



*The World's Largest Open Access Agricultural & Applied Economics Digital Library*

**This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.**

**Help ensure our sustainability.**

Give to AgEcon Search

AgEcon Search

<http://ageconsearch.umn.edu>

[aesearch@umn.edu](mailto:aesearch@umn.edu)

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

*No endorsement of AgEcon Search or its fundraising activities by the author(s) of the following work or their employer(s) is intended or implied.*

# Whole-Farm Evaluation of No-Till Profitability in Rice Production using Mixed Integer Programming

**K. Bradley Watkins, Jason L. Hill, Merle M. Anders, and Tony E. Windham**

Rice production in Arkansas usually involves intensive tillage. No-till rice has been studied, but the focus has been limited to impacts on yields and per acre returns. This study uses mixed integer programming to model optimal machinery selection and evaluate whole-farm profitability of no-till management for rice-soybean farms. Results indicate that lower machinery ownership expenses combined with lower fuel and labor expenses do enhance the profitability of no-till management, but the monetary gains appear to be modest, implying that other incentives may be necessary to entice producers to use the practice.

*Key Words:* conventional till, economies of size, machinery complements, mixed integer programming, no-till, rice, soybean, whole-farm net returns

**JEL Classifications:** Q12, Q15, Q16, Q24, Q25

Arkansas is the top rice-producing state in the United States and accounts for over 48% of total U.S. rice production (U.S. Department of Agriculture, Economic Research Service). Nearly all rice production occurs in the eastern part of the state in the Mississippi Alluvial Valley. Surface water quality in this region is significantly influenced by geography, climate, and agriculture. The area has little topographic relief, and soils are predominantly composed of dense alluvial clay sub-soils that limit water

infiltration (Kleiss et al.). Surface soils contain little organic matter and are comprised of silt and clay particles that are readily transported by runoff from tilled fields during heavy rainfall events (Huitink et al.). Sediment is the primary pollutant identified for most eastern Arkansas waterways (Arkansas Department of Environmental Quality, Huitink et al.), and conservation practices like no-till are commonly recommended as remedial mechanisms (Huitink et al.).

Conventional rice production in Arkansas involves intensive cultivation. Fields are “cut-to-grade” every few years, disked annually in either late fall or early spring, and “floated” (land planed) annually in early spring to ensure smooth water movement across the field. In 2004, conventional tillage (spring tillage and floating) accounted for 60.7% of all planted rice acres in Arkansas, while stale seedbed (fall tillage followed by burn-down herbicides

---

K. Bradley Watkins, Jason L. Hill, and Merle M. Anders are assistant professor of agricultural economics, program associate, and assistant professor and systems agronomist, respectively, University of Arkansas Rice Research & Extension Center, Stuttgart, AR. Tony E. Windham is State Leader, Department of Community and Economic Development, University of Arkansas Cooperative Extension Service, Little Rock, AR.

The authors wish to thank two anonymous reviewers of the *Journal* for their useful comments.

prior to planting in the spring) accounted for over 31.4% of planted rice acres.<sup>1</sup> True no-till management (rice planted directly into the previous crop residue without tillage at any time) accounted for 9.7% of planted Arkansas rice acreage in 2004 (Wilson and Branson).

The economics of no-till rice production have not been fully investigated. Most studies have been limited to partial budget analyses based on experimental research plots and have produced mixed findings regarding profitability (Pearce et al.; Smith and Baltazar; Watkins, Anders, and Windham). Although these studies account for operating (variable) expenses, they tend to ignore or inadequately account for ownership expenses associated with machinery selection. No-till involves significant changes in the types and quantities of both operating and machinery inputs relative to conventional till management (Epplin et al.). Thus ownership expenses related to machinery selection should not be excluded when determining the profitability of no-till management. The partial budget studies also fail to account for the impacts of farm size on profitability since economies of size are ignored.

The composition of the machinery complement can differ by farm size, and machinery investment decisions often involve more than one crop. Thus, economies of size and machinery selection are best evaluated using a whole-farm framework. This study uses Mixed Integer Programming to evaluate the profitability of no-till relative to conventional till rice management for farms of varying size growing both rice and soybeans in a two-year rotation.

### **Potential Benefits and Expenses of No-Till**

Erosion control is the primary benefit of no-till as cited in the literature (Fuglie; Hartell;

Krause and Black; Uri). However, no-till is also promoted for reasons other than erosion control, including reduced labor requirements, reduced fuel expenses, and lower machinery ownership expenses relative to conventional tillage (Epplin et al.; Fuglie; Krause and Black; Parsch et al.). No-till is also promoted as a method of carbon sequestration in agricultural production (Hartell; West and Post). Intensive tillage releases soil organic carbon in gaseous form into the atmosphere when the soil is turned and thus contributes to the accumulation of greenhouse gases in the atmosphere. No-till allows soil organic carbon to be sequestered, with the highest sequestration rates occurring immediately following conversion from conventional till to no-till management (Hartell; West and Post). Soil moisture conservation is also cited as a benefit of no-till (Krause and Black). No-till improves the soil's capacity to hold water by increasing water infiltration and limiting soil drying. In the case of rice, the additional soil moisture in the soil profile often eliminates the need to "flush" water across the field to ensure proper seed germination, stand emergence, and herbicide activation (Anders et al. 2003).

Yield advantages to no-till are ambiguous based on the literature. Several studies have evaluated crop yields under no-till management, but the agronomic results of these studies tend to be crop, soil, and region specific, and no definitive conclusions can be drawn (Hartell; Uri). Studies focusing on rice have found no clear yield advantage for no-till. Studies in Arkansas and Louisiana indicate that no-till rice yields are generally lower or not significantly different from conventional till rice yields (Anders et al. 2005; Bollich; Pearce et al.; Smith and Baltazar).

Higher herbicide expenses are often cited or assumed for no-till management in the literature (Epplin et al.; Fuglie; Krause and Black; Parsch et al.). No-till systems substitute herbicides for tillage in weed control, and the additional cost of herbicide applications can be substantial (Epplin et al.). However, Fuglie examined data on no-till adoption in the Cornbelt and found no significant difference in herbicide expenditures between no-till and con-

---

<sup>1</sup> Stale seedbed is considered by some to be a conservation tillage system in rice production. However, such a designation may be inappropriate. The amount of tillage is usually no less for stale seedbed than for conventional till systems. Only the timing of tillage is different. Tillage for stale seedbed systems is conducted in the fall, while tillage for conventional systems is conducted in early spring.

ventional till systems. Fuglie speculates that reliance on herbicides may lessen once no-till has been practiced in a field for several years. Adjustment costs may also be present when converting from conventional till to no-till technology. Adjustment costs would include the cost of replacing current machinery with new machinery as well as costs associated with lack of experience with no-till technology during the initial years of adoption (Krause and Black). Adjustment costs decline over time as the producer becomes more familiar with no-till technology.

As mentioned earlier, no-till systems are often promoted because of savings in machinery expenses compared with conventional tillage (Epplin et al.; Fuglie; Krause and Black; Parsch et al.). Machinery ownership and operating expenses constitute a large portion of total crop production expenses. Beaton et al. report that machinery expenses account for 28% to 46% of total crop production expenses in Kansas. Machinery expenses directly impact farm profitability and must be properly accounted for when making profitability comparisons among production systems like conventional till and no-till (Beaton et al.; Epplin et al.). The current study uses Mixed Integer Programming to model optimal machinery selection and evaluate whole-farm profitability of no-till relative to conventional till rice production.

#### **Mixed Integer Programming Studies Related to Conservation Tillage**

Mixed Integer Programming (MIP) involves the optimization of a linear objective function subject to linear constraints, nonnegativity conditions, and variables taking on both continuous and integer values. Mixed Integer Programming permits the modeling of fixed costs associated with items purchased in whole units, like tractors or implements. Many studies have used MIP to evaluate optimal machinery selection decisions at the whole-farm level (Al-Soboh et al.; Camarena, Gracia, and Sixto; Danok, McCarl, and White, 1978, 1980; Epplin et al.; Held and Helmers; Martin et al.; Pfeiffer and Peterson; Reid and Bradford; Salassi, Breaux, and Na-

quin). However, only two studies have used MIP to evaluate the whole-farm economics of conservation tillage systems.

Epplin et al. estimated machinery requirements and operating inputs for a representative 1,240-acre wheat farm under conventional till, minimum till, and no-till management. Mixed Integer Programming was used to obtain least cost tractor and implement combinations for each tillage treatment, and the results were used in the Oklahoma State University Enterprise Budget Generator to generate enterprise budgets for each tillage practice. The authors found that reduced tillage systems reduced preharvest labor, fuel, and machinery investment but increased annual operating capital and herbicide costs relative to the conventional plow system.

Martin et al. used a MIP model to determine the optimal crop mix and machinery complement for a representative 4,500-acre farm producing cotton, soybeans, corn, and grain sorghum with conventional and reduced tillage practices. The authors also used the MIP model to obtain optimal crop mixes and machinery complements for farm sizes ranging from 1,000 to 4,500 acres. The authors included decoupled government payments in the analysis and tied eligibility for these payments to a soil conservation compliance parameter. Conventional tillage systems failed to comply with soil conservation compliance. Thus reduced tillage systems were selected for each farm size and profit maximizing crop mix.

The current study differs from the previous two studies in the following ways. This study differs from Epplin et al. in that more than one farm size is modeled to evaluate the economies of size associated with both conventional till and no-till rice farms. This study also differs from Martin et al. in that only one crop mix is modeled (the typical rice-soybean rotation used in Arkansas rice production) and decoupled payments are excluded to determine the relative profitability of no-till to conventional till management without government direct payment assistance or compliance to environmental regulations.

### The Mixed Integer Programming Model Specification

Two MIP models were developed for this study: one for a typical farm growing both rice and soybeans using conventional tillage (CT) and one for a farm producing both crops using no-till management (NT). Both MIP models maximize returns above operating and ownership expenses. The objective functions of the MIP models are specified as follows:

(1) Maximize  $Z$

$$\begin{aligned} &= \sum_{a=1}^2 \sum_{b=1}^2 P_{ab} Q_{ab} - \sum_{a=1}^2 \sum_{b=1}^2 IP_a A_{ab} \\ &\quad - \sum_{a=1}^2 \sum_{b=1}^2 \sum_{c=1}^k \sum_{d=1}^l RMM_{aef} A_{abcde} \\ &\quad - \sum_{a=1}^2 \sum_{b=1}^2 RMW_{ag} A_{abg} - w \sum_{a=1}^2 \sum_{b=1}^2 L_{ab} \\ &\quad - f \sum_{a=1}^2 \sum_{b=1}^2 D_{ab} - \sum_{e=1}^m \Pi_e T_e \\ &\quad - \sum_{f=1}^n \Pi_f I_f - \sum_{g=1}^o \Pi_g W_g \end{aligned}$$

where  $a$  is crop type (rice or soybean);  $b$  is land type (owned or rented);  $c$  is production period (land preparation, planting, irrigation, and harvest for CT; planting, irrigation, and harvest for NT);  $d$  is operation (disking, floating, drilling, rolling, levee building, etc.);  $e$  is tractor type;  $f$  is implement type; and  $g$  is well type (total well or power unit only).  $P_{ab}$  is the price per bushel of crop  $a$  on land type  $b$ , and  $Q_{ab}$  is the total bushels of crop  $a$  produced on land type  $b$ .  $IP_a$  is the per acre nonmachinery operating expenses of crop production inputs (seed, fertilizer, herbicide, custom chemical application) for crop  $a$ ;  $A_{ab}$  is the number of acres in production of crop  $a$  on land type  $b$ ;  $RMM_{aef}$  is the per acre repairs and maintenance expense associated with tractor/implement combination  $ef$  and crop  $a$ ;  $A_{abcde}$  is the number of crop acres  $a$  on land type  $b$  allocated to tractor/implement combination  $ef$  during operation  $d$  in production period  $c$ ; and  $RMW_{ag}$  is the per acre repair and maintenance expense associated with well type  $g$  and crop

$a$ .  $A_{abg}$  is the number of crop acres  $a$  on land type  $b$  allocated to well type  $g$ . Variable  $w$  is the wage rate for labor (dollars per hour), and  $L_{ab}$  is the number of hours of hired machine and irrigation labor allocated to crop  $a$  on land type  $b$ . Variable  $f$  is the fuel price for diesel (dollars per gallon);  $D_{ab}$  is the number of gallons of machine and irrigation diesel fuel allocated to crop  $a$  on land type  $b$ ;  $\Pi_e$  is the annual fixed costs of tractor type  $e$ ;  $T_e$  is the integer number of type  $e$  tractors used;  $\Pi_f$  is the annual fixed costs of implement type  $f$ ; and  $I_f$  is the integer number of type  $f$  implements used.  $\Pi_g$  is the annual fixed costs of well type  $g$ , and  $W_g$  is the integer number of type  $g$  wells used.

The MIP models were solved subject to acreage constraints on total cropland available, owned cropland available, and rented cropland available. Both models also included operation sequencing rows (disked acres to floated acres; floated acres to cultivated acres), a yield balance row to account for the sale of rice and soybeans, a nonmachinery input purchase balance row, rice-soybean rotation requirement balance rows, tractor, implement, and well annual capacity rows, and labor and diesel fuel purchase balance rows.

The tractor and implement annual capacity rows were formulated as follows:

$$(2) \quad -CAP_{ce} T_e + \sum_{a=1}^2 \sum_{b=1}^2 \sum_{c=1}^k \sum_{d=1}^l TH_{aef} A_{abcde} \leq 0$$

$$(3) \quad -CAP_f I_f + \sum_{a=1}^2 \sum_{b=1}^2 \sum_{c=1}^k \sum_{d=1}^l IH_{aef} A_{abcde} \leq 0$$

where  $CAP_{ce}$  is the capacity of annual use hours of tractor type  $e$  available for production period  $c$ ,  $CAP_f$  is the capacity of annual use hours available for implement type  $f$ ,  $TH_{aef}$  is the per acre tractor use hours for tractor/implement combination  $ef$  on crop  $a$ ,  $IH_{aef}$  is the per acre implement use hours for tractor/implement combination  $ef$  on crop  $a$ , and  $A_{abcde}$ ,  $T_e$ , and  $I_f$  are as defined above. Irrigation well capacity rows were formulated as follows:

$$(4) \quad -CAP_g W_g + \sum_{a=1}^2 \sum_{b=1}^2 A_{abg} \leq 0$$

where  $CAP_g$  is the number of acres supplied with water by well type  $g$ , and  $A_{abg}$  and  $W_g$  are as previously defined.

Balance rows to accommodate the purchase of labor and diesel fuel were formulated as follows:

$$(5) \quad -L_{ab} + \sum_{a=1}^2 \sum_{b=1}^2 \sum_{c=1}^k \sum_{d=1}^l MLH_{aef} A_{abcde} \\ + \sum_{a=1}^2 \sum_{b=1}^2 ILH_{ag} A_{abg} \leq 0$$

$$(6) \quad -D_{ab} + \sum_{a=1}^2 \sum_{b=1}^2 \sum_{c=1}^k \sum_{d=1}^l MDG_{aef} A_{abcde} \\ + \sum_{a=1}^2 \sum_{b=1}^2 IDG_{ag} A_{abg} \leq 0$$

where  $MLH_{aef}$  is the per acre labor requirement for tractor/implement combination  $ef$  on crop  $a$ ,  $ILH_{ag}$  is the per acre labor requirement for well type  $g$  on crop  $a$ ,  $MDG_{aef}$  is the per acre diesel fuel requirement for tractor/implement combination  $ef$  on crop  $a$ ,  $IDG_{ag}$  is the per acre diesel fuel requirement for well type  $g$  on crop  $a$ , and  $A_{abcde}$ ,  $A_{abg}$ ,  $L_{ab}$ , and  $D_{ab}$  are as previously defined.

## Data and Methods

The complete list of machinery items used in the study is found in Table 1. Ownership expenses (depreciation, interest, taxes, insurance, and housing) for tractor and implement items were calculated based on ASAE machinery management standards (American Society of Agricultural Engineers 2003a,b). Depreciation was estimated for each machinery item based on 2004 current list prices and ASAE remaining value equations that account for the impact of machinery age (years of useful life) on implement value and the impacts of both machinery age and annual usage (hours) on the value of combines and tractors. The ASAE remaining value equations are reduced forms of functions estimated by Cross and Perry (1995, 1996). Depreciation and interest were annualized for each tractor/implement item using the capital recovery method and an interest rate of 5.75%. Additional annual costs for tax-

es, insurance, and housing were estimated as 1.5% of list price for each tractor/implement item. Ownership expenses associated with irrigation items (well, pump, gearhead, and power unit) were based on data reported in Bryant et al. for a standard well less than 120 feet deep and supplying water for 120 acres. Irrigation ownership cost data reported in Bryant et al. were adjusted to 2004 dollars using the Producer Price Index.

Items related to the estimation of machinery operating expenses (repairs and maintenance, fuel, engine oil, and labor) were also obtained using ASAE standard formulas and recommendations. Per acre repairs and maintenance costs for each machinery item were estimated based on ASAE standard formulas that relate repair and maintenance costs to both accumulated use hours and list price. Per acre diesel fuel consumption rates for tractors were estimated based on Nebraska Tractor Test Data as reported in the ASAE, which calculates fuel consumption as a product of Power Takeoff (PTO) horsepower. Engine oil costs were estimated at 15% of per acre fuel costs as per ASAE recommendations. Per acre machinery labor hours were estimated for each tractor/implement combination as a product of per acre machinery use hours and a labor adjustment factor that accounts for additional labor involved in locating, hooking up, adjusting, and transporting machinery. Operating expense items associated with irrigation (repairs and maintenance, fuel consumption, and irrigation labor) were taken directly from Bryant et al. for a standard well less than 120 feet deep and irrigating 120 acres.

Per acre nonmachinery operating expenses associated with crop inputs (seeds, fertilizer, pesticide) and custom chemical application were calculated based on input data from a long-term rice-based cropping systems study at Stuttgart, AR. All nonmachinery input purchase expenses were in 2004 dollars. Average crop yields were obtained from the long-term cropping systems study for the period 2001–2004 to represent expected crop yields for a typical rice-soybean rotation under conventional till and no-till management. Expected yields were 182 bushels per acre for rice and

**Table 1.** List of Tractor and Implement Combinations for Arkansas Farms Producing Both Rice and Soybeans Using Conventional Till or No-Till

Crop Enterprise	Tillage	Production Period	Operation	Implement	Tractor/Combine
Rice, soybean	CT <sup>a</sup>	Land preparation	Disk	26ft disk	MFWD 190hp <sup>b</sup>
Rice, soybean	CT	Land preparation	Disk	32ft disk	4wd 300hp
Rice, soybean	CT	Land preparation	Land float	14ft × 50ft land plane	2wd 150hp
Rice, soybean	CT	Land preparation	Land float	16ft × 56ft land plane	2wd 190hp
Rice, soybean	CT	Land preparation	Land float	16ft × 56ft land plane	MFWD 190hp
Rice, soybean	CT	Land preparation	Cultivate	20ft Triple-K	2wd 150hp
Rice, soybean	CT	Land preparation	Cultivate	27ft Triple-K	MFWD 190hp
Rice, soybean	CT	Land preparation	Cultivate	32ft Triple-K	4wd 300hp
Rice, soybean	CT	Planting	Grain drill	15ft grain drill	2wd 150hp
Rice, soybean	CT	Planting	Grain drill	24ft grain drill	2wd 150hp
Rice, soybean	CT	Planting	Grain drill	30ft grain drill	2wd 190hp
Rice, soybean	NT	Planting	Grain drill	15ft NT grain drill	MFWD 190hp
Rice, soybean	NT	Planting	Grain drill	20ft NT grain drill	MFWD 190hp
Rice, soybean	NT	Planting	Grain drill	30ft NT grain drill	MFWD 190hp
Rice, soybean	CT, NT	Planting	Ditching	Rear-mount ditcher	2wd 105hp
Rice, soybean	CT, NT	Planting	Rolling	32ft Roller	2wd 105hp
Rice, soybean	CT, NT	Irrigation	Levee building	Levee disk	MFWD 190hp
Rice	CT, NT	Irrigation	Levee building	Levee disk/seeder	MFWD 190hp
Rice, soybean	CT, NT	Irrigation	Butting levees	Rear-mount blade	2wd 105hp
Rice	CT, NT	Irrigation	Butting levees	Backhoe	2wd 105hp
Rice	CT, NT	Harvest	Combine	22ft rice header	240hp combine
Soybean	CT, NT	Harvest	Combine	25ft soybean header	240hp combine
Rice	CT, NT	Harvest	Combine	25ft rice header	275hp combine
Soybean	CT, NT	Harvest	Combine	30ft soybean header	275hp combine
Rice, soybean	CT, NT	Harvest	Grain cart	500bu grain buggy	MFWD 190hp
Rice, soybean	CT, NT	Harvest	Grain cart	700bu grain buggy	MFWD 190hp

<sup>a</sup> CT is conventional till; NT is no-till.<sup>b</sup> MFWD is mechanical front-wheel-drive tractor; 2wd is 2-wheel-drive tractor; 4wd is 4-wheel-drive tractor; hp is horsepower.

43 bushels per acre for soybeans under conventional till management and 173 bushels per acre for rice and 44 bushels per acre for soybeans under no-till management.

Market prices of \$2.58 per bushel for rice and \$5.67 per bushel for soybeans were used as expected prices in the study. These market prices correspond to season average Arkansas prices for the period 2001–2004 (U.S. Department of Agriculture, National Agricultural Statistics Service 2005d). A four-year average loan deficiency payment (LDP) of \$1.15 per bushel was added to the expected rice price to obtain a total cash price of \$3.73 per bushel. A rice drying and hauling expense of \$0.42 per bushel and a soybean hauling expense of \$0.15 per bushel were subtracted from expected crop prices to account for per unit custom charges.

Total cropland acres for each representative farm were split into 32% owned and 68% rented acres based on tenure data from the 2002 Census of Agriculture for Arkansas, Lonoke, Monroe, and Prairie counties comprising the Arkansas Grand Prairie region (U.S. Department of Agriculture, National Agricultural Statistics Service 2005a). A typical 25% straight share arrangement was used to model land tenure in the study (Parsch and Danforth). In this arrangement, the landlord receives 25% of the crop, pays 25% of custom drying expenses, and pays 100% of all belowground irrigation expenses (well, pump, and gearhead). The farm operator receives 75% of the crop, pays 75% of custom drying expenses, pays 100% of all aboveground irrigation expenses (power unit, fuel), and pays 100% of all other production expenses.

Implement capacities in Equation (3) were estimated as the potential area covered by each implement in a growing season multiplied by per acre use hours. Tractor/combine capacities in Equation (2) were obtained by distributing tractor/combine total annual use hours across each production period. All machinery capacities were developed based on expert opinion from agronomists and Arkansas Grand Prairie rice producers. Irrigation well capacities in Equation (4) were set to 120 acres based on data from Bryant et al.

Timing of operations is more critical with conventional till than with no-till due to the need to complete land preparation operations in time for optimal planting. Proper timing of rice land preparation is particularly important, since disking is usually done in early spring when fields have a tendency to be wetter than normal and the number of days suitable for fieldwork is more limiting. Many rice producers include a 4-wheel-drive tractor in their machinery complement to complete rice disking in a timely manner. Hours available for rice disking were constrained in the conventional till MIP model to allow for the selection of at least one 4-wheel-drive tractor and one 32-foot disk for farms operating 1800 or more cropland acres based on counsel from Arkansas rice producers. Hourly constraints on rice and soybean land preparation and planting were then constructed for alternative farm size ranges based on median April–June fieldwork day data from the Arkansas Agricultural Statistics Service (U.S. Department of Agriculture, National Agricultural Statistics Service 2005b) and recommended rice and soybean planting dates reported in the Arkansas Rice Production Handbook (University of Arkansas, Cooperative Extension Service 2000) and the Arkansas Soybean Handbook (University of Arkansas, Cooperative Extension Service 2001). The land preparation and planting constraints imposed on the conventional till MIP model are presented by crop and farm size range in Table 2.

Optimal whole-farm net return solutions were generated for conventional till farms (CT) and no-till farms (NT) ranging in size from 1,200 to 3,600 acres. A wage rate of \$8.12 per hour was charged for labor based on the wage reported for Arkansas field workers in 2004 (U.S. Department of Agriculture, National Agricultural Statistics Service 2005c). A charge of \$1.73 per gallon was used for diesel fuel. This charge represents the amount paid for off-road diesel in Arkansas during the latter part of 2004. The CT and NT MIP models were solved using the What's Best! Professional 7.0 Spreadsheet Solver (Lindo Systems, Inc.).



**Table 2.** Land Preparation and Planting Hour Constraints used in the Conventional Till Mixed Integer Programming Model by Crop and Farm Size Range

Variable	Farm Size Range (Acres)					
	<2100	2100–2300	2400–2600	2700–2900	3000–3200	>3300
<b>Rice</b>						
Land preparation <sup>a</sup>	March 7–April 8	March 7–April 11	March 7–April 12	March 7–April 16	March 7–April 19	March 7–April 22
Days	11.1 <sup>b</sup>	13.3	14.0	16.3	18.6	21.6
Hours	133.7	159.4	168.0	195.6	223.2	259.2
Planting	April 9–April 21	April 12–April 26	April 13–April 28	April 17–May 3	April 20–May 12	April 23–May 18
Days	9.2 <sup>c</sup>	11.3	12.0	13.3	17.1	17.7
Hours	110.1	135.6	144.3	159.6	205.7	212.6
<b>Soybean</b>						
Land preparation <sup>a</sup>	April 16–May 3	April 20–May 10	April 20–May 15	April 26–May 24	April 30–May 29	May 1–June 9
Days	13.6 <sup>c</sup>	16.0	18.9	19.9	20.6	22.9
Hours	163.5	192.0	226.3	238.3	247.7	274.5
Planting	April 27–May 8	May 4–May 17	May 11–May 24	May 17–May 31	May 18–June 1	June 2–June 14
Days	8.6 <sup>c</sup>	9.0	9.0	10.1	10.3	11.0
Hours	102.9	108.0	108.0	121.4	123.6	132.0

<sup>a</sup> Periods and fieldwork days derived from Mississippi Delta working day probability data for March (American Society of Agricultural Engineers, 2003b) and the median days suitable for fieldwork from April through June in eastern Arkansas for the period 1999–2004 (U.S. Department of Agriculture, National Agricultural Statistics Service, 2005b).

<sup>b</sup> Number of 12-hour fieldwork days required by the MIP model to complete rice disking operations in a timely manner for each farm size range. Assumes at least one 32-foot disk and one 4-wheel-drive 300-horsepower tractor would be required to complete disking operations for farms 1800 acres or larger.

<sup>c</sup> Number of 12-hour fieldwork days established to complete rice planting, soybean disking, and soybean planting by farm size. Planting periods are based on recommended planting dates reported in the Arkansas Rice Production Handbook (University of Arkansas–Cooperative Extension Service, 2000) and the Arkansas Soybean Handbook (University of Arkansas, Cooperative Extension Service, 2001).

**Table 3.** Optimal Machinery Complements for 2400-Acre Conventional Till and No-Till Farms Producing Rice and Soybeans

Crop	Description	Conventional Till Farm		No-Till Farm	
		Machinery Item	Number	Machinery Item	Number
Rice, soybean	Tractor	2wd 105hp <sup>a</sup>	2	2wd 105hp	2
Rice, soybean	Tractor	2wd 190hp	1		
Rice, soybean	Tractor	MFWD 190hp	2	MFWD 190hp	2
Rice, soybean	Tractor	4wd 300hp	1		
Rice, soybean	Combine	240hp combine	2	240hp combine	2
Rice, soybean	Disk	26ft disk	1		
Rice, soybean	Disk	32ft disk	1		
Rice, soybean	Land float	16ft × 56ft land plane	4		
Rice, soybean	Triple K	27ft Triple-K	1		
Rice, soybean	Triple K	32ft Triple-K	1		
Rice, soybean	Grain Drill	30ft grain drill	1	30ft NT grain drill	1
Rice, soybean	Ditching	Rear-mount ditcher	1	Rear-mount ditcher	1
Rice, soybean	Rolling	32ft roller	1	32ft roller	1
Rice, soybean	Levee build	Levee disk	2	Levee disk	2
Rice	Levee build	Levee disk/seeder	1	Levee disk/seeder	1
Rice, soybean	Butting levees	Rear-mount blade	1	Rear-mount blade	1
Rice	Butting levees	Backhoe	1	Backhoe	1
Rice	Combine header	22ft rice header	2	22ft rice header	2
Soybean	Combine header	25ft soybean header	2	25ft soybean header	2
Rice, soybean	Grain cart	500bu grain buggy	2	500bu grain buggy	2
Rice, soybean	Owned well	Wells	7	Wells	7
Rice, soybean	Rented well	Power units	14	Power units	14

<sup>a</sup> MFWD is mechanical front-wheel-drive; 2wd is 2-wheel drive; 4wd is 4-wheel drive; hp is horsepower.

## Results

Optimal machinery complements for 2,400-acre CT and NT rice farms are presented in Table 3. The CT machinery complement has six tractors and uses two disks, four land floats, and two triple-K implements (cultivators) to complete tillage and land preparation prior to planting. The NT machinery complement uses no tillage or land preparation equipment and uses two less tractors than the CT complement. Both machinery complements look relatively the same during and after planting and require approximately the same number and types of implements to complete all production and harvest operations beyond planting. Levee construction is the primary production activity for both farms between planting and harvest and employs an equal number of tractors for both farms (two MFWD 190-horsepower tractors; two 2-wheel-drive 105-horsepower tractors).

Optimal machinery complements for 3,600-acre CT and NT rice farms are presented for comparison in Table 4. As with the 2,400-acre farms, the machinery complements for the 3,600-acre CT and NT farms differ prior to planting in terms of tractors and implements required for tillage and land preparation but look relatively the same following planting. The 3,600-acre machinery complements require an additional grain drill to complete planting operations and replace one 240-horsepower combine with a 275-horsepower combine to complete harvest operations compared with the 2,400-acre farms. The 3,600-acre farms also require one more MFWD 190-horsepower tractor, an additional levee disk, and an additional levee disk with seeder to complete levee construction and seeding operations compared with the 2,400-acre farms. The 3,600-acre CT complement requires an additional 2-wheel-drive 150-horsepower tractor to complete planting operations and an additional 26ft disk to complete

**Table 4.** Optimal Machinery Complements for 3,600-Acre Conventional Till and No-Till Farms Producing Rice and Soybeans

Crop	Description	Conventional Till Farm		No-Till Farm	
		Machinery Item	Number	Machinery Item	Number
Rice, soybean	Tractor	2wd 105hp <sup>a</sup>	2	2wd 105hp	2
Rice, soybean	Tractor	2wd 150hp	1		
Rice, soybean	Tractor	2wd 190hp	1		
Rice, soybean	Tractor	MFWD 190hp	3	MFWD 190hp	3
Rice, soybean	Tractor	4wd 300hp	1		
Rice, soybean	Combine	240hp combine	1	240hp combine	1
Rice, soybean	Combine	275hp combine	1	275hp combine	1
Rice, soybean	Disk	26ft disk	2		
Rice, soybean	Disk	32ft disk	1		
Rice, soybean	Land float	14ft × 50ft land plane	2		
Rice, soybean	Land float	16ft × 56ft land plane	3		
Rice, soybean	Triple K	27ft Triple-K	1		
Rice, soybean	Triple K	32ft Triple-K	1		
Rice, soybean	Grain drill	24ft grain drill	1	20ft NT grain drill	1
Rice, soybean	Grain drill	30ft grain drill	1	30ft NT grain drill	1
Rice, soybean	Ditching	Rear-mount ditcher	2	Rear-mount ditcher	2
Rice, soybean	Rolling	32ft roller	2	32ft roller	2
Rice, soybean	Levee build	Levee disk	3	Levee disk	3
Rice	Levee build	Levee disk/seeder	2	Levee disk/seeder	2
Rice, soybean	Butting levees	Rear-mount blade	1	Rear-mount blade	1
Rice	Butting levees	Backhoe	1	Backhoe	1
Rice	Combine header	22ft rice header	1	22ft rice header	1
Soybean	Combine header	25ft soybean header	1	25ft soybean header	1
Rice	Combine header	25ft rice header	1	25ft rice header	1
Soybean	Combine header	30ft soybean header	1	30ft soybean header	1
Rice, soybean	Grain cart	500bu grain buggy	1	500bu grain buggy	1
Rice, soybean	Grain cart	700bu grain buggy	1	700bu grain buggy	1
Rice, soybean	Owned well	Wells	10	Wells	10
Rice, soybean	Rented well	Power Units	21	Power units	21

<sup>a</sup> MFWD is mechanical front-wheel-drive; 2wd is 2-wheel drive; 4wd is 4-wheel drive; hp is horsepower.

tillage operations relative to the 2,400-acre CT complement. The 3,600-acre CT complement uses eight tractors compared with six for the 2,400-acre CT complement, while the 3,600-acre NT complement uses five tractors compared with four for the 2,400-acre NT complement.

Crop sales and operating expenses for 1,200-, 2,400-, and 3,600-acre CT and NT farms are presented in Table 5. Crop sales are 3% greater for the CT farms compared with the NT farms due to higher rice yields for CT. The largest portion of operating expenses for both CT and NT is devoted to purchases of production inputs such as seed, fertilizer, and

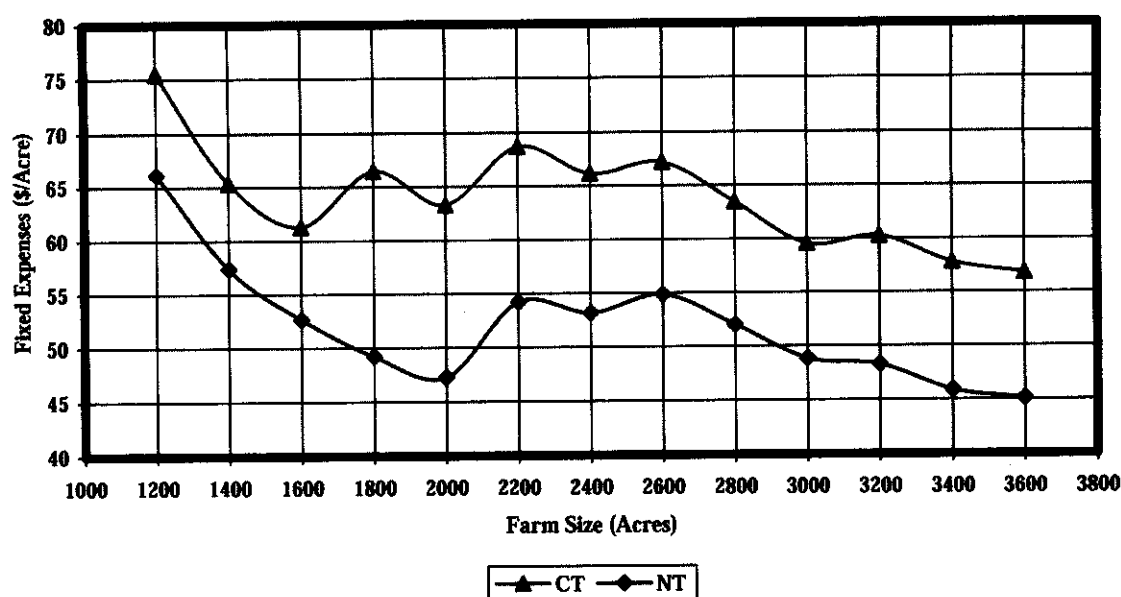
herbicide. Input purchase expenses account for 57% of total operating expenses for the CT farms and 64% of total operating expenses for the NT farms. Input purchase expenses are 13% larger for the NT farms due to greater dependence on herbicides to control weeds in the absence of tillage.

Irrigation and machinery fuel and oil expenses account for the second- and third-largest operating expense items for the CT and NT farms (Table 5). Fuel and oil expenses for irrigation are two to four times greater than those for machinery and account for 21–22% of total whole-farm operating expenses. The NT farms have slightly lower irrigation fuel

**Table 5. Whole-Farm Returns and Expenses for 1,200-, 2,400-, and 3,600-Acre Conventional Till and No-Till Farms Producing Rice and Soybeans, 2004 Dollars**

Economic Item	1,200-Acre Farms		2,400-Acre Farms		3,600-Acre Farms	
	CT <sup>a</sup>	NT	CT	NT	CT	NT
Crop sales <sup>b</sup>	415,676	403,667	831,352	807,334	1,247,028	1,211,001
Operating expenses:						
Machinery repairs and maintenance	5,666	5,823	11,197	12,091	16,846	18,143
Irrigation repairs and maintenance	3,398	3,223	6,795	6,447	10,193	9,670
Machinery labor	12,920	9,672	24,503	18,023	36,489	26,079
Irrigation labor	2,587	2,441	5,174	4,882	7,761	7,323
Machinery fuel and oil	19,566	11,834	39,882	22,107	58,744	32,764
Irrigation fuel and oil	46,581	44,192	93,162	88,385	139,744	132,577
Input purchase expenses <sup>c</sup>	118,170	133,992	236,340	267,984	354,510	401,976
Total operating expenses	208,888	211,178	417,054	419,918	624,287	628,533
Total ownership expenses	90,602	79,404	159,956	127,579	204,422	162,426
Total expenses	299,490	290,582	577,010	547,497	828,709	790,959
Returns above operating expenses	206,788	192,489	414,298	387,416	622,741	582,469
Returns above total expenses	116,187	113,085	254,342	259,837	418,319	420,042

<sup>a</sup> CT is conventional till; NT is no-till.<sup>b</sup> Net of custom drying and hauling expenses.<sup>c</sup> Seed, fertilizer, herbicide, custom chemical application, and operating interest expenses.



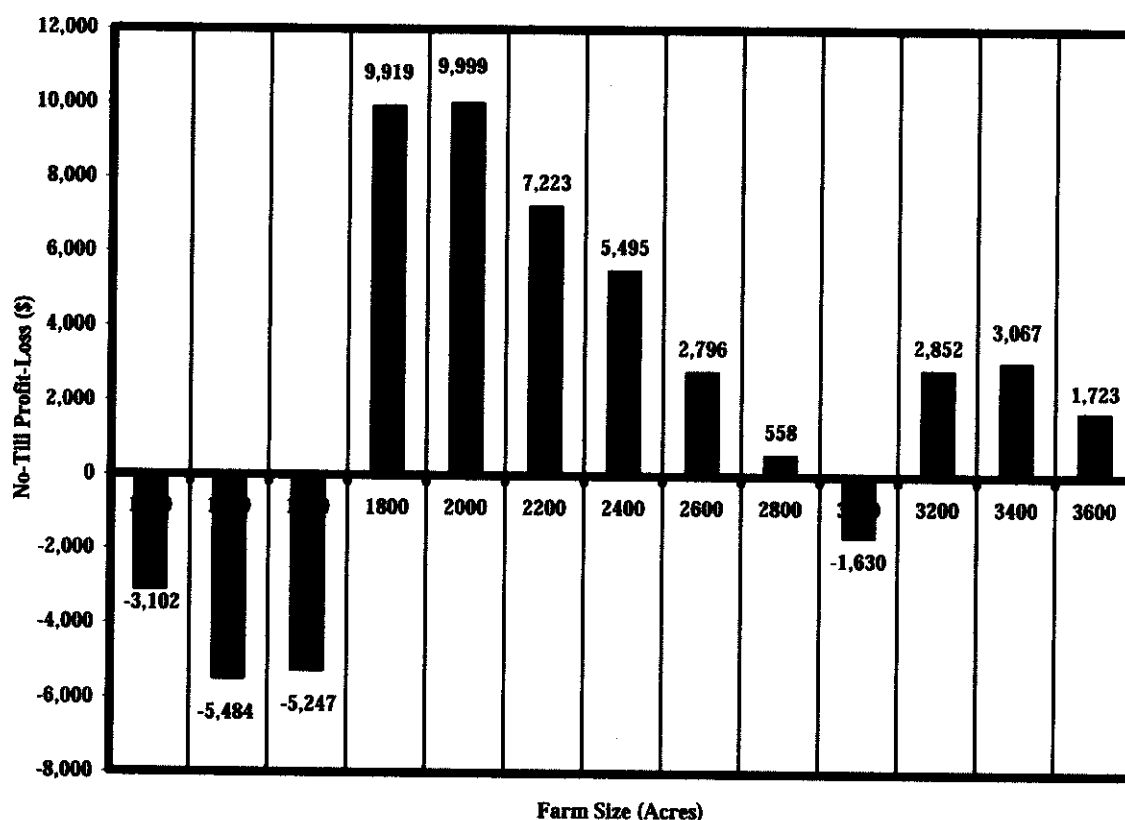
**Figure 1.** Whole-Farm Fixed Expenses Per Acre for Farms Producing Rice and Soybeans by Farm Size and Tillage, 2004 Dollars

and oil expenses than the CT farms because “flushing” to germinate seed and activate herbicides is usually unnecessary on no-till fields. Not flushing the field amounts to a water savings of approximately two acre-inches for the NT farm compared with the CT farm. The NT farms also have 40–45% smaller machinery fuel and oil expenses than the CT farms because no tillage or land preparation operations are required prior to planting with NT. Machinery and irrigation labor expenses follow the same rationale as irrigation fuel and oil expenses and are lower for the NT farms than for the CT farms. The cost savings resulting from lower fuel and labor are nearly enough to cover the higher input purchase expenses associated with NT. Thus total operating expenses for the NT farms are little different from those for the CT farms. Since whole-farm operating expenses are nearly equal for both tillage methods, net returns above operating expenses are larger for the CT farms.

Whole-farm ownership expenses are also reported by tillage method for 1,200-, 2,400- and 3,600-acre farms in Table 5. The difference in ownership expenses between CT and NT farms increases as farm size increases, ranging from \$11,198 for 1,200-acre opera-

tions to \$41,996 for 3,600-acre operations. Total expenses (operating plus ownership) are lower for the NT farms across farm sizes because of lower machinery ownership expenses. The gap in ownership expenses between the two tillage methods impacts the profitability of NT relative to CT. Whole-farm returns above total expenses are lower for NT than for CT at the 1,200-acre farm size due to the small difference in ownership expenses between the two tillage methods. However, whole-farm returns are slightly larger for NT at the 2,400-acre and 3,600-acre farm sizes, where the gap in ownership expenses is wider between the two tillage methods.

Whole-farm per acre fixed expenses are plotted by tillage method for farm sizes ranging from 1,200 to 3,600 acres in Figure 1. Per acre fixed expenses for NT are in every case lower than those for CT due to fewer tractors and implements related to land preparation in the machinery complement. These results agree with those found in the literature (Epplin et al.; Krause and Black; Parsch et al.). The gap in per acre fixed expenses between CT and NT is narrow in the range of 1,200 to 1,600 acres but widens as farm size increases beyond 1,600 acres. Per acre fixed expenses



**Figure 2.** Difference between No-Till and Conventional Till Whole-Farm Net Returns above Operating and Ownership Expenses for Farms Producing Rice and Soybeans by Farm Size, 2004 Dollars

for both tillage methods peak across farm sizes when high-cost items like additional tractors or combines must be obtained to complete production and harvest operations. These peaks occur in the 2,200 to 2,600 acre range for NT farms and the 1,800 to 2,600 acre range for CT farms. Beyond 2,600 acres, per acre fixed expenses decline as farm size increases for both tillage methods.

Differences in whole-farm net returns between NT and CT are plotted for farms ranging in size from 1,200 to 3,600 acres in Figure 2. Whole-farm returns are lower for NT than for CT in the 1,200 to 1,600 acre range. Beyond 1,600 acres, whole-farm returns to NT are slightly greater than those to CT for all plotted farm sizes except farms operating 3,000 acres, where whole-farm returns to NT are \$1,630 less than those to CT. The relative profitability of NT to CT is greatest in the

1,800 to 2,400 acre range, where net returns to NT farms are from \$5,495 to \$9,999 greater than those to CT farms. Beyond 2,400 acres, returns to NT range from -\$1,629 for the 3,000 acre farms to +\$3,067 for the 3,400 acre farms relative to CT.

Finally, findings from the current study are compared with those from two other farm-level economic studies in Table 6. Machinery fuel expenses, labor hours, and fixed expenses data reported for the current study in Table 6 exclude items associated with harvest equipment to allow for direct comparisons across the three studies. Similar trends emerge across the three studies despite obvious variations in farm size and cropping enterprises. All three studies report savings in machinery fuel, labor, and fixed expenses for NT compared with CT management and report higher herbicide costs for NT relative to CT. Percent differences be-

**Table 6.** Findings Across Farm Level Economic Studies Comparing No-Till to Conventional Till Management

Study Farm Type Farm size (acres)	Krause and Black Corn-Soybean 600	Epplin et al. Wheat 1,240	Present Study		
			Rice-Soybean 1,200	Rice-Soybean 2,400	Rice-Soybean 3,600
Machinery fuel and oil expenses (\$/acre)					
CT <sup>a</sup>	5.31	6.39 <sup>b</sup>	11.24 <sup>c</sup>	11.56	11.46
NT	1.79	1.19 <sup>b</sup>	4.80	4.15	4.26
Percent difference	-66.2%	-81.4%	-57.3%	-64.1%	-62.8%
Machinery labor (hours/acre)					
CT	1.09	1.25	1.00 <sup>c</sup>	0.93	0.94
NT	0.55	0.25	0.52	0.45	0.46
Percent difference	-50.0%	-80.0%	-47.7%	-51.2%	-51.3%
Herbicide expenses (\$/acre)					
CT	24.55	1.27	21.89	21.89	21.89
NT	31.79	21.06	39.82	39.82	39.82
Percent difference	29.5%	1,558.3%	81.9%	81.9%	81.9%
Machinery fixed expenses (\$/acre)					
CT	18.15	22.62	40.45 <sup>c</sup>	32.48	29.49
NT	11.28	16.5	31.08	18.95	17.83
Percent difference	-37.9%	-27.1%	-23.2%	-41.9%	-39.6%
Net returns above variable expenses (\$/acre)					
CT	194.32	NA <sup>d</sup>	172.32	172.62	172.98
NT	193.25	NA	160.41	161.42	161.80
Percent difference	-0.6%	NA	-6.9%	-6.5%	-6.5%
Net returns above total expenses (\$/acre)					
CT	176.17	NA	96.82	105.98	116.20
NT	181.97	NA	94.24	108.27	116.68
Percent difference	3.3%	NA	-2.7%	2.2%	0.4%

<sup>a</sup> CT is conventional till; NT is no-till.<sup>b</sup> Epplin report machinery fuel in gallons per acre rather than dollars per acre.<sup>c</sup> Machinery fuel and oil expenses, machinery labor, and machinery fixed expenses data from the present study exclude items associated with harvest equipment to allow for direct comparison with findings from Epplin and from Krause and Black.<sup>d</sup> NA is not available.

tween CT and NT in the present study tend to conform more closely with those from Krause and Black than with those from Epplin, possibly because corn and rice are both higher input crops relative to wheat.

### Summary and Conclusions

The results of this study indicate that expenses impact the profitability of no-till relative to conventional till management in rice production. The largest expenses associated with rice

production are input purchases (seeds, fertilizer, herbicides), followed in order by machinery ownership expenses, irrigation fuel expenses, machinery fuel expenses, and machinery labor expenses. Input purchase expenses are larger for no-till management due to greater herbicide application, but irrigation and machinery fuel and labor expenses are smaller for no-till due to fewer machinery operations required for land preparation and planting and slightly less water applied during the growing season. Machinery ownership ex-

penses are also lower for no-till management due to fewer tractors and implements required for planting and land preparation. Lower machinery ownership expenses, lower fuel expenses, and lower labor expenses improve the profitability of no-till relative to conventional till management. However, gains in profitability appear to be relatively small and alone may not be enough incentive to promote adoption of the practice by Arkansas rice producers.

Irrigation accounts for the largest share of fuel expenses in rice production and is therefore one of the most important areas to target with regards to cost savings. No-till reduces total irrigation fuel expenses to some extent relative to conventional till rice production by removing the need to flush water onto rice fields to germinate seeds and activate herbicides. Additional water savings may be gained at the end of the rice production period when water is drained from the field prior to harvest. The improved capacity for soils to hold water on no-till fields may allow earlier draining, thereby reducing the total amount of water required for rice production in a growing season. More research is required to determine if further water savings can be realized by early draining.

Differences in ownership expenses between conventional and no-till rice farms are attributed almost exclusively to equipment required for tillage and planting. Beyond planting, machinery complements for conventional till and no-till rice farms look relatively the same. Levee construction occupies a large amount of machinery between planting and harvest for both no-till and conventional till rice farms. Alternatives to contour levee construction such as straight levees and precision leveling may in certain instances provide significant economic benefits in the form of increased water use efficiency, lower labor and machinery costs, and lower pumping costs (Laughlin and Mehrle). More research is needed to appraise the potential economic benefits of non-contour levee practices in Arkansas rice production.

Some shortcomings need to be mentioned to qualify the interpretation of results from this study. The analysis did not include the impacts of pecuniary economies of size on farm prof-

itability. Large operations may receive volume discounts for purchasing inputs like seed, fertilizer, and pesticides in large quantities (Hall and LeVeen). Volume discounts for purchasing large quantities of inputs were not included in the analysis due to lack of data. In addition, this study did not include adjustment costs for no-till management. Krause and Black argue that adjustment costs associated with lack of experience and investment in new machinery may be present during the initial years of no-till adoption. Adjustment costs for no-till were assumed negligible in this study with the implicit assumption that modeled farms had already converted fully to either conventional till or no-till management.

The results would suggest that monetary gains from no-till management in rice production are modest even when adjustment costs are assumed negligible as in this analysis. However, there may be additional monetary benefits to no-till associated with early planting that are not captured in this study. Farmers using the practice in Arkansas indicate they are able to plant earlier with no-till than with conventional till. Also, profitability may not be the sole factor impacting adoption of no-till management. Ryan, Erickson, and De Young evaluated the reasons behind farmer adoption of conservation practices like no-till in the River Raisin watershed of Michigan and found that intrinsic motivations such as attachment to the land and the desire to conserve the land for future generations were ranked higher among farmers than economic motivations. Ryan, Erickson, and De Young also found that government programs play a strong role in motivating producers to use no-till management in the River Raisin watershed, since no-till management is often tied to the receipt of government subsidies in the watershed. No-till management is practiced on nearly 10% of all rice acres in Arkansas (Wilson and Branson). Clearly, more research is required to determine the motivating factors behind no-till adoption among Arkansas rice producers currently using the practice.

[Received September 2005; Accepted April 2006.]



## References

- Al-Soboh, G., A.K. Srivastava, T.H. Burkhardt, and J.D. Kelly. "A Mixed-Integer Linear Programming (MILP) Machinery Selection Model for Navybean Production Systems." *Transactions of the ASAE* 29(January–February 1986):81–84, 89.
- Anders, M.M., T.E. Windham, K.A.K. Moldenhauer, J. Gibbons, R.K. Bacon, R.W. McNew, J. Grantham, and J. Holzhauer. "Helping Arkansas Rice Farmers Exploit Market Opportunities by Improving Use of Soybean, Wheat, and Corn in Rice Rotations." *B.R. Wells Rice Research Studies* 2002. R.J. Norman, and J.-F. Meullenet, eds. Fayetteville, Arkansas: Arkansas Agricultural Experiment Station, Research Series No. 504, 2003, pp. 250–56.
- Anders, M.M., T.E. Windham, K.B. Watkins, K.A.K. Moldenhauer, J. Gibbons, R.W. McNew, and J. Holzhauer. "The Effect of Rotation, Tillage, Fertility, and Variety on Rice Grain Yield and Nutrient Uptake." *B.R. Wells Rice Research Studies* 2004. R.J. Norman, J.-F. Meullenet, and K.A.K. Moldenhauer, eds. Fayetteville, AR: Arkansas Agricultural Experiment Station, Research Series No. 529, 2005, pp. 250–58.
- American Society of Agricultural Engineers. *ASAE Standards, Agricultural Machinery Management*. St. Joseph, Michigan: ASAE–The Society for Engineering in Agriculture, Food, and Biological Systems, ASAE Publication No. EP496.2, 2003a.
- . *ASAE Standards, Agricultural Machinery Management Data*. St. Joseph, MI: ASAE–The Society for Engineering in Agriculture, Food, and Biological Systems, ASAE Publication No. D497.4, 2003b.
- Arkansas Department of Environmental Quality. *2002 Integrated Water Quality Monitoring and Assessment Report*. Little Rock, AR: Arkansas Department of Environmental Quality, Water Division, Publication No. WQ02-10-1, 2002.
- Beaton, A.J., K.C. Dhuyvetter, T.L. Kasterns, and J.R. Williams. "Per Unit Costs to Own and Operate Farm Machinery." *Journal of Agricultural and Applied Economics* 37(April 2005):131–44.
- Bryant, K.J., P. Tacker, E.D. Vories, T.E. Windham, and S. Stiles. *Estimating Irrigation Costs*. Little Rock, Arkansas: University of Arkansas Cooperative Extension Service, Fact Sheet No. FSA28, 2001.
- Bollich, P.K. 1991. "Conservation Tillage Practices for Rice in Southwest Louisiana." *Proceedings of the 1991 Southern Conservation Tillage Conference*. T.C. Keisling, ed. Fayetteville, AR: Arkansas Agricultural Experiment Station, Special Report No.148, 1991, pp. 11–12.
- Camarena, E.A., C. Gracia, and J.M. Cabrera Sixto. "A Mixed Integer Linear Programming Machinery Selection Model for Multifarm Systems." *Biosystems Engineering* 87(2004):145–54.
- Cross, T.L., and G.M. Perry. "Depreciation Patterns for Agricultural Machinery." *American Journal of Agricultural Economics* 77(February 1995): 94–204.
- . "Remaining Value Functions for Farm Equipment." *Applied Engineering in Agriculture* 12(1996):547–53.
- Danok, A., B. McCarl, and T.K. White. "Machinery Selection and Crop Planning on a State Farm in Iraq." *American Journal of Agricultural Economics* 60(August 1978):544–49.
- . "Machinery Selection Modeling: Incorporation of Weather Variability." *American Journal of Agricultural Economics* 62(November 1980):700–08.
- Epplin, F.M., T.F. Tice, A.E. Baquet, and S.J. Handke. "Impacts of Reduced Tillage on Operating Inputs and Machinery Requirements." *American Journal of Agricultural Economics* 64(December 1982):1039–46.
- Fuglie, K.O. "Conservation Tillage and Pesticide Use in the Cornbelt." *Journal of Agricultural and Applied Economics* 31(April 1999):133–47.
- Hall, B.F., and E.P. LeVein. "Farm Size and Economic Efficiency: The Case of California." *American Journal of Agricultural Economics* 60(November 1978):589–600.
- Hartell, J.G. "Pricing Benefit Externalities of Soil Carbon Sequestration in Multifunctional Agriculture." *Journal of Agricultural and Applied Economics* 36(August 2004):491–505.
- Held, L.J., and G.A. Helmers. "Impact of Machinery Ownership Costs on Risk Efficiency and Farm Organization." *Review of Agricultural Economics* 13(January 1991):85–98.
- Huitink, G., P. Tacker, J. Sills, M. Daniels, and J.C. Boils, Jr. *Soil Erosion and Clear Water*. Little Rock, AR: University of Arkansas Cooperative Extension Service, Fact Sheet No. FSA1028, 1998.
- Kleiss, B.A., R.H. Coupe, G.J. Gonthier, and B.G. Justus. "Water Quality in the Mississippi Embayment, Mississippi, Louisiana, Arkansas, Missouri, Tennessee, and Kentucky, 1995–98." Reston, VA: U.S. Department of the Interior, U.S. Geological Survey, Circular No. 1208, 2000.
- Krause, M.A., and J.R. Black. "Optimal Adoption

- Strategies for No-Till Technology in Michigan." *Review of Agricultural Economics* 17(September 1995):299–310.
- Laughlin, D.H., and R.K. Mehrle. *An Economic Evaluation ... Straight Versus Contour Levee Rice Production Practices in Mississippi*. Mississippi State, MS: Mississippi Agricultural & Forestry Experiment Station, Bulletin No. 1063, 1996.
- Lindo Systems Inc. *What's Best: the Spreadsheet Solver*. Chicago: LINDO Systems Inc., 2003.
- Martin, S.W., J.R.C. Robinson, F.T. Cooke, Jr., and D. Parvin. "Managing Tillage, Crop Rotations, and Environmental Concerns in a Whole-Farm Environment. *Plant Management Network*. Internet site: <http://www.plantmanagementnetwork.org/pub/cm/review/2005/whole/> (Accessed May 24, 2005).
- Parsch, L.D., and D.M. Danforth. "Rice Rental Arrangements in Arkansas." Proceedings of the 25th Rice Technical Working Groups, New Orleans, 1994, pp. 77–78.
- Parsch, L.D., T.C. Keisling, P.A. Sauer, L.R. Oliver, and N.S. Crabtree. "Economic Analysis of Conservation and Conventional Tillage Cropping Systems on Clayey Soil in Eastern Arkansas." *Agronomy Journal* 93(November–December 2001):1296–1304.
- Pearce, A.D., C.R. Dillon, T.C. Keisling, and C.E. Wilson, Jr. "Economic and Agronomic Effects of Four Tillage Practices on Rice Produced on Saline Soils." *Journal of Production Agriculture* 12(April–June 1999):305–12.
- Pfeiffer, G.H., and M.H. Peterson. "Optimum Machinery complements for Northern Red River Valley Grain Farms." *North Central Journal of Agricultural Economics* 2(January 1980):55–60.
- Reid, D.W., and G.L. Bradford. "A Farm Firm Model of Machinery Investment Decisions." *American Journal of Agricultural Economics* 69(February 1987):64–77.
- Ryan, R.L., D.L. Erickson, and R. De Young. "Farmers' Motivations for Adopting Conservation Practices along Riparian Zones in a Mid-Western Agricultural Watershed." *Journal of Environmental Planning and Management* 46(January 2003):19–37.
- Salassi, M.E., J.B. Breaux, and C.J. Naquin. "Modeling Within-Season Sugarcane Growth for Optimal Harvest System Selection." *Agricultural Systems* 73(September 2002):261–78.
- Smith, R.J., Jr., and A.M. Baltazar. "Reduced- and No-Tillage Systems for Rice and Soybeans." *Arkansas Rice Research Studies*, 1991. B.R. Wells, ed. Fayetteville, AR: Arkansas Agricultural Experiment Station, Research Series No. 422, 1992, pp. 104–07.
- U.S. Department of Agriculture–Economic Research Service. *Rice Situation and Outlook Yearbook*. Washington, DC: U.S. Department of Agriculture, Economic Research Service, Market and Trade Economics Division, Outlook Report No. RCS-2005, 2005.
- U.S. Department of Agriculture–National Agricultural Statistics Service. *2002 Census of Agriculture: Arkansas State and County Data*. Internet site: <http://www.nass.usda.gov/census/census02/volume1/ar/index2.htm> (Accessed January 5, 2005).
- . *Arkansas Weather and Crop Progress*. Internet site: [http://www.nass.usda.gov/Statistics\\_by\\_State/Arkansas/Publications/Crop\\_Progress\\_&\\_Condition/index.asp](http://www.nass.usda.gov/Statistics_by_State/Arkansas/Publications/Crop_Progress_&_Condition/index.asp) (Accessed January 10, 2005).
- . *Annual Average Farm Workers: Number, Hours Worked and Wage Rates, Arkansas, Delta Region and United States*. Internet site: <http://www.nass.usda.gov/ar/fmlabor.pdf> (Accessed May 21, 2005).
- . *Monthly Prices Received by Arkansas Farmers for Crops*. Internet site: <http://www.nass.usda.gov/ar/econcrop.pdf> (Accessed June 3, 2005).
- University of Arkansas–Cooperative Extension Service. *Arkansas Soybean Handbook*. University of Arkansas Cooperative Extension Service, Publication No. MP197 Revised, 2000.
- . *Rice Production Handbook*. University of Arkansas Cooperative Extension Service, Publication No. MP192 Revised, 2001.
- Uri, N.D. *Conservation Tillage in U.S. Agriculture, Environmental, Economic, and Policy Issues*. Binghamton, New York: Food Products Press, Haworth Press, Inc., 1999.
- Watkins, K.B., M.M. Anders, and T.E. Windham. "An Economic Comparison of Alternative Rice Production Systems in Arkansas." *Journal of Sustainable Agriculture* 24(2004), pp. 57–78.
- West, T.O., and W.M. Post. "Soil Organic Carbon Sequestration Rates by Tillage and Crop Rotation: A Global Data Analysis." *Soil Science Society of America Journal*, 66(November–December 2002):1930–46.
- Wilson, C.E. Jr., and J.W. Branson. "Trends in Arkansas Rice Production." *B.R. Wells Rice Research Studies 2004*. R.J. Norman, J.-F. Meulenet, and K.A.K. Moldenhouer, eds. Fayetteville, AR: Arkansas Agricultural Experiment Station, Research Series No. 529, 2005, pp. 15–24.

