analysis indicates that in the publicly available data set RC-II is preferred to the wider row classes, but that the two narrowest row classes cannot be ranked (Table 5). However, the actual difference in the means of RC-II and III is trivial ($0.05/acre). Rankings of mean net returns between RC-II and III switched after the parent public data sets were bootstrapped, but the rank order of the median values and standard deviations remained similar to the parent data set. The ranking patterns of the mean and standard error values of the public dataset are similar to the pattern observed in the larger Pioneer datasets.

A similar ranking pattern of mean net return estimates and mean-variance analysis results is observed in the Pioneer data set (Table 6). Mean-variance analysis of the net returns of this data set indicates 15 and 20-inch row classes are preferred to the 30-inch option, but the 10-inch alternative cannot dominate because of its relatively high standard deviation. With mean-variance analysis, the 15-inch is preferred to the others, but the comparison with the 20-inch alternative depends on a slight ($0.08/acre) difference in mean return. Stochastic dominance cannot rank the 15 and 20-inch row classes, but both mean-variance and stochastic dominance indicate that the 15-inch option dominates the widest 30-inch row class. Stochastic dominance results indicate the 10-inch row class dominates the widest row class by the second rule. Rankings of mean, median, and standard deviation estimates of the bootstrapped samples were identical to the rankings observed in the parent Pioneer data set. That the data structure remained intact following the bootstrap experiments may be attributable to the large sample size of this data set. It is notable that the distribution patterns observed in the public data set figures generally similar to the shape of the curves observed in the Pioneer cumulative density figures.

Combined analysis of corn-soybean systems

The 10S + 30C option had the highest estimated net returns of $239.34 ± 6.67/acre (Table 9). Mean net returns per acre for the C/S 20 option was $237.35 ± 6.45/acre) followed by the C/S 15 ($235.91 ± 6.21/acre), then the 15S + 30C alternative

($234.61 ± 6.67/acre). The estimated net return for the C/S 30 system was $218.40 ± 6.45/acre. When the mean-variance rule is applied, the C/S 30 alternative is dominated by the C/S 15 and 15S + 30C options. The 10S + 30C option did not dominate any alternatives since the relatively high variance of this dataset did not allow a ranking with the mean-variance criteria.

Probabilities were not assigned to K-S D statistic test results for the combined corn-soybean analysis since sample sizes (N = 100) were arbitrarily determined, but D-statistic values are presented in Table 10 to quantify the difference between the maximum deviation between the means of compared systems. Stochastic dominance results indicated that C/S 20 is FDSD over C/S 30 (Table 10). FDSD was also detected when the 10S + 30C and C/S 30 options were compared, with the 10S + 30C system dominating the C/S 30 alternative. The C/S 20 alternative dominates C/S 30 by the first rule since the cumulative distribution C/S 20 is always to the right of the C/S 30 CDF, and the FDSD condition of the 10S + 30C system over the C/S 30 alternative is apparent in Figure 3a. Comparison of the C/S 20 and 10S + 30C options shows considerable overlapping of both distributions after the 64th percentile, where the 10S + 30C option dominates the C/S 20 alternative until the endpoints of each distribution. However, the difference between expected net returns of these systems is only $2/acre (Table 9). No other instances of stochastic dominance were detected when remaining corn-soybean production systems were compared under baseline assumptions.

In all cases systems net returns per acre for systems with a narrow row soybean alternative are superior to the C/S 30 option. Inspection of the empirical distributions of net returns shows that 10S + 30C, C/S 15, 15S + 30C, and 20 alternatives are more likely to produce higher net returns per acre more frequently than wide row corn-soybean rotation systems. Net returns per acre from the 10S + 30C system are superior to the C/S 15 system after the 38th percentile ($230/acre) until the 98th percentile ($360/acre), though neither alternative stochastically dominated the other.

During moderate growing conditions, net returns per acre from the 10S + 30C option are superior to returns from the 15S + 30C system between the 32nd and 97th percentiles (about $230 and $370/acre level, respectively). Likewise, during moderate to good growing conditions net returns per acre are higher for the C/S 20 option compared to the C/S 15 and 15S + 30C alternatives. Between about the 26th and 96th percentiles ($210 and $360/acre) for the C/S 20 and 15 comparison, and the 19th and 98th percentiles ($190 and $360/acre) for the C/S 20 and 15S + 30C comparison, returns are greater for the C/S 20 option.

Although no instances of stochastic dominance were detected between the C/S 30 and 15 alternatives, net returns per acre are highest for the C/S 15 option as growing conditions improve. Following several crossing of the distributions in the lower tail, net returns for the C/S 15 system surpass returns from the C/S 30 option at the 5th percentile ($90/acre) and are to the right throughout the remainder of the comparison. Net returns per acre for the C/S 15 and 15S + 30C options are nearly identical throughout the ascent of each distribution, and stochastic dominance was not detected when C/S 30 and 15S +

30C were compared. However, like the comparison of the C/S 30 and 15 distributions, examination of the C/S 30 and 15S + 30C distributions in Figure 3a clearly indicates that 15S + 30C dominates net returns per acre from the C/S 30 option at all probability levels after the 5th percentile.

Rank of the bootstrap estimates of the mean, median, and standard deviations of all alternatives were identical to the rank order of the parent data set (Table 9).

Sensitivity analysis

Net revenue per acre for corn and soybean systems were recalculated based on current loan rates. Estimated mean of loan rates (Farm Service Agency, USDA, 2000) for corn and soybean across states included in this report were $1.78/bu and $5.08/bu, respectively. The rank order of the mean net returns per acre for the loan rate sensitivity analysis was different than the corn-soybean baseline analysis (Table 11).   Ranking between the 10S + 30C ($171.79 ± 5.02/acre), C/S 20 ($168.20 ± 4.83/acre) and C/S 30 ($153.09 ± 3.40/acre) remained the same, but ranking between the 15S + 30C and the CS 15 options switched, with returns from the 15S + 30C option higher than the C/S 15 alternative ($167.12/acre and $166.84/acre, respectively). Thus, the choice of the most preferred production system shifts to the option that produces more soybeans and wider corn widths. In this analysis, stochastic dominance and K-S D-statistic results for the loan rate sensitivity analysis were similar to the baseline corn-soybean results as well (Table 12, Figure 4).

When glyphosate-resistant soybeans were considered in combination with corn, net returns to the C/S 20 system were highest ($237.05 ± 6.45/acre) compared to 15S + 30C, C/S 15 and 10S + 30C systems ($234.31 ± 6.19, $235.61 ± 6.21, and $226.91 ± 6.67/acre, respectively, Table 11). Estimated returns to the C/S 30 system were lowest at $218.60 ± 6.45/acre. With glyphosate-resistant soybeans the drill system drops to the 4th place because it requires the most soybean seed, and glyphosate-resistant seed is expensive. The difference between the C/S 20 GR option is $2.19/acre less than the 10S + 30C net returns in the baseline study. The C/S 20 displayed SDSD over the 10S + 30C and C/S 30 options (Table 12, Figure 5). No other instances of stochastic dominance were detected between remaining production systems. .

Farm size, 900-acres

For the corn belt combined analysis at the smaller farm size, the rank order of net returns per acre were similar compared to the baseline combined results. Estimated returns for the 10S + 30C option were slightly higher greater than the C/S 20 alternative by $1.52/acre (Table 13). The mean-variance result rankings were similar to those of the baseline analysis.

At regional levels, net return per acre rankings were similar to baseline the results (Table 13). Likewise, mean-variance analysis results were not different from the baseline results. The 10S + 30C ($230.46 ± 7.13) option ranked best among alternatives in the

Northwest Corn Belt. However, because of the relatively high variance of this alternative, it did not dominate any other options by the mean-variance rule. The C/S 30 option was dominated by the 10S + 30C option by FDSD, while the C/S 20 alternative was SDSD over the C/S 30 choice. No other instances of stochastic dominance were detected, but C/S 15, 20, and 15S + 30C options dominated the conventional row width option by mean variance analysis.

The rank order of net returns per acre for the Northeast Corn Belt region was similar to the baseline results of this region (Table 13). The C/S 20 option produced the highest net returns per acre ($245.76 ± 6.34), followed by the 10S + 30C alternative ($245.05 ± 6.80). The C/S 15 option ($237.53 ± 6.11/acre) was slightly higher than the 15S + 30C alternative ($237.32 ± 6.32). The C/S 20 option was FDSD over the C/S 30 option ($225.62 ± 6.56), and dominated the 10S + 30C option by the second rule. The 10S + 30C option dominated the C/S 30 alternative by FDSD, and the C/S 15 alternative was SDSD over the 15S + 30C option. No other instances of stochastic dominance were detected, and mean-variance rankings were similar to the baseline, combined analysis.

In the Central Corn Belt region, the rank order of net returns per acre was similar to the Northwestern region and baseline results. The 10S + 30C alternative had the highest net returns per acre ($249.06 ± 7.01), followed by the option C/S 20 at $246/acre. Mean-variance analysis results were similar as well, with the 15-inch soybean alternatives dominating the conventional row width option. Like the Northwestern Corn Belt results, the C/S 20 option was SDSD over the conventional row width option. The 10S + 30C alternative dominated the C/S 30 option by FDSD in the Central Corn Belt region.

Conclusions

This study indicates that producers considering switching from a wide to narrow row soybean production strategy will find that the most attractive production alternative is the 10-inch or less drilled soybean option. At this width soybean yields are highest when white mold and other plant diseases are not a problem. In terms of annualized equipment costs per acre, moving from a wide row soybean production system to the drilled soybean option costs less than RC-II and III alternatives because drills are less expensive than planters. Compared to the conventional wide row planting strategy, the drilled soybean option actually brings a net savings in equipment cost per acre to the farm operation of $7.31/acre when separate planting equipment is used on 900 acres of soybean. Coupled with superior yields, the switch to RC-I from wider rows makes financial and economic sense. When upside variability is considered as a positive attribute, stochastic dominance results indicate that a risk-averse producer would choose the narrowest row class when the farm operation has separate planting equipment for soybeans. Though RC-III is also less risky than RC-IV in terms of mean-variance and stochastic dominance rulings, net returns per acre from this alternative are 7% less than drilled soybeans. Results using the Pioneer data set agree with this conclusion: the 10-inch drilled soybean option is the preferred option for producers considering switching from wide to narrow rows.

The second part of this study quantified the net returns per acre considering a 50/50 corn-soybean rotation when a conventional row width of 30-inches is replaced by a narrower row planting strategy for either soybeans only or both crops. In all cases, net estimated net returns per acre for systems with narrow row soybeans were superior to the corn-soybean 30-inch alternative. Under the baseline conditions, expected net returns per acre are highest for the drilled soybean/30-inch row corn combination. The expected mean returns from the C/S 20 and C/S 15 systems are from $2/acre to $4/acre less than the 10S+30C strategy, but the difference in the risk analysis between technology combinations is not so clear. The net return distributions of all the systems with narrow row soybeans are relatively similar, and these rankings could change with a small shift in technology, prices, or acres planted to corn and soybean.

A sensitivity analysis indicated that even if a commercial 15-inch corn head were an option, expected net returns for the 15-inch option would be only $0.14/acre less than the custom-built corn head. Results calculated using current loan rates for corn and soybean yields were produced similar findings. The 10S + 30C and C/S 20 rotation strategies make the most economic sense in terms of financial returns and risk aversion.

If a producer considers using glyphosate-resistant soybeans in their operation while moving from a wide row corn-soybean system to narrow row combinations, the corn-soybean planting strategy that yields the highest expected net returns per acre is the 20-inch alternative. The second highest returns are afforded by the C/S 15 option. Returns are highest for these systems because relatively less soybean seed is needed for the 20 and 15-inch soybean system than the 10-inch option, yield of soybean grown in narrower rows are superior to soybeans grown in wider rows.

A limitation of the corn-soybean analysis is that it assumed 50/50 corn-soybean rotation over an 1800-acre farm. This assumption overlooks the possibility of combining corn and soybean over the whole farm in different acre ratios. Producers try to respond to annual price expectations by planting more or less corn-to-soybean. Only one farm size was considered in this analysis. Equipment prices for smaller farms may be different. In this analysis, net returns to corn and soybean systems are sensitive to equipment costs and prices, and changes in costs may change preferred rankings of production alternatives. Another limitation is that only one herbicide program was considered in the simulation. Combinations of herbicides, varied application schedules, and competitive pricing will affect the cost per narrow row system, and ultimately net returns to a particular option. Additionally, seed and equipment costs may vary at regional levels, both of which will affect the outcomes of this analysis. Another limitation of this study is that data for strong white mold presence was not included in this analysis. And lastly, rankings of corn-soybean production alternatives may also be sensitive if the data were looked at on a regional level.

Table 1. Average yield (bu/acre) and percentage change of yield of row classes I through IV in the publicly available data. Column percents indicate the relative advantage in yield of that particular row class compared to the row class identified in the corresponding row of the table.

	RC- I <10"	RC- II 10-19.5"	RC- III 19.5-30"	RC- IV 30"<
Mean	58.45	55.79	55.66	50.43
Standard deviation	16.00	13.68	14.35	14.55
Min	1	3	14	3
Max	98	89	77	80
Class I v. II, III, IV		4.78%	5.01%	15.92%
Class II v. III, IV			0.22%	10.63%
Class III v. IV				10.39%

Table 2. Average yield (bu/acre) and percentage change of yield of row classes I through IV in the Pioneer data set. Column percents indicate the relative advantage in yield of that particular row class compared to the row class identified in the corresponding row of the table.

	RC- I 10"	RC- II 15"	RC- III 20"	RC- IV 30"
Mean	47.00	47.21	46.50	44.58
Std	12.75	10.59	14.12	11.18
Min	0	0	0	0
Max	104	87	79	82
Class I v. II, III, IV		-0.46%	1.05%	5.13%
Class II v. III, IV			1.50%	5.57%
Class III v. IV				4.13%

Table 3. Estimated planter cost differences for four row widths used to produce soybeans. †

Row Width	MSRP	Purchase price	Average salvage value	Average annual financial cost‡	Average annual repairs	Annualized equipment costs
			----$----			
RC-I	32 155	27 331	13 601	3 595	2 412	6 593
RC-II	80 060	68 051	33 865	8 950	6 005	15 683
RC-III	77 319	65 721	32 706	8 644	5 799	15 146
RC-IV	68 859	58 530	29 127	7 698	5 164	13 489

† Cost estimates based on soybeans grown in conventional tillage systems. Calculations based comparison on average cost of commercially available new equipment with a 40-ft width. This assumes a planter or drill is used for soybean only.

‡Costs annualized at a 10% discount rate. Assumes 10 yr useful life for planter or drill, plus dual hitch. Annualized costs include property tax, insurance, and repairs.

Table 4. Estimated changes in equipment cost for soybean cultivation at different row widths.†

Row Class Change	Change in purchase price	Change in annualized cost	Change in cost/acre with resale ¶
	--$--		
RC-IV to RC-I	-31 198	-6 896	-7.66
RC-IV to RC-II	28 188	2 194	1.84
RC-IV to RC-III	7 191	1 657	2.44

† Cost estimates based on soybeans grown in conventional tillage systems. Calculations based comparison on average cost of commercially available new equipment.

‡Costs annualized at a 10% discount rate. Assumes 10 yr useful life for planter or drill, plus dual hitch. Annualized costs include property tax, insurance, and repairs.

¶Per acre costs assume a 900-acre farm. Per acre costs would be similar for other equipment and farm sizes would be similar if equipment capacity matched acreage. Smaller farms with smaller equipment are likely to have higher per acre costs.

Table 5. Net returns to soybean grown at different row widths from the publicly available data set.

	Mean	Median	Standard deviation	Standard error	Min	Max	CV
	-----------------------------------$/acre-----------------------------						
Parent set							
RC-I	263.02	281.92	84.15	5.51	-38.38	471.65	31.99%
RC-II	245.03	246.50	71.96	8.15	-31.12	417.35	29.37%
RC-III	244.98	271.41	75.50	7.75	24.70	355.06	30.82%
RC-IV	211.68	225.85	76.56	5.05	-35.26	366.65	36.17%
Bootstrap 1 (m = 1000)							
RC-I	262.79	287.65	82.92	5.43	-17.58	458.53	31.56%
RC-II	244.07	246.38	67.53	7.65	-5.74	401.84	27.67%
RC-III	244.53	271.17	74.00	7.59	27.87	353.41	30.26%
RC-IV	211.30	224.23	75.75	5.00	-21.19	351.80	35.85%
Bootstrap 2 (m = 2500)							
RC-I	262.49	288.11	83.03	5.44	-17.62	458.10	31.63%
RC-II	243.91	246.89	67.94	7.69	-5.18	403.44	27.85%
RC-III	244.38	271.22	74.03	7.60	28.09	353.37	30.29%
RC-IV	211.29	224.30	75.82	5.00	-20.99	351.97	35.88%

† RC-I = soybean grown in rows 10 inches or less; RC-II = soybean grown in rows ranging between 10.5 and 19.5 inches; RC-III = soybean grown in rows ranging between 20 and 30 inches; RC-IV=soybean grown in rows wider than 30 inches.

Table 6. Pioneer data set of net returns from soybean grown in four row widths.

	N	Mean	Median	Standard deviation	Standard error	Min	Max	CV
				-----------------------------$/acre-----------------------------------				
Parent data set								
10"		201.73	203.10	69.49	1.33	-44.16	502.98	34.45%
15"		198.78	194.35	59.68	1.42	-47.66	410.05	30.02%
20"		197.58	215.97	74.27	2.55	-47.09	368.54	37.59%
30'		179.84	183.82	62.07	1.19	-52.93	378.48	34.51%
Bootstrap I (m=1000)								
10"		201.59	204.08	69.31	1.32	-44.16	498.66	34.38%
15"		198.71	196.36	59.38	1.41	-47.66	399.60	29.88%
20"		197.48	215.63	74.00	2.54	-41.59	366.76	37.47%
30"		179.83	183.79	61.92	1.18	-52.93	357.49	34.43%
Bootstrap II (m=2500)								
10"		201.58	204.02	69.31	1.32	-44.16	497.51	34.38%
15"		198.73	196.34	59.43	1.41	-47.66	399.67	29.90%
20"		197.46	215.75	73.99	2.54	-41.56	366.77	37.47%
30"		179.79	183.79	61.97	1.18	-52.93	358.43	34.47%

Table 7. Kolmogorov-Smirnov (D statistic) and stochastic dominance (SD) results for net returns soybean grown in different row widths (public data set).

D P-value SD	RC-II	RC-III	RC-IV
RC-I	0.2628 0.0006 Non-dominant	0.2385 0.0009 Non-dominant	0.3587 0.0001 RC-I, FDSD
RC-II		0.2140 0.0395 Non-dominant	0.2768 0.0003 Non-dominant
RC-III			0.3279 0.0001 RC-III, FDSD

Table 8. Kolmogorov-Smirnov (D statistic) and stochastic dominance (SD) results for net returns soybean grown in different row widths (Pioneer data set).

D (P-value), SD	RC-II	RC-III	RC-IV
RC-I	0.073262 0.0001 Non-dominant	0.114508 0.0001 Non-dominant	0.160592 0.0001 RC-I, SDSD
RC-II		0.1815 0.0001 Non-dominant	0.1563 0.0001 RC-II, SDSD
RC-III			0.2694 0.0001 Non-dominant

Table 9. Net returns from corn† and soybean rotations at different row widths.

	Mean	Median	Standard deviation	Standard error	Min	Max	CV
	------------------------------$/acre----------------------------						
Parent data set							
CS15	235.91	241.01	62.07	6.21	20.43	379.03	26.31%
CS20	237.35	254.91	64.46	6.45	45.98	352.39	27.16%
CS30	218.40	231.97	64.52	6.45	40.76	334.40	29.54%
10S+30C	239.34	255.24	66.73	6.67	44.77	357.00	27.88%
15S+30C	234.61	241.47	61.87	6.19	29.27	368.27	26.37%
Bootstrap I (m=1000)							
CS15	235.28	240.89	60.68	6.07	32.73	365.92	25.79%
CS20	248.05	266.96	67.21	6.72	55.47	359.26	27.10%
CS30	214.56	225.37	63.71	6.37	44.99	328.88	29.69%
10S+30C	238.59	252.98	65.92	6.59	52.64	353.49	27.63%
15S+30C	229.73	235.96	60.68	6.07	34.81	360.23	26.41%
Bootstrap II (m=2500)							
CS15	235.02	240.60	60.98	6.10	32.38	366.17	25.95%
CS20	248.30	267.30	66.97	6.70	56.00	359.23	26.97%
CS30	214.93	225.92	63.65	6.37	45.08	328.90	29.61%
10S+30C	238.75	253.23	65.79	6.58	52.77	353.47	27.56%
15S+30C	229.69	235.93	60.76	6.08	34.67	360.41	26.45%

†Estimated acreage net returns for corn produced in 15, 20 and 30-inch row widths were $219.58, $221.26, and $216.58, respectively.

Table 10. Kolmogorov-Smirnov (D statistic) and stochastic dominance (SD) results for net returns from corn-soybean system distributions.

D, SD	C/S 20	C/S 30	10S+30C	15S + 30C
CS15	0.1200 Non-dominant	0.1500 Non-dominant	0.1200 Non-dominant	0.0400 Non-dominant
CS20		0.2100 CS 20, FDSD	0.0600 Non-dominant	0.1400 Non-dominant
CS30			0.2000 10S+30C, FDSD	0.1300 Non-dominant
10S+30C				0.1400 Non-dominant

Table 11. Loan rate and GR-soybean sensitivity analysis of net returns from corn and soybean rotations at different row widths for loan rates and GR soybean.

	Mean	Median	Standard deviation	Standard Error	Min	Max	CV
			------------------------------$/acre---------------------------				
Returns at loan rates							
CS15	166.84	170.18	46.47	4.64	4.22	277.62	27.85%
CS20	168.20	181.94	48.33	4.83	25.10	252.68	28.73%
CS30	153.09	163.16	48.39	3.40	19.24	239.39	31.61%
10S+30C	171.79	183.18	51.51	5.02	22.88	290.50	29.99%
15S+30C	167.12	171.60	46.25	4.62	10.96	268.11	27.68%
Returns from GR soybean							
CS15	235.61	240.71	62.07	6.21	20.13	378.73	26.35%
CS20	237.05	254.61	64.46	6.45	45.68	352.09	27.19%
CS30	218.60	232.18	64.52	6.45	40.96	334.60	29.51%
10S+30C	226.91	242.81	66.73	6.67	32.34	344.58	29.41%
15S+30C	234.31	241.17	61.87	6.19	28.97	367.97	26.41%
Returns from CS15 with commercial header							
CS15							
	235.77	240.83	62.18	6.22	20.21	383.44	26.37%

Table 12. Kolmogorov-Smirnov (D statistic) and stochastic dominance (SD) results for net returns from sensitivity analysis results for corn-soybean system distributions.

	CS20	CS30	10S+30C	15S+30C
K-S D/SD-loan rates				
CS15	0.1400	0.1600	0.1500	0.0300
	Non-dominant	Non-dominant	Non-dominant	Non-dominant
CS20		0.2200	0.0900	0.1400
		CS 20, FDSD	Non-dominant	Non-dominant
CS30			0.2300	0.1500
			10S+30C, FDSD	Non-dominant
10S+30C				0.1500
				Non-dominant
KS/SD-GMO soybean				
	CS20	CS30	10S+30C	15S+30C
CS15	0.1200	0.1500	0.1100	0.0400
	Non-dominant	Non-dominant	Non-dominant	Non-dominant
CS20		0.2100	0.1100	0.1400
		CS20, FDSD	CS 20, SDSD	Non-dominant
CS30			0.1100	0.1300
			Non-dominant	Non-dominant
10S+30C				0.1000
				Non-dominant

Table 13. Estimated net returns per acre for corn and soybean at different row widths by region (900-acre farm, 20-ft wide equipment).†

	Mean	Std	Rank
	------------------------$/acre---------------------------		
Northwest			
CS30	211.02	69.04	5
CS20	228.90	67.29	2
CS15	220.75	64.52	4
15S+30C	222.73	66.37	3
10S+30C	230.46	71.27	1
Central			
CS30	229.62	67.70	5
CS20	246.22	71.26	2
CS15	238.06	68.25	4
15S+30C	241.33	65.13	3
10S+30C	249.06	70.09	1
Northeast			
CS30	225.62	65.62	5
CS20	245.67	63.37	1
CS15	237.53	61.11	3
15S+30C	237.32	63.22	4
10S+30C	245.05	67.96	2
Combined			
CS30	219.30	64.52	5
CS20	237.21	64.46	2
CS15	229.01	62.05	4
15S+30C	231.00	61.85	3
10S+30C	238.73	66.73	1

† Corn price vectors for the regional analysis were: Northwest, $2.33/bu; Northeast, $2.40/bu; and Central, $2.53/bu.
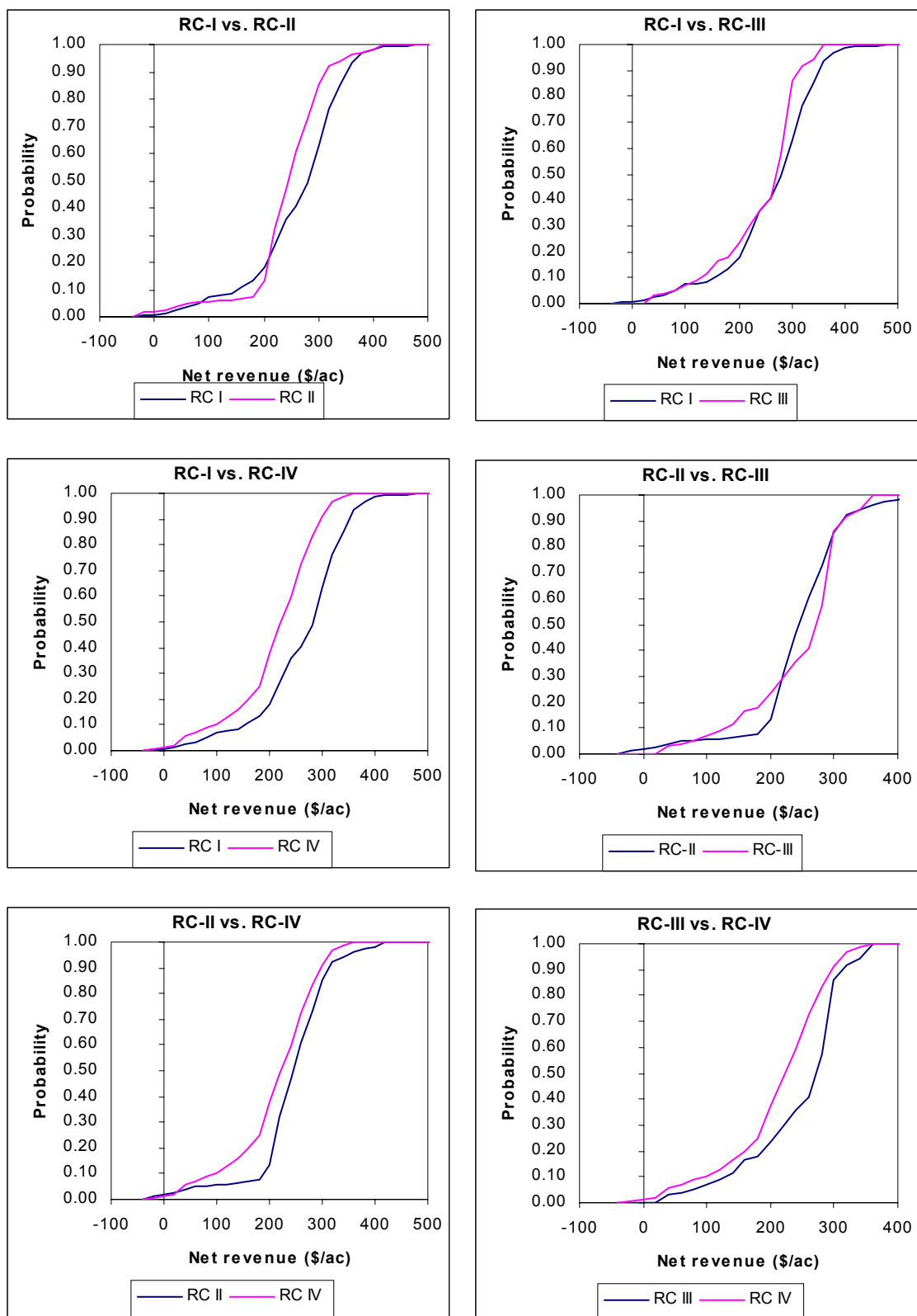
Figure 1a. Estimated cumulative density functions of net returns from soybean grown in different row widths (publicly available data set).
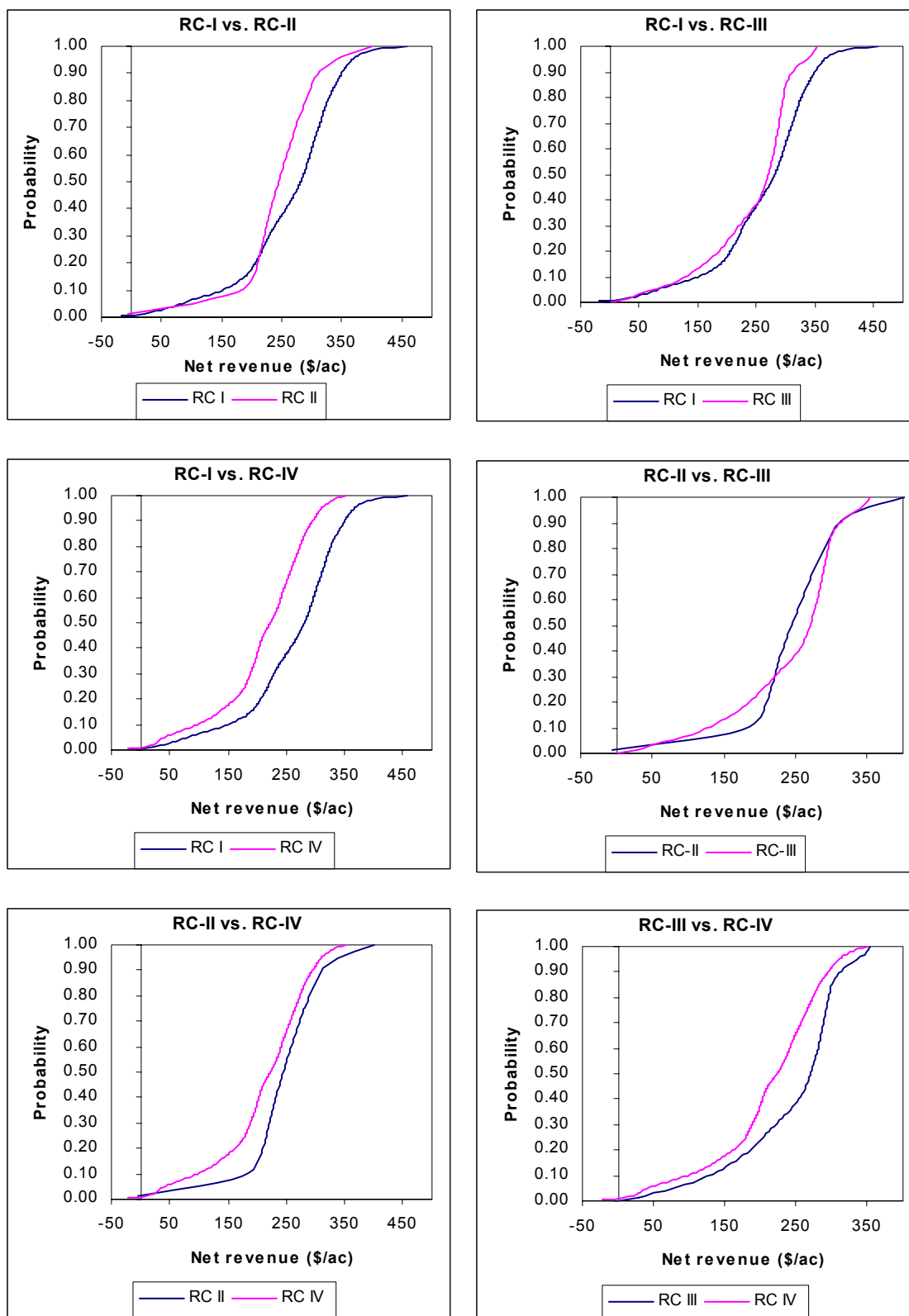
Figure 1b. Bootstrapped cumulative density functions (m=1000) net returns from soybean grown in different row widths (publicly available data set).
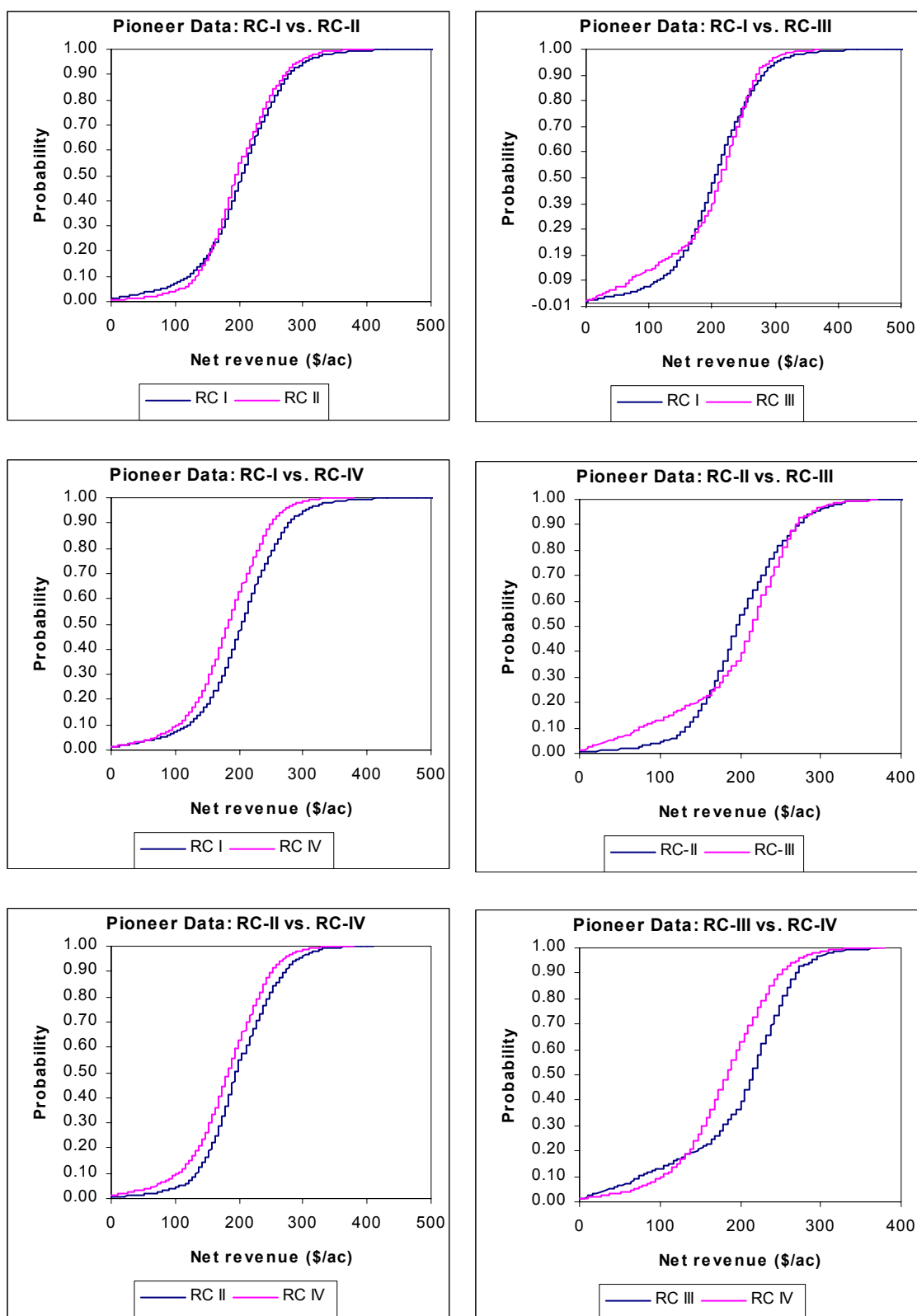
Figure 2a. Cumulative density functions of net returns from soybean grown in different row widths (Pioneer data set).
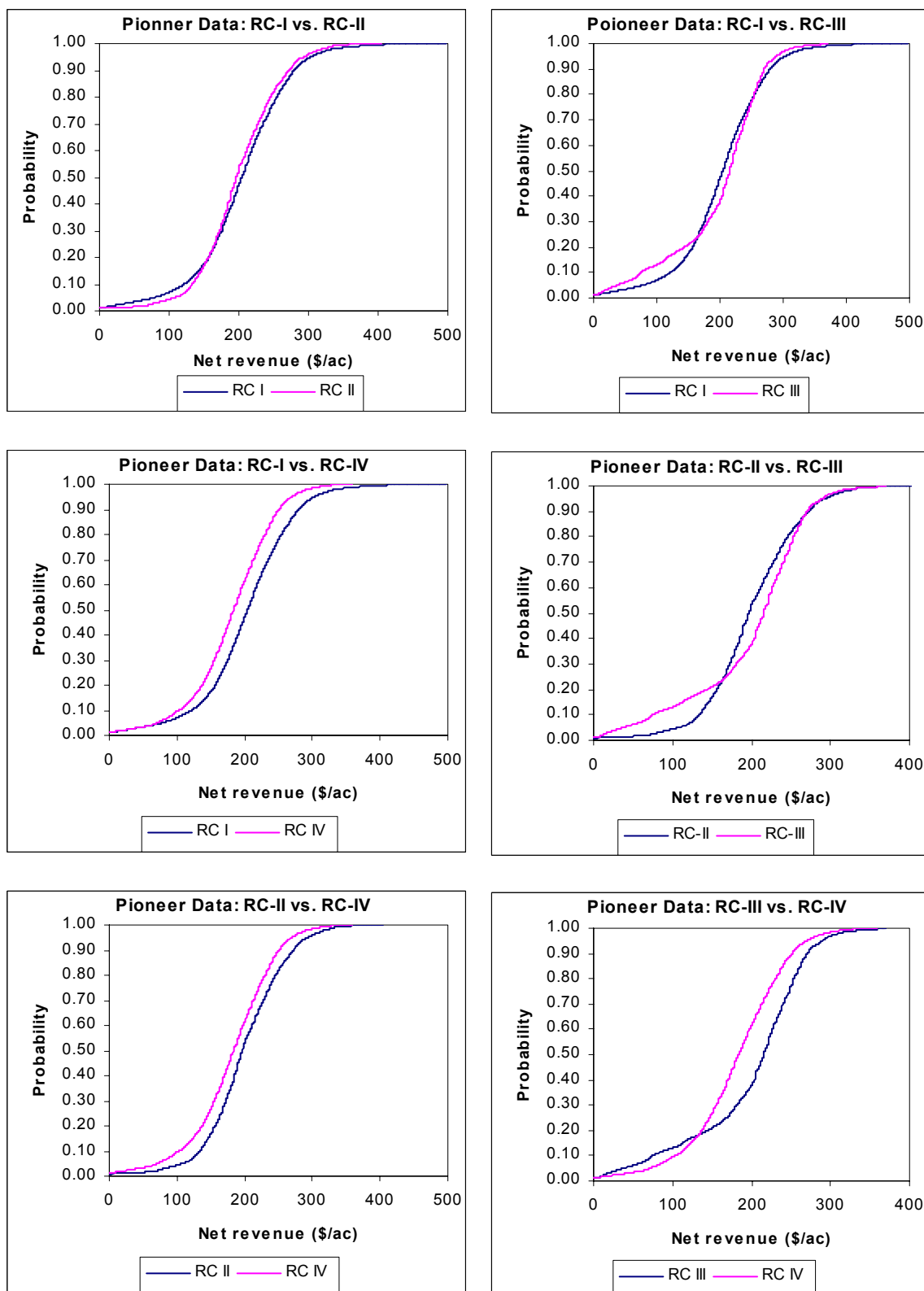
Figure 2b. Bootstrapped cumulative density functions (m=1000) of net returns from soybean grown in different row widths (Pioneer data set).
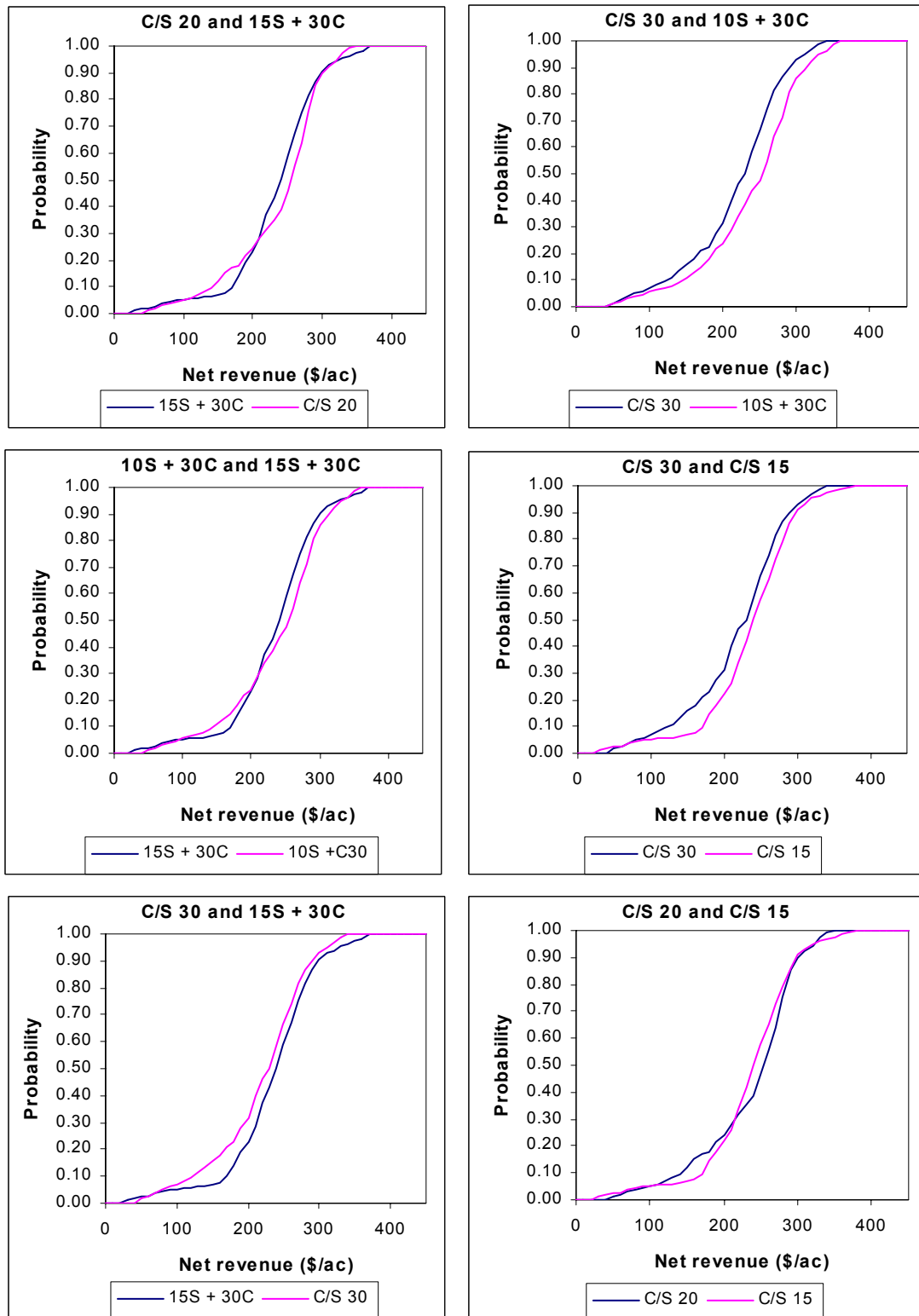
Figure 3a. Estimated cumulative density functions of net returns from corn-soybean systems of different widths.
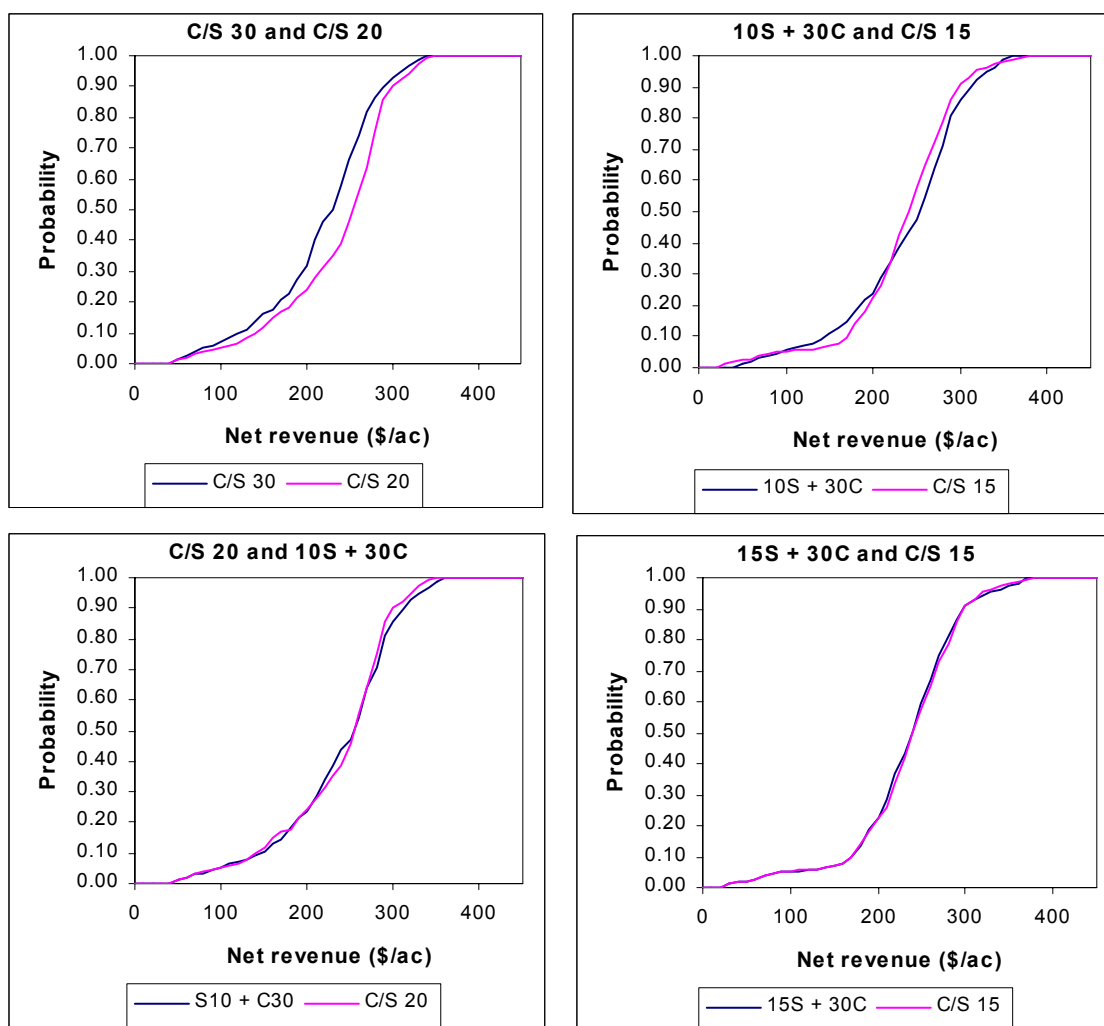
Figure 3a. Estimated cumulative density functions of net returns from corn-soybean systems of different row widths.
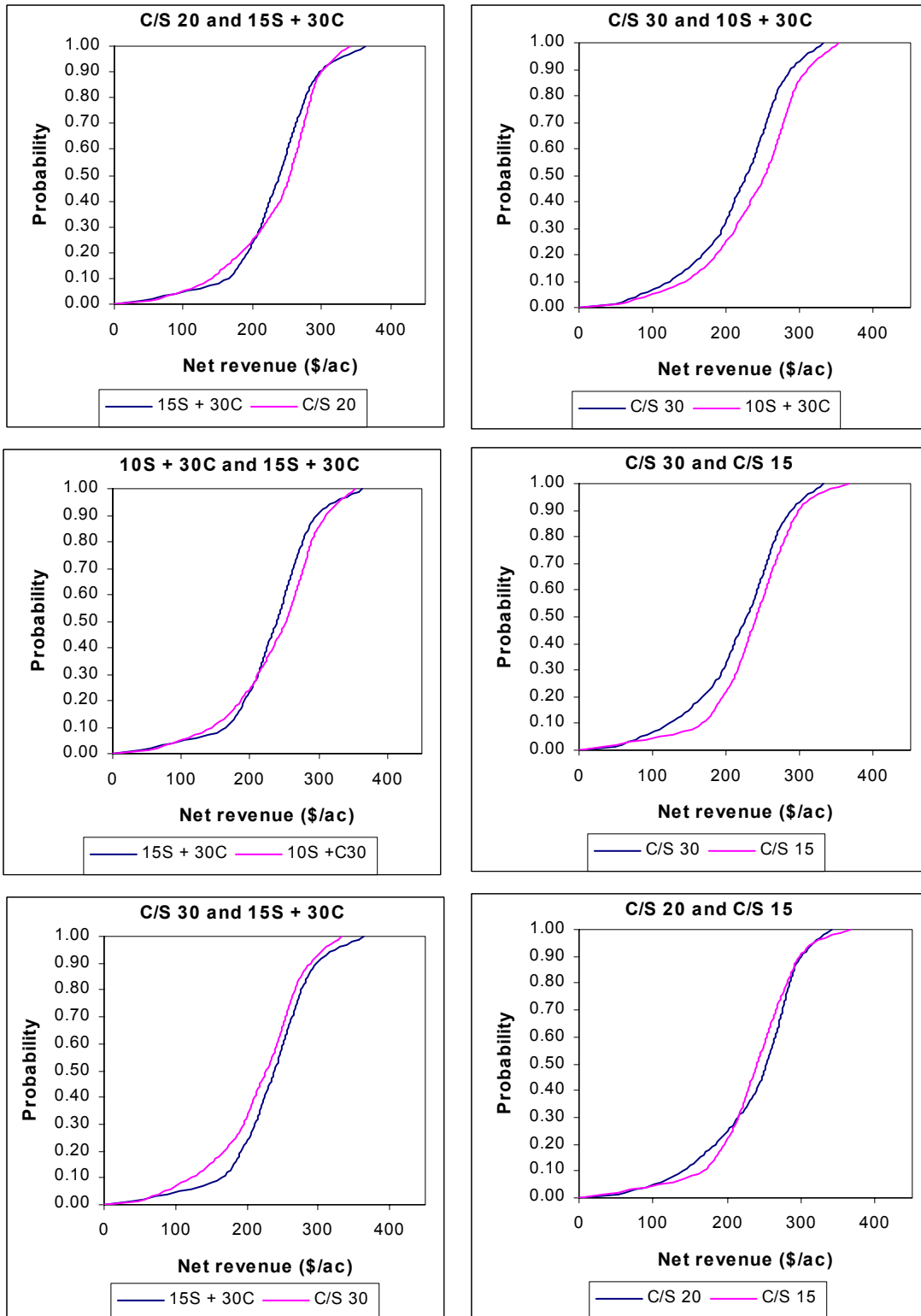
Figure 3b. Cumulative density functions of bootstrapped (m = 1000) net returns from corn-soybean systems of different row widths.
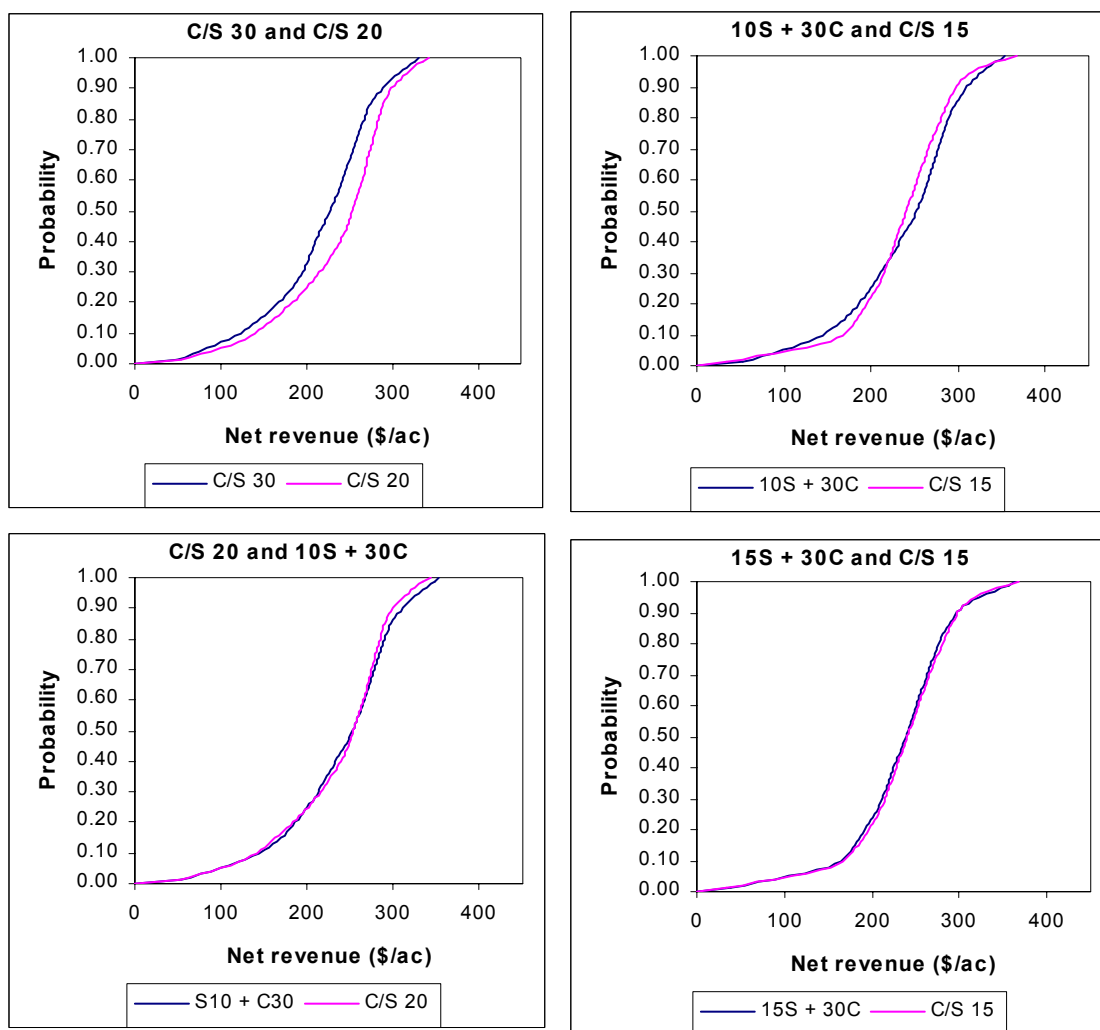
Figure 3b. Cumulative density functions of bootstrapped (m = 1000) net returns from corn-soybean systems of different row widths.
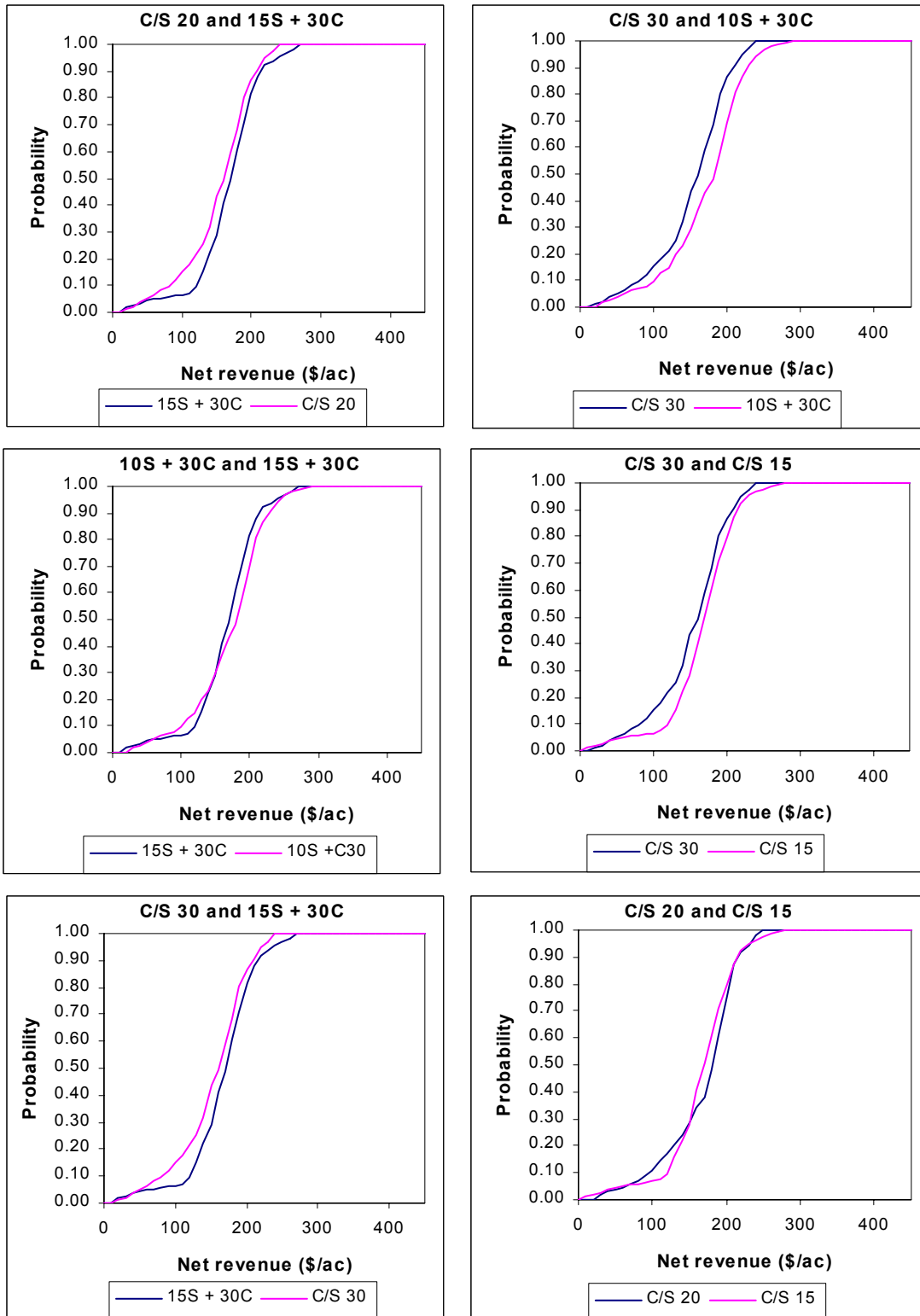
Figure 4a. Estimated cumulative distributions of net returns for corn-soybean systems calculated at loan rates.
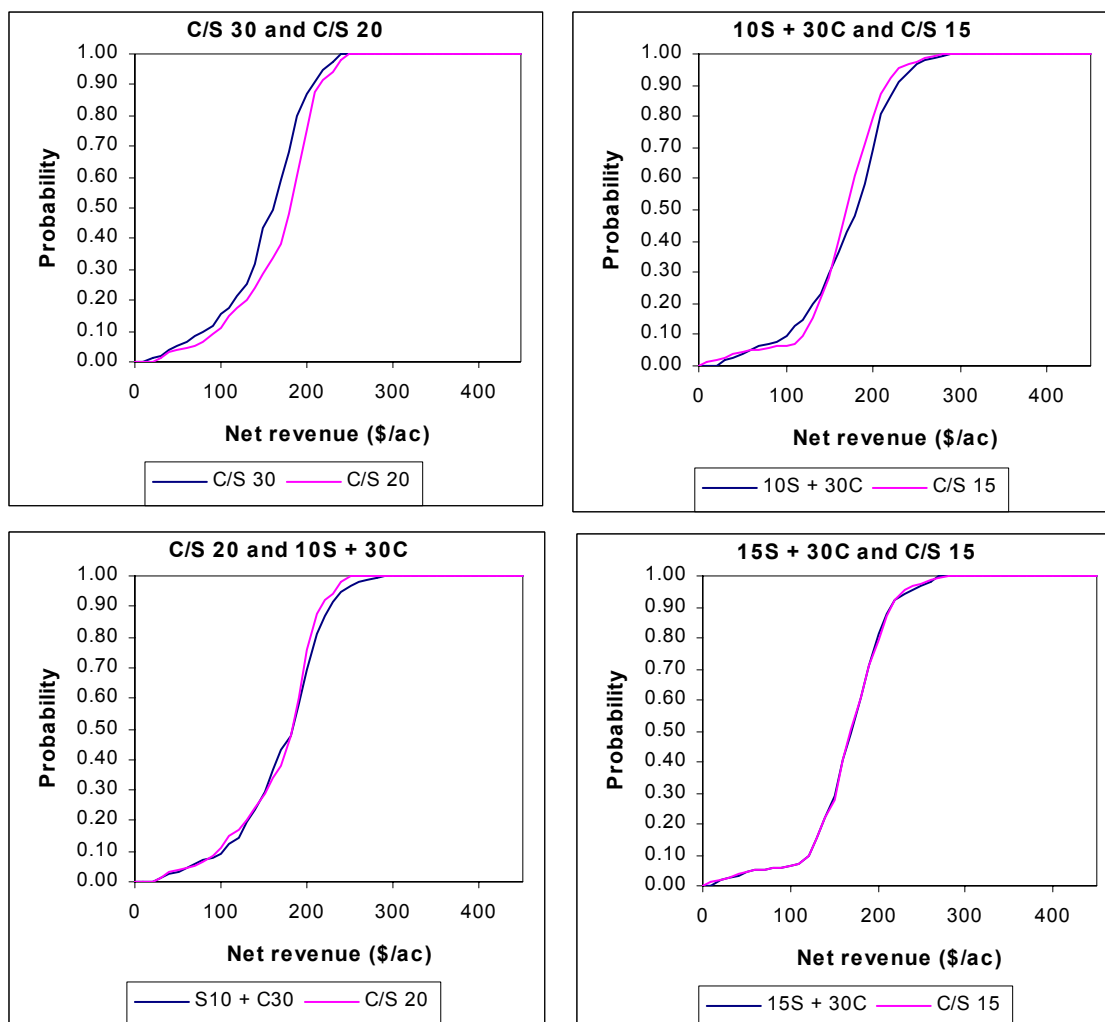
Figure 4a. Estimated cumulative distributions of net returns for corn-soybean systems calculated at loan rates.
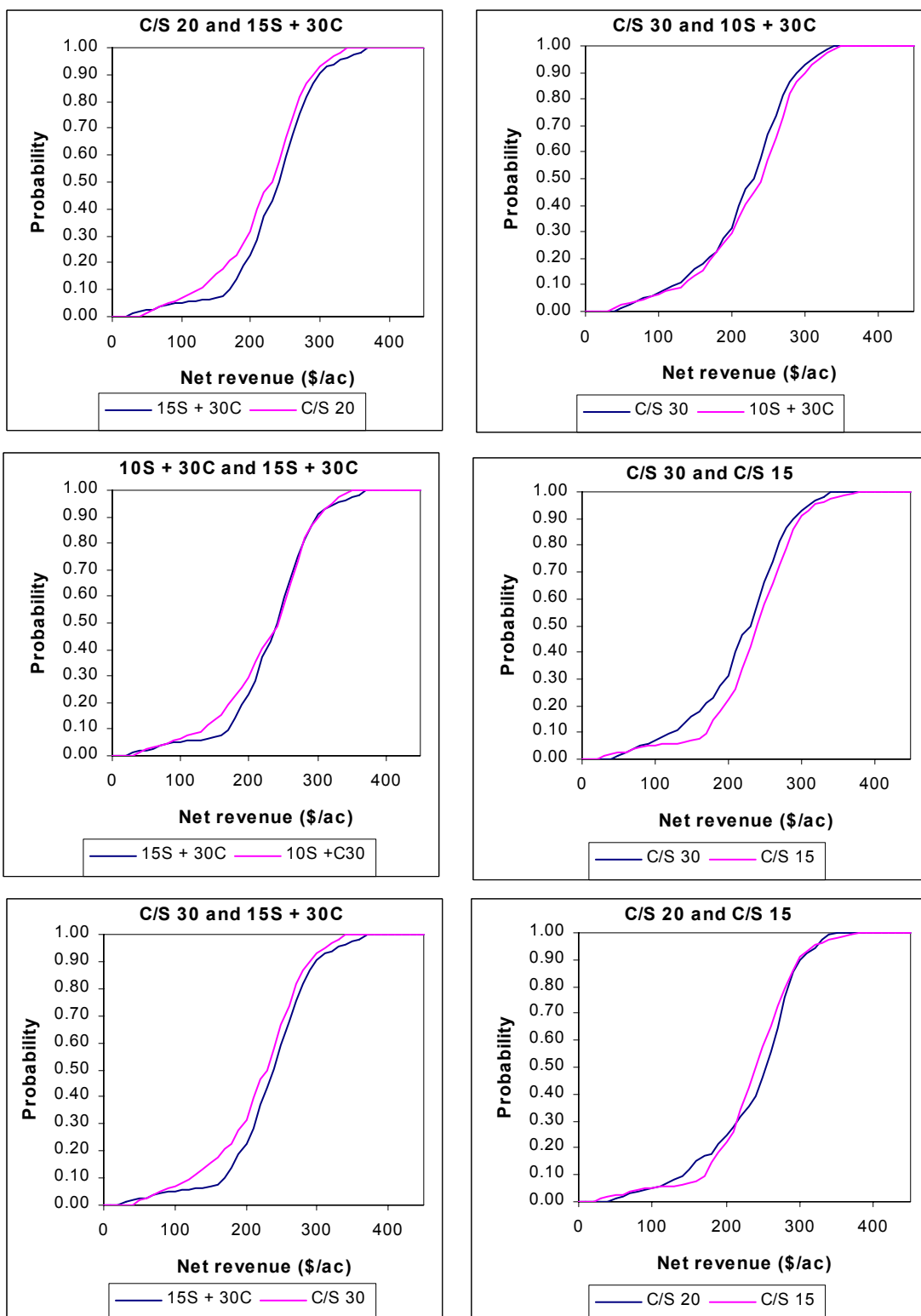
Figure 5a. Estimated cumulative distributions of net returns from corn-soybean systems assuming use of GR-soybeans.
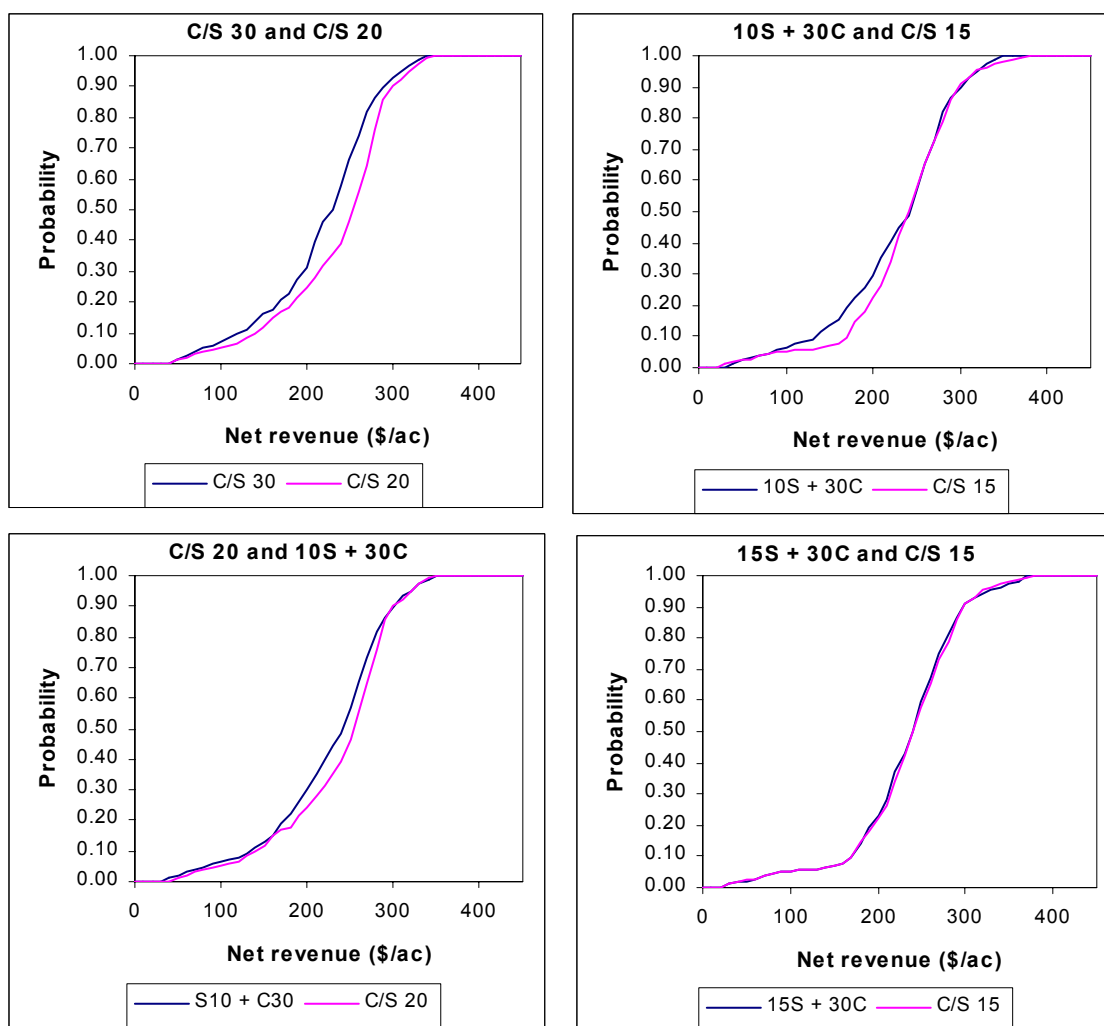
Figure 5a. Estimated cumulative distributions of net returns from corn-soybean systems assuming use of GR-soybeans.

Appendix I. Combining corn and soybean distributions.
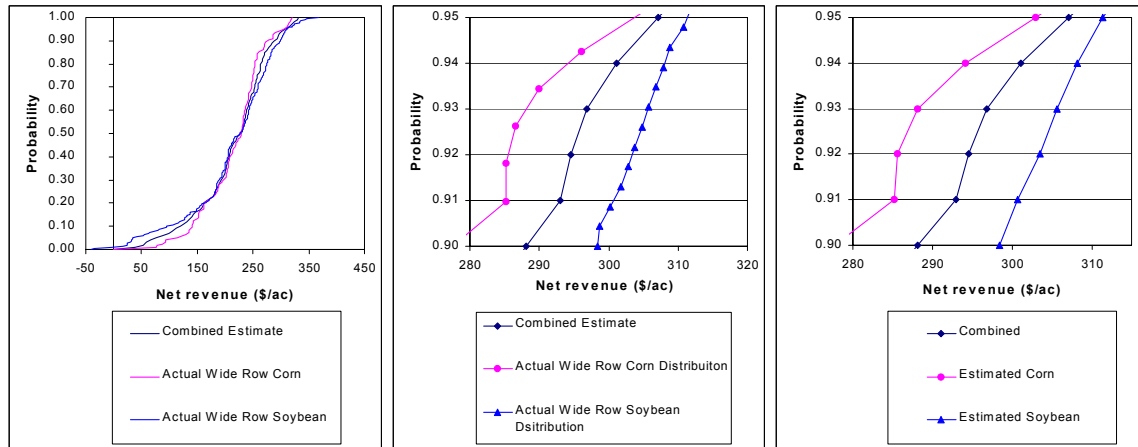
Figure 1. Steps in estimating a CDF for a crop rotation.

Mathematically, the combined distributions for a rotation are in fact a weighted average of corn and soybean distributions at every probability level. Because of the way the CDFs were estimated and because the crops do not have equal numbers of observations, it was necessary to impose a common probability scale and estimate net revenues on that probability scale. The simplest probability scale was one with equal increments; 1% increments were used so the resulting CDF for the rotation is based on N=100.

The mental image for this process is of a farmer with a certain proportion of the farm crop area planted to each crop. The producer would like to estimate what level of revenue for the rotation can be achieved at a given level of probability. The individual crop CDFs give the revenue for each crop and probability. The combined revenue for the rotation is the sum of the revenues by crop, where each crop is weighted by its proportion of the total farm crop acreage. The alternative approach of calculating weighted average probabilities for a given revenue level results in a rotation CDF that appears to be similar, but leads to difficulties in interpretation. What is a "weighted average probability"?

Figure 2 illustrates the problems with the weighted average probability approach. If a revenue of $178 occurs at the 50% probability level for one crop and only 23% probability for another crop, the weighted average probability is 36%, but the expected revenue at 36% probability is not necessarily $178. If the two CDFs have a similar shape, the weighted average probability at a given revenue will be similar (see Figure 2, CDF for Crop B with similar shape to Crop A) to the weighted average revenue at that probability. If the two CDFs are dissimilar in shape, the two estimates may be quite different. In Figure 2, the weighted average probability is 36% at revenue $178, but with the dissimilar CDF revenue at a probability of 36% is $224.
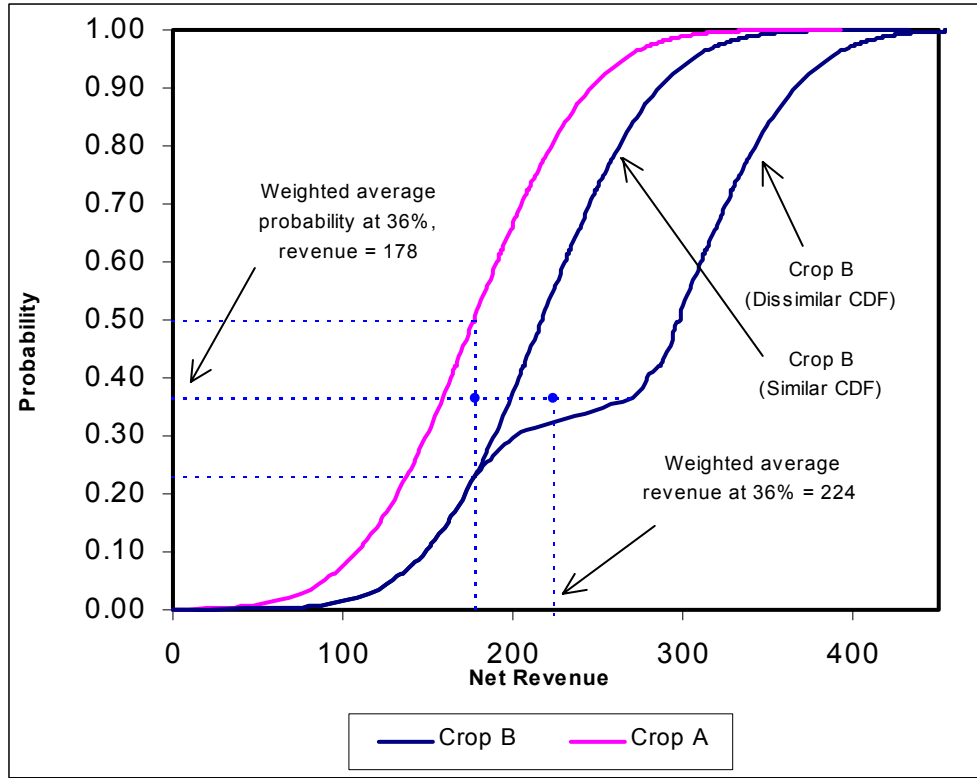
Figure 2. Example of the problem interpreting weighted average probabilities.

Net revenue per acre distributions for corn-soybean rotation systems were estimated at each probability level with the following equation:

$$(1) \qquad \hat{R}_{i,l}^h = (P_s^h - P_{i-1}^h)*(R_i^h - R_{i-1}^h)/(P_i^h - P_{i-1}^h) + R_{i-1}^h$$

Where: $\hat{R}_{i,l}^h$ = the estimated revenue of observation i at the l-th rescaled probability level of the h-th crop (corn, soybean);

$\quad P_i^h$ = the probability level of the i-th observation from the parent data set;

$\quad R_i^h$ = the revenue of crop h of the i-th original observation and

$\quad P_s^h$ = the l-th rescaled probability level.

In effect, the term P_s^h is a rescaling parameter, and determines how many observations will compose the combined data set. It is an arbitrary value, and takes on values between zero and one. This parameter estimates the net return value of a technology as if that actual probability level was found in the original distribution. For example, with a sample size of N = 233 the CDF would increase at each level of probability by 1/233, or every increment of 0.0043. Another data set may have a sample size of N = 78, with each observation represented in the CDF along increments of 0.013. Combining both

data sets entails re-estimating each respective data set on a common scale, so that net returns per acre for a particular system can be estimated at a given probability level (panel two above). Once corn and soybean net returns were rescaled using the same rescaling value, combined portfolio returns of corn and soybean were determined at each common probability level using:

(2) $$\hat{R}_{i,l}^{Combined} = (\sum w_h * \hat{R}_{i,l}^h)$$

Where: $\hat{R}_{i,l}^{Combined}$ = the i-th combined revenue at the scaled probability level l, and

w_h = the proportion of farm crop acreage devoted to crop h.

Equation (2) is the weighted average of estimated net returns from all crops in a rotation at a given probability. The focus of this study was on a 50/50 corn/soybean rotation, so $w_{corn} = w_{soy} = 0.5$, but other proportions of corn and soybeans, or more complex rotations could be analyzed by the same method.

Appendix II. Net returns per acre for soybeans produced in different row widths by region.

Region	Row class	N	Mean	Standard deviation	Min	Max
			------------------------$/acre------------------------			
Central	RC-I	174	270.53	81.83	24.18	471.99
	RC-II	22	221.69	29.84	184.92	310.10
	RC-III	83	244.54	80.15	25.48	355.84
	RC-IV	141	213.87	81.82	-5.60	367.34
Northeast	RC-I	33	252.06	55.56	72.12	318.98
	RC-II	52	273.04	50.25	150.14	418.16
	RC-III	12	254.26	26.99	204.87	294.64
	RC-IV	63	218.71	53.36	29.39	342.86
Northwest	RC-I	15	149.96	90.11	-38.04	283.07
	RC-II	4	25.02	40.43	-30.32	65.57
	RC-III	0	0.00	0.00	0.00	0.00
	RC-IV	15	128.71	76.24	-34.57	234.84
Ohio Valley	RC-I	11	338.55	19.21	307.76	364.88
	RC-II	0	0.00	0.00	0.00	0.00
	RC-III	0	0.00	0.00	0.00	0.00
	RC-IV	11	270.99	13.17	249.01	289.82
Central*	RC-I	185	280.71	81.10	30.32	478.13
	RC-II	22	221.69	29.84	184.92	310.10
	RC-III	83	244.54	80.15	25.48	355.84
	RC-IV	152	218.00	80.24	-5.60	367.34

*OV combined with central

Appendix III. Annualized‡ equipment costs for corn-soybean rotation systems at different row widths (900-acre farm).

	10S/30C	15S/30C	CS 15	CS 20	CS 30
	--$--				
10" drill	3149	0	0	0	0
Planter	3739	6262	6262	4725	3739
Cornhead	3775	3775	7535	5235	3775
Difference from C/S 30	3149	2523	7016	3179	Base

‡Costs annualized at a 10% discount rate. Assumes 10-yr useful life for planter or drill, plus dual hitch, and combine head and 5-yr useful life for the tires. Annualized costs include property tax, insurance, and repairs. Planter costs for C/S 15, 20, and 30 are spread over 900 acres. Planter costs for 10S + 30C are spread over 450 acres. Cost estimates based on soybeans grown in conventional tillage systems. Calculations based comparison on average cost of commercially available new equipment.

¶ Key: 10S + 30C = soybean drilled in 10-inch or less rows, and corn planted in 30-inch rows; 15S + 30C = soybean planted in 15-inch row widths and corn planted in 30-inch row widths; C/S 15, 20, and 30 = corn and soybean cultivated in 15, 20 and 30-inch row widths.

* The row width for this technology is 22-inches for the 900-acre farm size analysis since no prices for 8 row 20-inch planters were found.

Appendix IV. Differences in annualized and purchase price costs† between corn-soybean rotation systems at different row widths compared to C/S 30.

	10S + 30C ¶	C/S 15	C/S 20	C/S 30
	Annualized costs‡			
10" drill	$6,592.69	$0	$0	$0
Planter	$6,744.44	$7,841.57	$7,573.07	$6,744.44
Total Cost of Planting equipment	$13,023.69	$7,841.57	$7,573.07	$6,744.44
Cornhead	$6,210.37	$9,970.93	$8,307.36	$6,210.37
Tractor tires	$1,523.71	$1,814.50	$1,814.50	$1,523.71
Combine frame extension and/or combine tires	$1,535.34	$1,977.34	$1,977.34	$1,535.34
Sub total	$22,293.12	$21,604.33	$19,672.26	$16,013.87
Total difference in annualized costs	$6,593	$5,592	$3,659	Base
	Purchase price**			
10" drill	$28,831.47			
Planter	$58,529.87	$68,051.00	$65,720.87	$58,529.87
Sub-Total	$87,361.33	$68,051.00	$65,720.87	$58,529.87
Cornhead	$23,863.47	$45,074.67	$37,554.33	$23,863.47
Tractor tires	$5,567.50	$6,630.00	$6,630.00	$5,567.50
Combine frame extension and/or combine tires	$5,610.00	$7,225.00	$7,225.00	$5,610.00
Total purchase price	$122,402.30	$126,980.67	$117,130.20	$93,570.83
Total difference purchase price	$28,831.47	$33,409.83	$23,559.37	

†Cost estimates based on soybeans grown in conventional tillage systems. Calculations based comparison on average cost of commercially available new equipment.

¶ Key: 10S + 30C = soybean drilled in 10 in. or less rows, and corn planted in 30 in. rows; C/S 15, 20, and 30 = corn and soybean cultivated in 15, 20 and 30 in. row widths.

‡Costs annualized at a 10% discount rate. Assumes 10 yr useful life for planter or drill, plus dual hitch, and combine head and 5 yr useful life for the tires. Annualized costs include property tax, insurance, and repairs. Planter costs for C/S 15, 20, and 30 are spread over 1800 acres. Planter costs for 10S + 30C are spread over 900 acres.

**Purchase price estimated at 85% of list price.

Appendix V. Publicly available soybean yield data. Yields are bu/acre. Row widths are in centimeters.

RC-I		RC-II		RC-III		RC-IV	
YIELD	WIDTH	YIELD	WIDTH	YIELD	WIDTH	YLD_BU4	WIDTH
50	19	50	38	.	.	48	76
51	19	51	38	.	.	49	76
53	19	51	38	.	.	49	76
52	19	52	38	.	.	49	76
52	19	52	38	.	.	48	76
50	19	49	38	.	.	47	76
49	19	49	38	.	.	47	76
52	19	51	38	.	.	48	76
54	19	52	38	.	.	49	76
50	19	51	38	.	.	48	76
51	19	51	38	.	.	48	76
.	.	.	.	.	.	16	75
.	.	.	.	.	.	49	100
.	.	.	.	.	.	62	75
.	.	.	.	.	.	16	75
72	13	.	.	67	50	60	100
57	25	.	.	.	.	.	.
61	13	.	.	61	50	56	100
69	13	.	.	63	50	54	100
65	25	.	.	.	.	.	.
58	13	.	.	59	50	56	100
71	25	.	.	.	.	.	.
67	25	.	.	63	50	58	100
.	.	.	.	.	.	62	75
.	.	.	.	.	.	16	75
16	25	.	.	14	50	15	100
.	.	.	.	.	.	47	75
50	25	.	.	48	50	47	100
49	25	.	.	47	50	46	100
15	25	.	.	14	50	14	100
.	.	.	.	.	.	61	75
73	25	.	.	.	.	.	.
.	.	.	.	.	.	46	75
.	.	.	.	.	.	47	75
66	25	.	.	61	50	56	100
68	17	.	.	65	50	.	.
66	17	.	.	63	50	.	.
72	17	.	.	59	50	.	.
79	17	.	.	65	50	.	.
71	17	.	.	65	50	.	.
71	17	.	.	66	50	.	.
83	17	.	.	72	50	72	75
67	17	.	.	75	50	73	75
76	17	.	.	76	50	69	75
75	17	.	.	75	50	71	75
81	17	.	.	76	50	73	75
61	17	.	.	50	50	.	.

68	17	.	.	62	50	.	.
64	17	.	.	65	50	65	75
86	17	.	.	77	50	68	75
62	17	.	.	.	.	54	75
76	17	.	.	.	.	62	75
73	17	.	.	.	.	62	75
75	17	.	.	.	.	60	75
70	17	.	.	.	.	64	75
76	17	.	.	.	.	69	75
69	17	.	.	.	.	62	75
74	17	.	.	.	.	65	75
83	17	.	.	.	.	68	75
77	17	.	.	.	.	65	75
66	17	.	.	68	50	.	.
75	17	.	.	72	50	67	75
58	20	.	.	59	50	56	80
63	17	.	.	63	50	.	.
62	17	.	.	59	50	57	75
63	17	.	.	.	.	62	75
65	17	.	.	.	.	57	75
69	17	.	.	.	.	64	75
72	17	.	.	.	.	60	75
65	17	.	.	.	.	51	75
66	17	.	.	.	.	65	75
74	17	.	.	.	.	68	75
69	17	.	.	.	.	60	75
75	17	.	.	.	.	62	75
67	17	.	.	.	.	63	75
69	17	.	.	.	.	59	75
66	17	.	.	.	.	61	75
70	17	.	.	.	.	59	75
79	17	.	.	.	.	71	75
79	17	.	.	.	.	64	75
78	17	.	.	.	.	69	75
83	17	.	.	.	.	74	75
98	17	.	.	.	.	80	75
88	17	.	.	.	.	76	75
74	17	.	.	.	.	60	75
73	17	.	.	.	.	67	75
98	17	.	.	.	.	67	75
75	17	.	.	.	.	63	75
36	20	.	.	40	50	36	80
38	20	.	.	38	50	36	80
64	17	.	.	64	50	.	.
70	17	.	.	61	50	.	.
68	17	.	.	.	.	61	75
27	20	.	.	26	50	25	80
56	17	.	.	65	50	.	.
69	17	.	.	.	.	60	75
.	.	.	.	.	.	55	100
.	.	66	38	.	.	62	76

57	25	.	.	.	.	55	75
67	17	.	.	63	50	.	.
65	17	.	.	52	50	.	.
68	17	.	.	63	50	.	.
64	17	.	.	60	50	.	.
57	17	.	.	54	50	.	.
71	17	.	.	66	50	.	.
67	17	.	.	65	50	.	.
57	17	.	.	53	50	.	.
39	20	.	.	39	50	38	80
64	20	.	.	65	50	59	80
62	20	.	.	63	50	56	80
62	20	.	.	61	50	57	80
57	17	.	.	.	.	59	75
78	17	.	.	.	.	68	75
73	17	.	.	.	.	60	75
65	17	.	.	65	50	.	.
63	17	.	.	61	50	.	.
65	17	.	.	66	50	.	.
64	17	.	.	63	50	.	.
65	17	.	.	66	50	.	.
68	17	.	.	60	50	.	.
62	17	.	.	60	50	.	.
59	17	.	.	52	50	.	.
61	17	.	.	67	50	.	.
66	17	.	.	66	50	.	.
69	17	.	.	68	50	.	.
79	17	.	.	76	50	.	.
70	17	.	.	65	50	.	.
50	17	.	.	57	50	.	.
72	17	.	.	69	50	.	.
68	17	.	.	64	50	.	.
61	17	.	.	64	50	.	.
.	.	68	38	.	.	57	100
41	25	.	.	.	.	63	75
64	17	.	.	62	50	.	.
53	19	51	38	.	.	48	76
54	19	53	38	.	.	49	76
50	19	49	38	.	.	45	76
.	.	.	.	.	.	20	75
.	.	.	.	.	.	22	75
.	.	.	.	.	.	38	75
40	25	.	.	.	.	.	.
22	25	.	.	.	.	.	.
24	25	.	.	.	.	.	.
58	25	.	.	.	.	.	.
.	.	.	.	.	.	54	75
53	25	.	.	.	.	50	75
32	25	.	.	30	50	28	75
46	25	.	.	.	.	.	.
.	.	.	.	.	.	49	75

.	.	.	.	.	.	34	75
18	25	.	.	.	.	.	.
54	25	.	.	.	.	.	.
69	25	.	.	.	.	.	.
.	.	.	.	.	.	67	75
.	.	.	.	.	.	57	75
60	25	.	.	.	.	.	.
39	25	.	.	.	.	39	75
50	25	.	.	.	.	.	.
.	.	.	.	.	.	45	75
47	25	.	.	47	50	.	.
.	.	.	.	.	.	44	75
65	25	.	.	.	.	.	.
.	.	.	.	.	.	63	75
26	25	.	.	26	50	.	.
27	25	.	.	.	.	27	75
41	25	.	.	.	.	.	.
22	20	.	.	.	.	25	75
27	20	.	.	.	.	33	75
59	20	.	.	.	.	57	75
46	20	.	.	.	.	50	75
13	20	.	.	.	.	9	75
.	.	.	.	15	50	16	75
41	25	.	.	39	50	38	75
.	.	.	.	35	50	31	100
.	.	.	.	.	.	34	75
.	.	.	.	33	50	30	100
.	.	.	.	.	.	32	75
.	.	.	.	37	50	34	100
.	.	.	.	.	.	36	75
.	.	.	.	.	.	20	75
.	.	.	.	21	50	18	100
.	.	.	.	36	50	33	100
.	.	.	.	.	.	35	75
32	25	.	.	30	50	.	.
.	.	.	.	.	.	28	75
54	25	.	.	.	.	.	.
.	.	.	.	.	.	46	75
.	.	.	.	.	.	22	75
45	17	.	.	.	.	45	75
62	17	.	.	.	.	69	75
63	17	.	.	.	.	51	75
64	17	.	.	.	.	53	75
71	17	.	.	.	.	55	75
69	17	.	.	.	.	54	75
38	17	.	.	.	.	40	75
68	17	.	.	.	.	54	75
70	17	.	.	.	.	58	75
69	17	.	.	.	.	55	75
67	17	.	.	.	.	56	75
54	17	.	.	.	.	49	75

48	18	.	.	45	50	.	.
50	25	48	36	.	.	.	.
47	18	.	.	45	50	.	.
48	18	.	.	45	50	.	.
51	25	49	36	.	.	.	.
51	18	.	.	47	50	.	.
46	25	44	36	.	.	.	.
49	18	.	.	44	50	.	.
47	25	46	36	.	.	.	.
48	25	47	36	.	.	.	.
47	25	46	36	.	.	.	.
51	18	.	.	47	50	.	.
65	17	.	.	.	.	57	76
63	17	.	.	.	.	59	76
52	17	.	.	.	.	44	76
60	17	.	.	.	.	44	76
22	17	.	.	.	.	16	76
58	19	.	.	.	.	54	76
24	19	.	.	.	.	16	76
63	17	.	.	.	.	75	76
59	19	.	.	.	.	57	76
67	17	.	.	.	.	63	76
57	18	57	35	53	53	45	71
60	18	60	35	59	53	54	71
65	18	64	35	64	53	63	71
62	18	58	35	56	53	55	71
59	18	55	35	55	53	53	71
69	18	66	35	61	53	50	71
57	18	56	35	48	53	44	71
58	18	55	35	51	53	43	71
63	18	60	35	60	53	58	71
64	18	60	35	58	53	49	71
65	18	72	35	65	53	67	71
65	18	62	35	58	53	59	71
.	.	70	27	.	.	59	76
.	.	82	27	.	.	67	76
.	.	55	27	.	.	48	76
.	.	57	27	.	.	50	76
46	20	46	38	.	.	49	76
.	.	58	27	.	.	45	76
.	.	63	27	.	.	50	76
.	.	53	27	.	.	47	76
.	.	53	27	.	.	44	76
.	.	52	27	.	.	43	76
52	19	55	38	.	.	51	76
.	.	60	27	.	.	48	76
.	.	64	27	.	.	48	76
.	.	58	27	.	.	49	76
.	.	68	27	.	.	56	76
.	.	68	27	.	.	56	76
.	.	64	27	.	.	56	76

.	.	57	27	.	.	47	76
.	.	66	27	.	.	56	76
.	.	65	27	.	.	51	76
58	18	61	38	.	.	56	76
56	18	59	38	.	.	51	76
53	18	53	38	.	.	49	76
65	18	66	38	.	.	58	76
55	18	57	38	.	.	51	76
57	18	59	38	.	.	54	76
49	20	.	.	.	.	46	76
51	19	50	38	.	.	53	76
.	.	62	27	.	.	45	76
.	.	86	27	.	.	68	76
.	.	77	27	.	.	68	76
.	.	77	27	.	.	66	76
.	.	55	27	.	.	43	76
41	20	38	38	.	.	39	76
.	.	47	27	.	.	45	76
.	.	48	27	.	.	45	76
.	.	61	27	.	.	49	76
.	.	63	27	.	.	53	76
.	.	56	27	.	.	46	76
.	.	89	27	.	.	71	76
.	.	67	27	.	.	54	76
53	25	.	.	.	.	48	76
43	25	.	.	.	.	39	76
46	25	.	.	.	.	41	76
37	25	.	.	.	.	35	76
44	25	.	.	.	.	42	76
48	25	.	.	.	.	45	76
36	25	.	.	.	.	32	76
44	25	.	.	.	.	40	76
62	25	.	.	.	.	55	76
47	25	.	.	.	.	44	76
46	25	.	.	.	.	42	76
1	15	3	45	.	.	3	90
20	15	22	45	.	.	24	90
10	15	14	45	.	.	13	90
16	15	16	45	.	.	15	90
76	18	.	.	.	.	64	76
70	18	.	.	.	.	61	76
78	18	.	.	.	.	65	76
77	18	.	.	.	.	63	76
73	18	.	.	.	.	57	76
72	18	.	.	.	.	63	76
67	18	.	.	.	.	59	76
71	18	.	.	.	.	64	76
73	18	.	.	.	.	62	76
75	18	.	.	.	.	59	76
67	18	.	.	.	.	59	76

References

Alessi, J. and J.F. Power. 1982. Effects of plant and row spacing on dryland soybean yield and water-use efficiency. *Agronomy J.* 74: 851-854.

Anderson, J. 1974. Risk efficiency in the interpretation of agricultural production research. *Review of Marketing and Agricultural Economics* 42: 131-184.

Bryan, A.A., R.G. Eckhardt, G.F. Sprague. 1940. Spacing experiments with corn. *Journal of the American Society of Agronomy.* 32: 707-715.

Butzen, Steve. 1998. Managing white mold of soybeans. *Crop Insights*. Pioneer Hi-bred, http://www.pioneer.com/use/crop_management/national/manage_whitemold.htm.

Cooper, R.L. 1977. Response of soybean cultivars to narrow rows and planting rates under weed-free conditions. *Agronomy Journal* 69: 89-92.

Cooper, R.L., and D.L. Jeffers. 1984. Use of nitrogen stress to demonstrate the effect of yield limiting factors on the yield response of soybean to narrow row systems. *Agronomy Journal* 76: 254-259.

Costa, J.A., E.S. Oplinger, and J.W. Pendleton. 1980. Response of soybean cultivars to planting patterns. *Agronomy Journal* 72: 153-156.

Dorrance, Anne E., and Patrick E. Lipps. 1998. Sclerotinia White Mold of Soybean. Ohio State University Extension; Department of Plant Pathology. The Ohio State University. AC-45-98.

Doster, D.H. 1996. Mini-PMC user guide: calculating machinery costs with the Purdue machinery cost calculator. Purdue University Department of Agricultural Economics Cooperative Extension Service, West Lafayette, IN.

Doster, D.H., S.D. Parsons, E.P. Christmas, D.B. Mengle, and R.L. Neilsen. 1998. Influence of production practices on yield estimates for corn, soybean, and wheat. Purdue University Cooperative Extension Service. ID-152.

Devlin, D.L., D.L. Fjell, J.P. Shroyer, W.B. Gordon, B.H. Marsh, L.D. Maddux, V.L. Martin, and S.R. Ducan. 1995. Row spacing and seeding rates for soybean in low and high yielding environments. *Journal of Production Agriculture* 8(2): 215-222.

Edwards, M.E., Kurle, J.E., Grau, C.R., Oplinger, E.S., and Martinka, M.J. 1999. Row spacing and tillage effects on yield and Sclerotinia stem rot severity in soybean. Agron. Abstracts. Page 115. 31 Oct.-4 Nov. 1999. Salt Lake City, Utah.

Grau, C.R. and V.L. Radke. 1984, Effect of cultivars and cultural practices on Sclerotinia stem rot of soybean. Plant Disease 68: 56-58.

Hadar, J., and W. Russel. 1969. Rules for ordering uncertain prospects. *American Economic Review* 59: 25-34.

Hallman, Alan, and Jess Lowenberg-DeBoer. 1999a. Cost, average returns, and risk of switching to narrow row corn. *Journal of Production Agriculture* 12(4): 685-691.

Hallman, Alan, and Jess Lowenberg-DeBoer. 1999b. Deciding to switch to narrow-row corn. Purdue Agricultural Economics Report, June 1999.

Hien, V., D. Kaboré, S. Youl, and J. Lowenberg-DeBoer. 1997. Stochastic dominance analysis of on-farm trial data: the riskiness of alternative phosphate sources in Burkina Faso, 1989 to 1991. *Agricultural Economics* 15(3): 213-221.

Hume, A.N., O.D. Center, and A. Hegnauser. 1908. Distance between hills of corn in the Illinois corn belt. Illinois Agricultural Experiment Station Bulletin, 126.

Hunt, D. 1995. Farm power and machinery management. Iowa State University Press, Ames.

Leuschen, W.E., and J.H. Ford, S.D. Evans, B.K. Kanne, T.R. Hoverstad, G.W. Randall, J.H. Orf, and D.R. Hicks. 1992. Tillage, row spacing, and planting date effects on soybean following corn and wheat. *Journal of Production Agriculture* 5(2): 254-260.

Lowenberg-DeBoer, J., M. Krause, R.R. Deuson, and K.C. Reddy. 1990. A simulation model of millet and cowpea intercrop. Purdue University Agricultural Experiment Station Bulletin 575.

Lohr, Sharon L. 2000. Sampling: design and analysis. Duxbury Press: Cincinnati.

Markowitz, H. 1952. Portfolio selection. *Journal of Finance* 7: 77-91.

Mickelson, James A., and Karen A. Renner. 1997. Weed control using reduced rates of postemergence herbicides in narrow and wide row soybean. *Journal of Production Agriculture* 10: 431-437.

Nielson, R.L. 1996. Perspective on narrow row spacing for corn. AGRY-96-17, http://www.agry.purdue.edu/agronomy/ext/corn/pubs/agry9617.htm.

Nelson, Kelly A., and Karen A. Renner. 1998. Weed control in wide- and narrow-row soybean (*Glycine max*) with imazamox, imazethapyr, and CGA-277476 plus quizalofop. *Weed Technology*. 12: 137-144.

Nelson, Kelly A., and Karen A. Renner. 1999. Weed management in wide- and narrow-row glyphosate-resistant soybean. *Journal of Production Agriculture* 12: 46-465.

Ohio Enterprise Budgets. 2001. Department of Agricultural, Environmental, and Development Economics. Ohio State University, http://www-agecon.ag.ohio-state.edu/faculty/rmoore/index.htm.

Oplinger, E.S. 1980. Seeding soybeans in narrow rows. University of Wisconsin Extension Bulletin, A3079. University of Wisconsin, Madison, U.S.A.

Oriade, Caleb A., Carl R. Dillon, E.D. Vories, and M.E. Bohanan. 1997. An economic analysis of alternative cropping and row spacing systems for soybean production. *J. Prod. Agric.* 10(4): 619-624.

Parker, M.B., W.H. Marchant, and B.J. Mullinix, Jr. 1981. Date of planting and row effects on four soybean cultivars. *Agronomy Journal*. 73(5): 759-762.

Paskiewicz, S. 1996. Narrow row width influence on corn yield. *Crop Insights*. Pioneer Hi-bred, http://www.pioneer.com/customer/research/ci214.htm.

Paskiewicz, S. 1998. Row spacing and seeding rater effects on no-till soybeans. *Crop Insights*. Pioneer Hi-bred, http://www.pioneer.com/usa/crop_management/national/notill_soybeans.htm.

Pierce, Vern. 2000. Partial budgeting. University of Missouri Commercial Agriculture. Available at http://agebb.missouri.edu/download/university/partbudg.exe

Purdue Crop Diagnostic Training and Research Center. 1999. Corn and Soybean Field Guide. Purdue University Cooperative Extension Sevice.

Shibles, R.M., and C.R. Weber. 1965. Leaf area solar radiation interception and dry matter accumulation by soybeans. *Crop Science* 6: 55-59.

Taylor, H.M. 1980. Soybean growth and yield as affected by row spacing and by seasonal water supply. *Agronomy Journal* 72: 513-547.

USDA, 2000 Crop Corn. Grain Sorghum, and Soybean Schedule of County Loan Rates. Price Support Division, Farm Service Agency, USDA. Notice LP-1733.

Wiggans, R.G. 1939. The influence of space and arrangement on the production of soybean plants. Journal of the American Society of Agronomy, 31:314-323.

Yelverton, Fred H., and Harold D. Coble. 1991. Narrow row spacing and canopy formation reduces weed resurgence in soybeans (*Glycine max*). *Weed Technology* 5: 169-174.