A Case Study of Timeliness in the Selection of Risk-Efficient Machinery Complements

Michael E. Wetzstein, Wesley N. Musser, Ronald W. McClendon, and David M. Edwards

Abstract

The importance of timeliness is investigated in the selection of machinery complements for double-crop wheat and soybean production in the southeastern coastal plain. An intertemporal stochastic simulation model was developed to generate probability distributions that were evaluated with stochastic dominance analysis. This research investigated the importance of intertemporal production linkages and inadequate soil moisture on machinery selection. Failure to include these dimensions can result in erroneous machinery choices.

Key words: double-cropping, wheat, soybeans, stochastic simulation.

Machinery selection is an important and complex decision in capital intensive farming. Edwards and Boehlje identified a number of complexities associated with this decision: (1) the performance of one machinery unit is influenced by the total technology set employed in production; (2) various costs associated with machinery selection, including economic depreciation, are not easily measured; (3) machinery sets influence timeliness of operations for land preparation, planting, and harvesting that can result in lower yields; (4) the stochastic nature of agricultural production systems and market prices complicates the process of isolating machinery influences on returns; and (5) machinery selection is lumpy. Previous research has not attempted to present a complete model of this complex machinery decision process. Rather, the approach was to consider manageable components of machinery selection. For example, past research has considered interaction between machinery choice and crop enterprise combinations (Danok *et al.* 1978, 1980) and income taxes and other intertemporal financial aspects in determining the optimal life of a particular machine with capital budgeting methods (Reid and Bradford).

This paper is concerned with the intertemporal stochastic impacts of timeliness issues related to machinery choice. Timeliness has received considerable attention in the machinery selection literature. However, previous research has only focused on planting delays caused by excess soil moisture. On sandy soils with limited moisture retention capacity, inadequate moisture for germination can also cause planting delays. Furthermore, spring planting delays can influence production in the next period. Brink and McCarl demonstrated that planting delays postpone crop maturity and harvesting, which may preclude fall tillage operations (such as plowing) in preparation for spring planting the following year. These intertemporal effects, possibly resulting from limited machinery capacity and weather, can be more critical for multiple-cropping systems. Delays in harvesting spring planted crops, such as soybeans, directly affect the timeliness of fall operations, such as planting winter wheat. Total acreage planted in fall then affects the crop enterprise mix and, thus, influences yield and income in the following year. In a risk management context, this intertemporal stochastic variation in yield, acreage, and income may be of considerable importance. Capital budgeting models of machinery choice, including Reid and Bradford, have considered timeliness in an intertemporal framework but not these stochastic intertemporal effects among years. Finally, past research on the effect of timeliness on yield variation has not always considered the interrelations of stochastic prices with stochastic yields. For example, Danok *et al.* (1980) assumed fixed prices.

The specific purpose of this article is to present a case study on the effect timeliness in machinery operations has on machinery selection for a soybean and wheat double-crop production system in the southeastern coastal plain. Because sandy soils predominate in this region, the influence of both excess and inadequate soil moisture on timeliness of field operations is considered. As in previous machinery choice research, this case study abstracts

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from components of the interaction of machinery choice on production and financial decisions to facilitate the analysis. Among these components are income taxes and finance, crop enterprise selection, and variable production input levels.[1] An additional assumption is the designation of machinery complements as the decision variable (Danok *et al.*, 1978; Edwards and Boehlje).

CONCEPTUAL MODEL

For the research in this article, the stochastic economic choice variable is net income before taxes associated with machinery complement j in year t, π_{jt}, defined as

$$\begin{aligned}\pi_{ij} = \; & p_{st}(Y_{sst}A_{sst} + Y_{sdt}A_{sdt}) + p_{wt}Y_{wt}A_{wt} \\ & - VC_{mjt} - FC_{mj} - VC_{ss}A_{sst} - VC_{sd}A_{sdt}, \\ & - VC_{w}A_{wt},\end{aligned}$$

where p_{st}, and p_{wt}, are per bushel soybean and wheat prices in year t, respectively; Y_{sst}, Y_{sdt}, and Y_{wt} are yields in bushels per acre for single- and double-crop soybeans and wheat in year t, respectively; A_{sst}, A_{sdt}, and A_{wt} are total acreages of single- and double-crop soybeans and wheat in year t, respectively; VC_{ss}, VC_{sd}, and VC_{w} are annual per acre variable costs other than machinery for single and double-crop soybeans and wheat, respectively; and VC_{mjt} and FC_{mj} are total annual machinery variable and fixed costs for machinery complement j, respectively. Machinery complements are assumed to be used solely for the crops. Variable machinery costs are not allocated directly to individual crops because they are specific to machinery complements. As formulated, variable costs specific to crops are invariant with machinery choice. Following standard procedures, FC_{mj}, VC_{ss}, VC_{sd}, and VC_{w} are assumed to be known at the beginning of a production season (Dillon). However, the variables Y_{sst}, A_{sst}, Y_{sdt}, P_{st}, A_{sdt}, Y_{wt}, A_{wt}, P_{wt}, and VC_{mjt} would usually be stochastic. Timeliness of field operations, which depend on weather events, influences planted acreages and yields. In turn, planted acreages determine machinery variable costs. Acreage of wheat, A_{w}, by definition is assumed to equal acreage of double-crop soybeans, A_{sdt}. These variables are based on the stochastic outcome of machinery complement j and stochastic variables, particularly single- and double-crop soybean acreage in the previous production period $A_{ss,t-1}$ and $A_{sd,t-1}$. Thus, risk in π_{jt} reflects inter-temporal linkages in acreage among production seasons.

Risk, multiple time periods, and discrete choice are standard justifications for use of simulation models (Johnson and Rausser). The simulation model for this study has target levels of crop acreages, A^*_{ss}, A^*_{sd}, and A^*_{w}. These target levels reflect enterprise choices given land and other resources that are exogenous to the analysis, similar to previous studies by Edwards and Boehlje and Russell *et al.* The simulation model determines endogenous, stochastic values of $A_{sst} \leq A^*_{ss}$, $A_{sdt} \leq A^*_{sd}$, and $A_{wt} \leq A^*_{w}$ for different machinery complements and weather conditions represented in period t and previous periods. These endogenous variables are determined by available field days, machinery capacity, and delays in field operations discussed in the next section.

SIMULATION MODEL

Probability distributions of π_{jt} were derived with a microanalytic simulation model, DCMOD (Chen and McClendon 1984, 1985). DCMOD simulates soybean and wheat double-crop production in the southeastern United States. DCMOD was modified to incorporate intertemporal production levels, stochastic output prices, and inadequate soil moisture for planting. A brief discussion of the unique modifications associated with the modified model, DCTEM, along with data sources is presented below. Wetzstein *et al.* present a more detailed discussion.

DCTEM simulates an intertemporal dynamic production system based on daily precipitation data over a set of years. In accordance with Russell *et al.*, past weather observations were assumed to be a random sample from the universe of possible weather conditions. A machinery complement and target levels for crop acreages are parameters in the model. The simulator generates endogenous acreages planted to the various crops based on the interaction of machinery set capacity and available work days within the constraints of feasible planting and harvesting dates. Harvest summary information is calculated for each weather year. DCTEM then simulates the production system for the next weather year with acreages of fall wheat plantings in the first weather year as wheat acreage to be harvested in the following spring. All wheat acreage is planted to double-cropped soybeans. If planted wheat acreage

[1] Crop enterprise selection is not so limiting in this application because soybean production represents the largest production area devoted to a single crop in Georgia, with acreage more than doubling in the past decade (Georgia Crop Reporting Service). In addition, recent research has also focused on variable input levels for soybeans independent of machinery choice (Boggess *et al.*, 1983, 1985).

Table 1. Assumed Major Cropping Practices in the Simulation Model

Decision Cropping Practice	Assumption
1. Single-Crop Soybean Planting Initiation	1 May
2. First Day of Wheat Harvest	15 May
3. Last Day of Wheat Planting	16 December
4. Single-Crop Soybean Land Preparation Initiation	15 March
5. Double-Crop Soybean Planting Method	No-Till

is less than targeted wheat acreage, single-crop soybeans in the following year are planted to acreage initially targeted for double-cropped soybeans. Thus, weather years are linked by fall plantings and subsequent spring harvested acreage.

The model was calibrated for the Georgia coastal plain soybean and wheat double-crop production system. Based on farm record data, the representative soybean and wheat double-crop operation was assumed to include 600 acres with 67 percent of the acreage double-cropped. Typical equipment for such a farm is six-row scale and includes two tractors (not including a tractor in a harvesting system), plows, disks, do-alls, row planters, grain drills (for no-till planting), and cultivators, and one harvesting system (Farm Economics Information Center).[2] A harvesting system consists of a combine, a 300-bushel trailer, and a 95-hp tractor.

Weather data consisted of 58 years (1925 to 1982) of daily precipitation records from the Coastal Plain Experiment Station at Tifton, Georgia. Weather relationship to field time availability considered both excessive and inadequate soil moisture. The relationship of field time to excessive soil moisture is complex. However, Chen and McClendon (1984, 1985) have demonstrated that a simple precipitation delay schedule can adequately approximate available field days related to excessive moisture. This type of approximation is particularly suitable for the sandy soil conditions in the study area. The appropriate delay schedule for coastal plain soils was developed after consultation with agricultural engineers (Threadgill). No field work is allowed if either precipitation on a given day exceeds 1.5 inches or if accumulated precipitation for the previous two days exceeds two inches. Double-crop soybean planting was an exception; two inches or more of precipitation on a given day are necessary to cause field work delays for this operation. No-till planting equipment used for this operation can function under higher soil moisture content than a conventional row planter. Insufficient soil moisture was determined by a soil moisture schedule developed by agronomists (Hargrove and Radcliffe). For each inch of precipitation, 3.5 suitable planting days are obtained. However, only seven suitable planting days are allowed to accumulate for each rain event because of rapid percolation and evaporation of water in sandy soils.

In past research, Danok *et al.* (1978, 1980), Edwards and Boehlje, and Chen and McClendon (1984, 1985) have assumed potential soybean yields as a function of planting date. The importance of planting date on yield is well documented in the agronomy literature (Lewis and Phillips; Ungar and Stewart; Erbach and Lovely). Consequently, this approach was also followed here. Data relating planting dates to expected soybean yields and maturity dates are from a three-year study conducted at the Coastal Plain Experiment Station (Parker *et al.*). Intertemporal stochastic effects on soybean yields and percent double-crop soybeans were generated by delays in planting dates based on available machinery and weather conditions. Actual soybean yields were assumed to be 85.5 percent of potential yields to account for harvest and other losses. After maturity, a number of days are required for soybean moisture content to drop to an acceptable level for harvest. This process was modeled with a schedule developed by Chen and McClendon (1984) for daily reduction in moisture content. Zero yield is assumed when late maturation precludes harvesting past a cutoff date. December 20 was specified as this harvest cutoff date because all soybeans in the coastal plain region of Georgia are generally harvested prior to this date (Georgia Crop Reporting Service).

With the exception of planting and harvesting of soybeans, all other crop operator decision variables were constant at the conventional level listed in Table 1. Operations one through three reflect the historical dates indicated in *Georgia Agricultural Facts* (Georgia Crop Reporting Service, 1983). Operation four reflects the normal time that land preparation generally begins in the Georgia coastal plain. No-till double-crop soybeans was assumed for operation five reflecting practices of many double-cropping enterprises in the Georgia coastal plain.

Table 2 presents the machinery costs and capacities for the equipment complements considered. Per hour field capacities of each implement, taking into account the sandy soils of the coastal

[2] Do-all is a finishing harrow modified by the incorporation of spraying equipment.

Table 2. Machinery Costs and Capacity, Soybean and Wheat Double - Cropping in the Georgia Coastal Plain [a]

Implement	Annual Fixed Cost (Dollars)	Variable Cost Per Hour (Dollars)	Field Capacity Per Day (Acres)
Tractor			
Small-95 hp	1,773.21	6.97	—
Medium-110 hp	2,617.20	8.41	—
Large-135 hp	3,462.00	10.54	—
Chisel Plow			
4-Row	360.49	1.17	48.4
6-Row	380.00	1.24	64.5
8-Row	1,017.82	3.31	84.7
Disk			
4-Row	562.69	1.83	48.4
6-Row	819.86	2.67	72.6
8-row	1,390.44	4.53	96.8
Disk Plus Incorporate			
4-Row	587.11	1.91	32.2
6-Row	862.42	2.81	48.4
8-Row	1,448.14	4.71	64.5
Do-All			
4-Row	830.91	3.28	47.0
6-Row	1,003.18	3.96	70.6
8-Row	1,307.17	5.16	94.0
Row Planter			
4-Row	564.64	4.23	40.5
6-Row	853.01	6.31	60.8
8-Row	1,012.29	7.49	81.0
Grain Drill			
4-Row	506.02	3.75	30.9
6-Row	623.18	4.61	61.7
8-Row	678.39	5.02	87.5
Cultivator			
4-Row	224.97	0.73	43.0
6-Row	358.85	1.41	40.3
8-Row	445.71	1.75	53.8
Cultivate Plus Post Late			
4-Row	253.73	1.00	26.9
6-Row	358.85	1.41	40.3
8-Row	445.71	1.75	53.8
Combine			
4-Row	6,733.25	19.32	27.1
6- and 8-Row	9,644.37	28.61	41.8
300 Bushel Trailer	250.38	0.47	—

[a] Machinery costs were calculated with the Oklahoma State Budget Generator (Kletke) with parameters appropriate for the Georgia Coastal Plain.

Table 3. Alternative Machinery Complements for Planting and Harvesting on 600 Acres, 67 Percent Soybean and Wheat Double-Crop Production Area; Four-, Six-, and Eight-row Equipment in the Georgia Coastal Plain

	Numbers			
Strategy	Tractors	Harvesting Systems[a]	Row Planters	Grain Drills
Four-row	95 hp			
4.A	1	1	1	1
4.B	2	1	1	1
4.C	2	1	2	2
4.D	3	1	3	3
4.E	3	2	3	3
Six-row	110 hp			
6.A	1	1	1	1
6.B	1	2	1	1
6.C	2	1	1	1
6.D	2	2	1	1
6.E[b]	2	1	2	2
6.F	2	2	2	2
6.G	3	1	3	3
6.H	3	2	3	3
Eight-row	135 hp			
8.A	1	1	1	1
8.B	1	2	1	1
8.C	2	1	2	2
8.D	2	2	2	2
8.E	3	1	3	3
8.F	3	2	3	3

[a]Harvesting system includes a combine,trailer, and a 95-hp tractor.
[b]Representative machinery complement.

plain, were determined following the *Agricultural Engineers Yearbook.* Daily capacity was estimated by assuming eight hours of machinery operation per day. Accounting for machinery downtime and labor breaks, eight hours of machinery operation during a usual ten-hour workday was assumed based on estimates of field operations during planting and harvesting from surveys in this area (Miller). Machinery costs for the Georgia coastal plain were calculated with the Oklahoma State Budget Generator (Kletke) and listed in Table 2 along with daily field capacity. The simulation analysis considered the following three scale sizes of equipment: four-, six-, and eight-row. Different complements within each of the equipment scales were constructed by varying the number of tractors, harvesting systems, row planters, and grain drills with other components constant. The various complements considered in the analysis are listed in Table 3.

Other parameters for the model, including expected values of input prices and variable costs of materials, were estimated with standard budgeting practices. A stochastic yield response function for wheat was unavailable so a fixed yield of 35 bushels per acre was assumed. This assumption is based upon historical yields in Georgia (Georgia Crop Reporting Service). While this assumption may be limiting, wheat yields are more stable over production seasons than soybean yields and wheat is generally considered as the secondary crop. Stochastic prices for soybeans and wheat were estimated with an application of the Gaussian elimination methodology (Clements *et al.*). Wetzstein *et al.* provide a detailed description of this procedure used in the simulation analysis. The following equation summarizes this method:

$$P = \bar{P} + AW$$

where P is a (3 x1) vector of soybean and wheat prices and soybean yield; $\bar{P}$ is a (3x1) mean vector of P; A is a (3x3) upper-triangular, variance-covariance matrix of P; and W is a (3x1) vector of random normal deviates. Mean prices of \$6.47 and \$3.14 per bushel were assumed for soybeans and wheat, respectively. The variance-covariance matrix was estimated with Georgia state average price data and Georgia coastal plain county yield data for 1973 through 1981 (Georgia Crop Reporting Service).[3] In this simulation, wheat and soybean prices were calculated for each weather year of the simulation with simulated soybean yields in P, the above values of $\bar{P}$ and A, and values of W from a random normal number generator. This procedure allows aggregate market forces on prices to be influenced by aggregate stochastic farm-firm events through the variance-covariance matrix. Reduced yields associated with planting delays caused by poor weather conditions can impact market prices in areas such as Georgia. As Tew *et al.* demonstrated, a general assumption of a non-zero covariance between price and yields is appropriate for risk analysis.

First and second degree stochastic dominance criteria (FSD and SSD, respectively) were applied to the probability distributions of net returns for identifying risk-efficient sets of machinery complements. Transitivity properties of stochastic dominance were utilized in this study to reduce the number of pair-wise comparisons. Machinery complements were classified into scale sets defined by four-, six-, and eight-row equipment. Stochastic dominance was first applied to the distributions of net returns for all complements of the same scale. Then the overall efficient set, considering all three scale sets, was determined with stochastic dominance of the efficient sets within each machinery scale.

RESULTS

Base Run of Intertemporal Model

A summary of the simulation output for the different complements is provided in Table 4. For the representative six-row equipment scale, strategies 6.E and 6.G are FSD over strategies 6.B, 6.C, 6.D, 6.F, and 6.H; and 6.E is SSD over 6.A. Addition of a harvesting system to 6.E and 6.G results in inefficient sets 6.F and 6.H, respectively. An additional tractor without an associated row planter and grain drill, represented by 6.C and 6.D, is not SSD efficient. Results indicate that the representative farm complement, 6.E, is within the six-row efficient set and that less machinery within this scale is not risk-efficient. However, additional planting equipment, as in 6.G, may be efficient.

Considering the four-row equipment scale in Table 4, the largest complements within the four-row scale, 4.D and 4.E, are SSD risk-efficient. Thus, four-row equipment may be limiting for the farm size and percent double-cropping considered. The FSD and SSD efficient set for eight-row equipment includes 8.A, 8.C, and 8.E. Similar to the six-row results, these complements employ one tractor for each set of row planters and grain drills and one harvesting system. If any additional machinery beyond the representative complement, 6.E, is required, it should be in the form of planting capacity.

The overall SSD set, derived from the efficient sets for each scale of equipment, contains 6.E and 6.G (Table 4). Increasing machinery within the representative six-row scale may be efficient; however, converting to a larger or smaller equipment scale is SSD inefficient.

The overall SSD efficient complements also correspond closely to the maximum expected profit choice. Machinery complement 6.E has the highest expected profits, followed by 4.D, 6.G, 6.A, and 8.A. This similarity between expected profit and risk aversion criteria is similar to results reported by Russell *et al.*

The similarity between optimal choices with expected profit and risk aversion has implications for the common perception that overcapitalization in machinery is related to reducing production risk.[4] Extra machinery capacity allows planting and harvesting within a smaller interval about the optimal times in situations with unfavorable weather. Furthermore, it precludes underutilization of planned acreage due to insufficient machinery capacity to perform machinery operations during biologically feasible periods. Average percent targeted acreage in Table 4 allows a consideration of underutilized acreage. The acreage percentage for 6.E and 6.G was

[3] The Georgia coastal plain counties included are Appling, Atkinson, Bacon, Ben Hill, Berrian, Brooks, Bulloch, Candler, Coffie, Calquitt, Cook, Emanuel, Evans, Grady, Irwin, Jeff Davis, Lanier, Loundes, Mitchell, Montgomery, Tatnall, Thomas, Tift, Toombs, and Worth.

[4] This principle is implicit in most stochastic analyses of machinery choice and is widely accepted as a risk management strategy. Heady (p. 526) and Castle *et al.* (p. 174) are examples of textbook treatments of this view over the past 35 years.

Table 4. Percent Targeted Acreage, Net Returns and Stochastic Dominance Results with Intertemporal Acerage Effects, Soil Moisture Constraints, and Stochastic Prices for Soybean and Wheat Double-Cropping in the Gerogia Costal Plain[a]

Strategy	Percent Targeted Acreage[b]	Annual Net Returns Per Acre: Expected Annual Net Returns (Dollars)	Lowest Value (Dollars)	Highest Value (Dollars)	Variance	Undominated Strategy Within Scales: 4.D	4.E	6.E	6.G	8.A	8.C	8.E
Four-Row												
4.A	80	27.51	-65.85	104.19	1542.78	1	1					
4.B	83	30.40	-68.81	107.55	1640.51	1	1					
4.C	91	65.12	-36.46	143.32	1354.72	2	0					
4.D	93	67.78	-34.43	139.58	1063.73		0	1	0			
4.E	95	55.66	-14.45	126.91	829.97	0		1	1			
Six-Row												
6.A	97	66.84	-37.57	146.12	1353.11			2	0			
6.B	98	47.89	-57.91	125.19	1210.65			1	1			
6.C	97	63.07	-41.93	141.76	1334.76			1	1			
6.D	98	44.19	-62.27	120.83	1157.75			1	1			
6.E	98	72.58	5.35	144.89	820.86	-1	-1		0	-1	-2	-1
6.F	98	52.46	-14.99	123.98	818.85			1	1			
6.G	98	67.05	6.09	138.04	764.19	0	-1	0		-2	-1	-2
6.H	99	46.84	-14.25	118.11	777.92			1	1			
Eight-Row												
8.A	98	66.74	-38.90	142.58	1212.72			1	2		0	0
8.B	99	48.02	-59.24	121.64	1052.56					1	1	1
8.C	99	65.14	3.68	133.14	763.03			2	1	0		0
8.D	99	45.09	-16.66	116.89	779.21					0	1	1
8.E	100	59.60	4.54	124.50	702.57			1	2	0	0	
8.F	100	39.56	-16.39	108.21	726.64					0	1	1

[a]1 implies column strategy is FSD over row strategy.
2 implies column strategy is SSD over row strategy.
-1 implies row strategy is FSD over column strategy.
-2 implies row strategy is SSD over column strategy.
0 implies no dominates in terms of FSD and SSD.

[b]Percent targeted acreage is the portion of taryeted single and double-crop soybean and wheat acreage that is actually planted.

98 percent. Not surprisingly, the four-row complements have smaller percentages and the eight-row complements higher percentages. Variances in annual net returns in Table 4 also support these influences. Generally, variance is higher for smaller capacity within each scale set and higher for smaller scale sets. The maximum expected profit choice, 6.E, does not have the lowest variance. Larger six- and eight-row complements have lower variances. However, the lower variance complements have higher machinery costs associated with the larger capacity, and thus, lower expected returns, which account for the SSD and expected profit results. Machinery capacity obviously affects production risk in the farm opportunity set. In this case, production risk also affects expected profits such that the maximum expected profit machinery choice is the representative set. Thus, risk aversion in the objective function does not contribute any additional refinement to explanation of observed machinery capacity. As in research on enterprise choice, the perceived importance of risk aversion in machinery choice may reflect incomplete specification of

Table 5. Percent Targeted Acreage, Net Returns and Stochastic Dominance Results with Independence Between Years, Soil Moisture Constraints, and Stochastic Prices for Soybean and Wheat Double-Cropping in the Georgia Coastal Plain[a]

		Annual Net Returns Per Acre				Undominated Strategy Within Scales						
Strategy	Percent Targeted Acreage[b]	Expected Annual Net Returns (Dollars)	Lowest Value (Dollars)	Highest Value (Dollars)	Variance	4.C	4.D	6.A	6.E	6.G	8.A	8.C
Four-Row												
4.A	100	64.18	-20.80	136.49	777.61	1	1					
4.B	100	61.23	-23.75	133.54	777.62	1	1					
4.C	100	72.58	-12.98	143.32	805.70		0	0	2	0		
4.D	100	72.28	-3.89	139.58	762.24	0		0	1	0		
4.E	100	57.13	-17.08	126.91	764.91	1	1					
Six-Row												
6.A	100	72.77	-17.20	146.12	828.96	0	0		0	0	0	0
6.B	100	52.48	-32.44	125.19	807.65			1	1	1		
6.C	100	68.41	-21.56	141.76	828.96			1	1	0		
6.D	100	48.11	-37.30	120.83	807.65			1	1	1		
6.E	100	74.09	3.85	144.89	751.28	-2	-1	0		0	-1	0
6.F	100	53.96	-12.19	123.98	747.97			0	1	1		
6.G	100	68.45	8.56	138.04	708.64	0	0	0	0		0	-1
6.H	100	48.24	-12.38	118.11	721.59			0	1	1		
Eight-Row												
8.A	100	71.16	-13.66	142.58	799.57			0	1	0		0
8.B	100	50.73	-30.16	121.65	797.24						1	1
8.C	100	66.56	6.19	133.14	706.11			0	1	0		0
8.D	100	46.51	-13.93	116.89	720.99						1	1
8.E	100	59.60	4.54	124.50	702.57						0	1
8.F	100	39.56	-16.39	108.21	726.64						1	1

[a]1 implies column strategy is FSD over row strategy.
2 implies column strategy is SSD over row strategy.
-1 implies row strategy is FSD over column strategy.
-2 implies row strategy is SSD over column strategy.
0 implies no dominates in terms of FSD and SSD.

[b]Percent targeted acreage is the portion of total soybean and wheat acreage that was actually planted over the 58 weather years.

production set relations rather than risk aversion (Baker and McCarl; Musser *et al.*).

Exogenous Acreage Model

The intertemporal acreage influences on machinery selection were evaluated by removing from DCTEM the linkages in wheat acreage among years. Instead of wheat acreage being determined endogenously by the interaction of harvest time and fall weather in the previous year, 400 acres of wheat (67 percent of the total acreage) was assumed to be harvested every year. Compared with endogenously determined wheat acreage (Table 4), expected annual net returns are higher when the acreage planted is equal to the targeted acreage (Table 5). This result corresponds to Brink and McCarl's findings that an assumption of independence among years consistently resulted in estimates higher than actual income achieved.

Of interest is the influence of intertemporal acreage effects on the efficient set in each scale of equipment. By removing the intertemporal effect, the size of the efficient set for six-row equipment is increased with the addition of complement 6.A to complements 6.E and 6.G in the intertemporal model. Thus, in the independent acreage model, less machinery capacity is also risk-efficient. Less rather than more machinery capacity is further indicated with results for four- and eight-row efficient sets. Complements 4.C and 4.D are now FSD efficient compared with 4.D and 4.E in the intertemporal model, and complement 8.E is dropped from the FSD eight-row efficient set. Complements 4.E and 8.E are eliminated from the risk-efficient set, because their impacts on wheat production and returns in the subsequent years are ignored. This failure to account for the indirect intertemporal acreage effects can lead to significantly different results.

The overall SSD efficient set consists of 6.A, 6.E and 6.G. Again, 6.E has the highest expected profit level, followed by 6.A. While the representative complement, 6.E, continued to be consistent with both risk aversion and risk neutrality, smaller capacity complements tended to be risk-efficient in contrast to the intertemporal acreage model.

Removal of Insufficient Soil Moisture Constraint

The risk-efficient set for each equipment scale in the previous sections contains one tractor for each set of row planters and grain drills but only one harvesting system for six- and eight-row equipment (Tables 3 and 4). Thus, planting capacity, not harvest capacity, is crucial to these machinery set decisions. Estimating the number of available planting days during peak planting time, May 25 through June 25, with the base model indicates a mean available planting days of only 5.27 days with a standard deviation of 2.64 days. Removing the insufficient soil moisture constraint from the intertemporal model resulted in the mean available planting days increasing to 23.45 days with a standard deviation of 2.00 days. Limited planting days associated with the insufficient soil moisture constraint was assessed by deleting this constraint from the base model. Results, in Table 6, indicate that the overall SSD efficient set contained complements 4.A and 6.A compared with 6.E and 6.G in the intertemporal model (Table 4). Complement 4.A also had the highest expected profit followed by 6.A.

On sandy soils, determination of field work days seems to require both excessive and insufficient precipitation. Not considering inadequate precipitation in the modeling effort indicates that decreasing machinery capacity, from the representative complement 6.E, is risk-efficient. Considering both excessive and insufficient soil moisture indicates increasing capacity when insufficient soil moisture is considered.

Percent Double-Cropping Effects

Representative complement 6.E is within the efficient sets associated with the endogenous acreage and exogenous annual acreage models. This robustness is further indicated when the percentage of double-crop is varied in the base endogenous acreage model. Table 7 presents the overall efficient machinery complement results for zero, 33, 67, and 100 percent targeted double-cropping. Representative complement 6.E is in the SSD efficient set for each percent double-cropping level. Complement 6.G is also within the SSD efficient sets, except for the 100 percent double-cropping case. The extra planting equipment appears to be necessary largely for planting delays with single-crop soybeans. For zero and 33 percent double-cropping, the four-row equipment scale enters the overall efficient machinery complement set. As the percent of double-cropping increases, six-row equipment is stochastically efficient with the representative complement 6.E generally dominating. Maximum expected profit is associated with complement 6.E for 33, 67, and 100 percent double-cropping with complement 4.C corresponding to maximum expected profit for the zero and 33 percent level of double-cropping.

The FSD efficient set and the maximum expected profit choice among the various percentages of double-cropping is the 100 percent double-cropping level with 6.E machinery. The potential increased returns associated with expanded usage of the double-cropping technology supports the view of Marra and Carlson that limited machinery capacity may be slowing the adoption of double-cropping practices in the southeastern United States.

CONCLUSIONS

This study demonstrates that detailed specification of interactions between the environment and agricultural production is necessary to model machinery selection. The double-crop wheat and soybean production system in the southeastern coastal plain region has some unique features compared with production systems modeled in previous machinery selection research. Existing survey information indicates that six-row equipment is representative of this production system. A simulation analysis of various equipment sizes found six-row

Table 6. Net Returns and Stochastic Dominance Results for Machinery Complements in Georgia Coastal Plain With Intertemporal Years, Stochastic Prices, and No Soil Moisture Constraint[a]

		Annual Net Returns Per Acre			Undominated Strategy Within Scales		
Strategy	Expected Annual Net Returns (Dollars)	Lowest Value (Dollars)	Highest Value (Dollars)	Variance	4.A	6.A	8.A
Four-Row							
4.A	86.61	6.41	153.39	826.97		0	
4.B	84.23	3.46	150.43	841.63	2		
4.C	82.49	-1.64	148.81	852.67	1		
4.D	77.79	-6.32	144.12	852.94	1		
4.E	64.25	7.83	129.65	737.60	1		
Six-Row							
6.A	86.48	30.49	152.10	744.68	0		-1
6.B	65.93	9.51	131.29	736.59		1	
6.C	82.44	26.13	147.74	736.57		1	
6.D	61.57	5.15	126.93	736.59		1	
6.E	80.06	23.71	145.38	737.27		1	
6.F	59.17	2.71	124.41	736.34		1	
6.G	73.27	16.91	138.60	737.47		1	
6.H	52.38	-4.10	117.72	736.54		1	
Eight-Row							
8.A	80.14	24.16	145.42	737.12		1	
8.B	59.63	3.19	124.99	736.96			1
8.C	71.78	15.61	136.91	734.89			1
8.D	51.11	-5.37	116.48	737.41			1
8.E	63.22	7.03	128.34	735.02			1
8.F	42.54	-13.94	107.92	737.53			1

[a]1 implies column strategy is FSD over row strategy.
2 implies column strategy is SSD over row strategy.
-1 implies row strategy is FSD over column strategy.
-2 implies row strategy is SSD over column strategy.
0 implies no dominates in terms of FSD and SSD.

equipment under general economic criteria to be risk efficient. However, risk aversion as a choice criterion was not an important determinant of the results. The expected profit maximization complement also was the representative six-row complement. Production risk associated with time available to plant soybeans in the choice set was crucial to both the risk-aversion and risk-neutrality choices.

Two specific features of the production system were demonstrated to be necessary for these results. First, the intertemporal acreage effects of machinery choice on wheat acreage had to be included in the model. When wheat acreage was specified exogenously, smaller machinery complements tended to be optimal. Endogenously determined wheat acreage required larger planting equipment to avoid severe soybean planting and harvesting delays, which in turn, delayed wheat planting. The other crucial element was insufficient moisture for soybean germination and emergence, which is related to the limited moisture retention capacity of sandy soils. Again, when the inadequate moisture constraint was removed, smaller equipment did not cause soybean planting delays and tended to be in the efficient set. Six-row machinery would have

Table 7. Expected Returns and Stochastic Dominance Simulation for Machinery Complements in Southeastern Georgia Coastal Plain, Results With Intertemporal Effects, Soil Moisture Constraints, and Stochastic Prices for Zero, 33, 67, and 100 Percent Double Cropping

Economic Criteria	Percent Double Cropping 0	33	67	100
	—Efficient Machinery Complements—			
SSD	4.C, 4.D, 6.E, 6.G	4.C, 4.D, 6.E, 6.G	6.E, 6.G	6.E
Maximum Expected Net Return	4.C	4.C, 6.E[a]	6.E	6.E

[a] The expected return for 4.C and 6.E are $34.20 and $34.33 per acre, respectively. These net returns are within 0.4 percent and, thus, are assumed to be equivalent.

been too large without either of these production features.

Although the solutions are specific to double-crop soybean and wheat in the southeastern coastal plain region, other production regions have similar production conditions. Other multiple crop production systems and systems that require fall planting and tillage operations could have intertemporal acreage effects from machinery. Production systems on sandy soils and in semi-arid climates also could be subject to insufficient soil moisture effects. Explicit attention to these issues appears warranted if such production practices are considered.

The results of this study suggest that failure to consider all relevant field time constraints may contribute to the perceived machinery overcapitalization of many farmers. This explanation of machinery overcapitalization may be a relevant alternative to other explanations such as income tax management and labor availability. As with other machinery choice literature, detailed consideration of these issues is beyond the scope of this research.

Variation in the percentage of acreage double-cropped supports the efficiency of six-row equipment. Four-row equipment enters the risk-efficient set only for low levels of double-cropping, and eight-row equipment does not enter the risk-efficient set even at 100 percent double-cropping. Representative complement 6.E tends to dominate these results indicating the potential superiority of this equipment complement. As with all machinery research, this conclusion may not hold if the production and financial choice set were expanded to include alternative crops and tillage methods, custom machinery operations, and leasing machinery. However, available survey data do not indicate use of these alternatives. Inasmuch as 6.E is optimal in both economic results and is the representative choice of farmers, these alternatives likely will not be superior to the situation considered.

The dominance of the representative complement in this research also has some interesting implications for farm management research and extension. As determined in this research, farmers in the southeastern coastal plain have evolved to the optimum six-row size and even the specific complement. While past farm management programs may have contributed to this outcome, the results also suggest caution in prescribing choices markedly different from current practices. As this research indicates, machinery choices require complex consideration of many elements of production systems. If optimal decisions can be made in this case, one would expect optimality in less complex management decisions. Farm management programs may provide assistance in agricultural methods and in adjusting to rapid changes in prices and technology. However, care is required in suggesting different management strategies. As indicated in this research, failure to consider all relevant elements of the production system may be the source of the recommendations. Finally, this research supports the classic farm management activity of maintaining farm management surveys so that representative practices can be determined.

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