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Conventional tillage has long been the most widely used technology for producing crops. With this technology, the land is first plowed (usually with a moldboard plow) and then disked 2 or 3 times. Row crops are planted with a conventional planter, and weeds are controlled by mechanical cultivation (meadow and small-grain crops are planted with a grain drill and not cultivated). Although in recent years chemical weed control has replaced some of the mechanical cultivations, conventional tillage remains the most common tillage technique.

Conventional tillage, especially of severely sloping land, subjects the land to serious soil losses due to erosion, and cumulative soil losses over several years can reduce soil productivity. Several cultural techniques have been developed to reduce these losses: contour cropping, strip cropping, and terracing, for example. The introduction of chemical herbicides, beginning in the 1940s, permitted the development of various forms of reduced tillage. With reduced tillage, a crop may be planted directly into existing vegetation which has been killed by herbicides, frequently with no plowing and no subsequent cultivation. Dead vegetation is left on the land as a mulch, reducing both soil losses to erosion and moisture losses to evaporation and runoff. Since reduced tillage requires fewer field operations than conventional tillage, it uses less tractor fuel and may extend the life of tractors and other machinery, thus reducing machinery costs. Reduction in the number of required field operations may permit more timely performance of the remaining field operations, especially in seasons when the number of field days is reduced by unfavorable weather.

The above is a formidable list of advantages for reduced tillage, and beginning in the 1960s, but especially since the early 1970s, reduced tillage has become widespread in the major crop-producing areas of the U.S.[1] Reduced tillage would probably be even more widespread except for some disadvantages. First, reduced tillage typically requires heavier herbicide applications than conventional tillage. Many herbicides are manufactured from fossil fuels, thus offsetting some of the savings in tractor fuel attributable to reduced-tillage. Second, some weeds are resistant to herbicides so far developed and others appear to develop resistance over time, making occasional mechanical cultivation necessary. Finally, the cumulative long-term effects of heavy herbicide applications are largely unknown. In the absence of evidence that these effects are benign, it seems imprudent to assume that they are.

Choices between conventional tillage and reduced tillage are not entirely unambiguous in the current state of technology. It thus seems unlikely that reduced tillage will completely replace conventional tillage. Hence, analyses of the tradeoffs between the two tillage systems could provide useful information. This report summarizes several studies of alternative tillage technologies conducted by the Department of Agricultural Economics at the University of Kentucky, funded jointly by the Kentucky Agricultural Experiment station and a Title XII grant from the U.S. Agency for International Development. All of the studies use Kentucky data and analyze these technologies under Kentucky conditions. These studies were designed in part to facilitate similar studies in less-developed, equatorial countries.

These studies had three primary foci: comparative microeconomic analysis of the relative costs and returns to conventional and minimum tillage, comparison of the socioeconomic characteristics of adopters and nonadopters of minimum tillage, and comparison of the regional economic impacts of adoption of minimum tillage.

ECONOMIC ANALYSES

Benefits to farmers of a new tillage technology are measured by increased returns or a reduction in production costs. Increases in returns from the adoption of new technology usually occur because crop yields are increased. Costs are reduced because of a reduction in the use of machinery, labor and fuel to power tractors. Adoption of a new tillage technology may require that the farmer purchase new machinery specifically suited to the new tillage system.

Energy Costs and Choice of Tillage System

Debrah studied the effects of increased energy prices on crop production under conventional- and no-tillage. He modeled two hypothetical 500-acre Western-Kentucky grain farms by linear programming to determine the effects of alternative energy prices on the allocation of land among corn, corn silage, single-crop soybeans, and double-crop wheat-soybeans for the two tillage systems.

Debrah considered two fertilization rates for corn (under both conventional tillage and no-tillage) and alternative row spacings for single-crop soybeans (two spacings under conventional tillage and one under no-tillage). Under no-tillage, soybeans could be produced either as a single crop or as a double crop with wheat; single-crop wheat was not considered. Liquid-fuel prices for 1979 were used as the benchmark, and price increases of up to 10 times the 1979 prices were considered.

Debrah's results indicated that, at 1979 prices, net returns from no-tillage exceeded those from conventional tillage by a small margin. As energy prices increased, the difference in favor of no-tillage increased although net returns to both tillage systems declined. Also as fuel prices increased, corn acreage decreased and wheat-soybean acreages increased for both tillage systems (Table 1).

Over a sufficiently long period, no-tillage cultivation may arrest or at least reduce declines in soil productivity due to excessive erosion. Precise quantitative estimates of this advantage are not available, and Debrah made no attempt to incorporate them in his models, considering only short-term economic returns for the two systems. Since these returns are always higher for no-tillage production, any reductions in soil-productivity losses can be viewed as an additional, unquantified advantage of no-tillage over conventional tillage. Debrah's analysis also ignores any long-term effects of the heavier herbicide rates required by no-tillage. If such effects exist, they must be weighed against the advantages of reduced soil erosion; Debrah's models were not designed to make such comparisons.

Conventional- Versus No-Tillage Grain Production

Hall and Taneja also compared conventional-tillage and no-tillage cultivation for a major grain-producing area (Christian County) in Western Kentucky. They modeled a hypothetical 400-acre grain farm by linear programming to compare (a) the total net returns under conventional tillage and no-tillage, (b) the combinations of crops yielding maximum net returns under both tillage systems, and (c) the variable costs of producing these crops under both tillage systems. They compared net returns and optimum crop combinations by solving two linear-programming models, one for each tillage system.

Hall and Taneja considered corn, single-crop soybeans, double-crop wheat-soybeans, and red clover. They considered four classes of land and used various rotations to control the proportion of time certain classes of land could be in row crops. Various combinations of planting and harvesting dates were modeled for corn and single-crop soybeans. Hall and Taneja consider a single set of fuel and other input prices. Compared to Debrah's models, however, theirs incorporated detailed estimates of the effects on crop yields and, hence, on costs per unit of output of either untimely planting or untimely harvesting. In that sense, the Hall-Taneja models more closely approximate the day-to-day management choices faced by a farmer and the effect of those choices on net returns.

Hall and Taneja's results showed that total net returns over variable costs were about 2 percent higher for no-tillage than for conventional tillage (Table 2). However, differences in net returns between conventional tillage and no-tillage depended on land class, yields, and the associated crop combinations. For example, on land classes I and IVe, net returns were higher for conventional tillage than for no-tillage; on land classes IIe and IIIe, net returns were higher for no-tillage than for conventional tillage. The results also indicated that, due to the possibility of double cropping (of wheat and soybeans, for example) on some land classes and to the use of less labor and machinery, land use was more intensive for no-tillage than for conventional tillage (Table 2). Finally, due to greater total crop acreage and greater per acre costs for seed, fertilizer, and chemicals to produce corn and double-crop soybeans, total cash costs were higher for no-tillage than for conventional tillage.

Like Debrah, Hall and Taneja ignore differences between the two tillage systems in long-term soil-productivity losses, and for the same reasons. They also ignore long-term effects of the heavier herbicide rates required by no-tillage.

Intertemporal Farm Production Investment Analysis

The Debrah and Hall-Taneja studies considered only two tillage systems (conventional tillage and no-tillage) and ignored the simultaneity in decisions about production, investment, and other farm activities. Shifts from one tillage system to another involve investment decisions as well as production decisions. Moreover, analysis of investments in durable production inputs such as farm tractors, combines, tillage and harvesting equipment, and cropland requires multiperiod planning because the returns and costs associated with these inputs are spread over several periods. Decisions to make either complete or partial shifts to new tillage systems require information on more than annual returns. Hence, studies that consider the simultaneity in production, investment, and other farm activities (decisions) are necessary.

Shrestha formulated a multiperiod model to analyze three tillage technologies--conventional tillage, minimum tillage, and no-tillage. His model investigated the effects of tillage system on multiperiod farm production, investment, resource allocation, and profitability to determine the optimal tillage technology or combination of tillage technologies.

Using an MLP model with a planning horizon of 6 years, Shrestha modeled a hypothetical 750-acre Western-Kentucky grain farm. Each year was further divided into 5 production periods in order to model the competition among crops for labor and machinery services available within each period of the year. Each year was also subdivided into 2 accounting periods to model the effect of operating-capital availability. Both intrayear and interyear transfers of resources were allowed.

The alternative crop enterprises were corn, single-crop soybeans, double-crop wheat-soybeans, grain sorghum, and alfalfa hay. Two objective functions maximized terminal (ending) net worth; one included the ending values for capital items, the other excluded those values. Two cash-withdrawal situations for family consumption were considered: withdrawal of specific amounts of cash and no withdrawal of cash. Two processes for producing crops were considered: rotation and no-rotation. For the crop-rotation scenario, the available rotation alternatives were corn/single-crop soybeans (C/SS), corn/double-crop wheat-soybeans (C/DWS), corn/alfalfa hay (C/AH), and grain sorghum/single-crop soybeans (GS/SS). For no-rotation, crops were not required to follow fixed sequences.

Both farm and off-farm investments were allowed. The farm-investment alternatives were purchases of tractors and tillage equipment, purchases of combines, and purchases of cropland. Cash not needed for farming expenses or family living was assumed to be deposited in a savings account. Seasonal hiring of labor and renting-in or renting-out of cropland were allowed.

Empirical results indicated that crop rotations in the optimal rotation crop-production plans did not vary with the tillage system (Table 3). For each tillage system, selected crop rotations were corn/single-crop soybeans (C/SS) and corn/double-crop wheat-soybeans (C/DWS). However, acreages of the selected crop rotations varied substantially with the tillage system. No-tillage crop-production plans included the largest acreages of the C/SS rotation; conventional-tillage crop-production plans included the largest acreages of the C/DWS rotation. In general, optimal C/SS acreages increased and C/CWS acreages decreased as the tillage system changed from conventional tillage to minimum tillage to no-tillage.

Optimal no-rotation crop acreages varied with the tillage system (Table 3). Corn acreage increased with a shift from conventional tillage to minimum tillage but decreased with a shift from minimum tillage to no-tillage. Optimal acreages of single-crop soybeans and double-crop wheat-soybeans also changed with changes in tillage systems, but these changes were less consistent than the changes in optimal corn acreages. Because corn and soybeans compete for the same production resources, changes in corn and soybean acreage were mixed. If corn and single-crop soybean acreages changed in the same direction, for example, then double-crop wheat-soybean acreage changed in the opposite direction. Alfalfa hay acreage increased with a change from conventional tillage to minimum tillage but decreased with a change from minimum tillage to no-tillage.

Both farm and off-farm investments varied with the tillage system (Table 4). Investment in cropland increased with a change from minimum tillage to no-tillage, regardless of the objective function. Investment in tractors and tillage equipment, whether measured as total investment or investment per 100 acres of land in crops, was highest for conventional tillage, lowest for no-tillage, and intermediate for minimum tillage. Because of the large amount of land in crops, investment in combines and harvesting equipment was highest for no-tillage. For every tillage system, farm investments and off-farm investment changed in opposite directions.

No-tillage production-investment plans were the most profitable (Table 5). Objective-function values for rotation crop production were higher than those for no-rotation crop production for both minimum tillage and no-tillage; for conventional tillage, no-rotation produced a larger objective-function value.[2]

Investment patterns varied with the cash-withdrawal scenario (Table 4). Cropland was purchased every year under both scenarios, for example, but the amount purchased was always higher when no cash was withdrawn. Investment in tractors and tillage equipment and in combines and harvesting equipment was generally higher when no cash was withdrawn, with some exceptions. There was no off-farm investment for either cash-withdrawal scenario.

A separate model for each tillage system was run first, and no-tillage produced the highest objective-function value. Then, a model which allowed combinations of tillage systems was run, indicating that 95.60 percent no-tillage and 4.40 percent minimum tillage was optimal. The objective-function value for this combination of tillage systems exceeds that for 100 percent no-tillage by only $470.02 ($3,083,462.99 - 3,082,992.97).

Like Debrah and like Hall and Taneja, Shrestha ignores differences among tillage systems in long-term soil-productivity losses, and for the same reasons. He likewise ignored long-term effects of the heavier herbicide rates required by both minimum tillage and no tillage.

The three studies reviewed here are not directly comparable because of different planning horizons, objective functions, and data. Except for corn, to which more land is allocated under conventional tillage than under no-tillage in all three studies, crop acreages vary from one study to another (Table 6). Similar amounts of land are allocated to alfalfa in Shrestha and to red clover in Hall and Taneja; in both studies, more land is allocated to hay under conventional tillage than under no-tillage.

Debrah's results for conventional tillage and no-tillage are not strictly comparable since his two models include different activities and constraints. His no-tillage model included double-crop wheat-soybeans, for example, but his conventional-tillage model did not; his conventional-tillage model included single-crop wheat but his no-tillage model did not. Thus, inherent differences between the two tillage systems are confounded with differences in the type of activities allowed.

TILLAGE ADOPTION IN KENTUCKY

New technology is initially adopted by only a small fraction of a clientele. The new technology may be widely adopted over some period of time if the clientele becomes convinced of its merits. In 1979, only 37.2 percent of harvested crops was minimum-tilled in Kentucky (Kentucky Crop and Livestock Reporting Service), a leading state in the adoption of minimum-tillage technology.

Mohammad examined socioeconomic factors that affect the adoption of minimum tillage in Kentucky. He gathered data by mail survey from 3 major grain-producing counties in Western Kentucky (Daviess, Graves, and Todd). He used econometric techniques (logit, probit, and ordinary least squares) to analyze the data from 505 completed questionnaires of 2700 mailed out. Proportion of sloping land farmed, number of years of formal schooling plus additional training in agriculture, gross farm income, and extent of contact with different information sources significantly affected the decision to adopt minimum tillage (Table 7). As the proportion of farm labor requirements supplied by the farm family increased, the adoption rate for minimum tillage decreased, but the effect was neither as strong nor as convincing as the effects of the other variables. Mohammad's results suggest that increases in the levels of education of farmers and the use of effective means of communication to and from the farmers increase the adoption rate for minimum-tillage technology.

REGIONAL ECONOMIC ANALYSIS

Shifts among tillage systems may affect an entire local or regional economy, both its agricultural and nonagricultural sectors, as well as individual farmers. In the agricultural sector, shifts in tillage systems may change the employment and incomes of farmers who make such shifts. In the nonagricultural sector, incomes of farm-input suppliers may be affected because shifts in tillage systems may affect farmer purchases of machinery, fertilizer, herbicides, fuel, and oil. Changes in business profits affect the personal incomes of agricultural-input suppliers as well as wages and salary payments to their employees. When personal incomes are respent, the business volume, employment, and incomes in the local or regional economy are changed due to multiplier effects. Thus, shifts from an existing tillage technology to a new technology may affect the aggregate economy.

Adutwum conducted an input-output (I-O) study to assess the aggregate effects of shifts between tillage systems on the economy of Western Kentucky, hypothesizing four scenarios. Scenario 1 increased the final demand for corn and soybeans in the region by 1 percent and fully met the demand by production from one of three tillage systems (conventional tillage, minimum tillage, and no-tillage) at a time. Scenario 2 changed the final demand for corn and soybeans by the same rate as the change in corn and soybean acreages under each tillage system between 1981 and 1983, and fully met the demand by production from one tillage system at a time. Scenario 3 assumed 100 percent replacement of conventional tillage by minimum tillage or no-tillage, with the acreages of corn and soybeans under minimum tillage and no-tillage maintained at their 1981 proportions; final demand in Scenario 3 was thus met by production from only minimum tillage and no-tillage. Scenario 4 assumed a 50 percent replacement of conventional tillage by minimum tillage or no-tillage, with the acreages of corn and soybeans under minimum tillage and no-tillage maintained at their 1981 proportions.

Under Scenario 1, output, income, and employment were higher when final demand was met by conventional-tillage production than by either minimum-tillage or no-tillage production (Table 8). Compared with minimum-tillage or no-tillage production, conventional-tillage production to meet final demand increased income by 400 percent or more and employment by 1.5 times. Under Scenario 2, output, income, and employment declined, no matter which tillage system was used. Between 1981 and 1983, the acreage under conventional tillage decreased while the acreages under minimum tillage and no-tillage increased. The negative impacts on income and employment due to a decrease in conventional-tillage acreage were 1.7 times greater than the positive impacts on income and employment due to increases in minimum-tillage and no-tillage acreages. Output, income, and employment all declined under Scenario 3. The decreases in income and employment due to the decrease in conventional-tillage acreage were more than 1.9 times greater than the increases due to the increases in minimum-tillage and no-tillage acreages. Scenario 4 led to declines in output, income, and employment. The negative impacts on income and employment due to the decrease in conventional-tillage acreage were 1.8 times greater than the positive impacts due to increases in minimum-tillage and no-tillage acreages. These results indicate that a shift from conventional tillage to either minimum tillage or no-tillage decreases both income and employment in Western Kentucky.

IMPLICATIONS

The three microeconomic studies used an economic-engineering approach (hypothetical farms) to generate technical coefficients for the models. Alternatively, technical coefficients could have been estimated from farm records, from composite farm budgets based on farm records, or from standardized or adjusted data from actual farms. An evaluation, based on farm-survey data, of the potential impacts of alternative tillage systems on farm production and investment could provide information to help farm operators make informed choices among tillage technologies.

One objective of the minimum-tillage project was to develop methods to evaluate the potential applicability of minimum tillage or no-tillage to high-altitude tropical areas with severe soil-erosion problems. By developing models designed to evaluate the interactions between reduced tillage and farm production, this project has begun work on this objective. Complete achievement of this objective will require explicit modeling of the effects of soil erosion on farm production and investment under alternative tillage systems, a task perhaps more difficult and demanding than any accomplished to date.

Continuous reduced tillage may lead to a buildup of herbicide-resistant weed species that can be controlled only by occasional cultivation. Thus, satisfactory weed control may require periodic switching from reduced tillage to conventional tillage. None of the three microeconomic studies evaluates this possibility; Shrestha's combined-tillage model allowed more than one tillage system in the optimal solution, but it did not allow switching among tillage systems over time. A study that considers this problem could be useful.

Footnotes

[1] Reduced tillage has also been adopted in many parts of Europe. In addition, work in West Africa indicates hat many of the advantages of reduced tillage, first demonstrated in temperate areas, can also be obtained in subtropical and tropical areas. Many areas of the world have a shortage of cultivable land or a problem of land degradation through erosion or both. Reduced tillage may increase food supplies in such areas without increasing soil losses.

[2]The crop-production plans which generated these objective-function values were based on the yield scenario in which corn yield varied among the tillage systems (110 bushels for conventional tillage, 112 bushels for minimum tillage, and 115 bushels for no-tillage) while the yields of other crops remained constant (39 bushels for single-crop soybeans, 30 bushels for double-crop soybeans, 40 bushels for double-crop wheat, 83 bushels for grain sorghum, and 4.5 tons for alfalfa hay). A sensitivity analysis was performed by using two additional corn-yield scenarios, with the yields of other crops held constant across tillage systems. One scenario used corn yield of 110 bushels per acre for all tillage systems while the other used corn yields of 110, 108, and 105 bushels per acre for conventional tillage, minimum tillage, and no-tillage, respectively. Objective-function values were highest for no-tillage, intermediate for minimum tillage, and lowest for conventional tillage under all scenarios.

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Table 1. Impacts of Energy-Price Increases on Crop Combinations and Net Returns on a 500-Acre Farm Under Two Alternative Tillage Systems.

Energy-Price Index	Tillage System	Crop Combinations Corn	Silage	SC Soybeans	DC Soybeans	Wheat	Net Returns ($)
		---Percent---					
100	CT	100	0	0	NM	0	132,332
	NT	96	0	4	0	0	123,716
200	CT	100	0	0	NM	0	125,982
	NT	96	0	4	0	0	118,207
300	CT	100	0	0	NM	0	118,361
	NT	96	0	4	0	0	112,119
400	CT	100	0	0	NM	0	109,484
	NT	78	0	22	0	0	105,522
500	CT	82	0	18	NM	0	100,811
	NT	67	0	33	0	0	100,103
600	CT	82	0	18	NM	0	88,304
	NT	67	0	33	0	0	92,701
700	CT	82	0	18	NM	0	77,222
	NT	45	0	0	55	55	96,172
800	CT	54	0	46	NM	0	49,675
	NT	26	0	0	74	74	85,183
900	CT	0	0	100	NM	0	25,944
	NT	0	0	0	100	100	72,136
1000	CT	0	0	0	NM	100	20,955
	NT	0	0	0	100	100	61,736

Source: Debrah, Tables 13 and 14, p. 73 and 75.
SC=single crop; DC=double crop; CT=conventional tillage; NT=no-tillage; NM=not modeled.

Table 2. Optimal Crop Acreages and Net Returns Above Cash Costs by Class of Land and Tillage System.

Land Class	Crop	Crop Acreages CT	Crop Acreages NT	Net Returns CT	Net Returns NT
				---------$--------	
I	Wheat	60.0	60.0	16,436	16,098
	Double-crop Soybeans	60.0	60.0		
IIe	Wheat	140.8	193.3	51,062	51,430
	Double-crop Soybeans	140.8	193.3		
	Corn	79.2	26.7		
IIIe	Corn	20.0	40.0	6,347	8,377
	Meadow	40.0	--		
	Wheat	--	20.0		
	Double-crop Soybeans	--	20.0		
IVe	Corn	15.0	30.0	4,720	4,070
	Meadow	45.0	30.0		
Total Returns				78,565	79,975

Source: Hall and Taneja, Tables 2 and 3, p. 9.

Note: CT = Conventional Tillage; NT = No-tillage; Meadow is red clover for hay.

Table 3. Optimal Crop-Production Plans, Various Cash Withdrawal Scenarios and Tillage Systems.

Crop Year	Production Activity	Unit	Cash Withdrawal CT	Cash Withdrawal MT	Cash Withdrawal NT	No Cash Withdrawal CT	No Cash Withdrawal MT	No Cash Withdrawal NT
	C-NR	Acre	159.13	264 49	214.96			
	C-R							
	C/SS		440 94	570.23	585 16	427 40	598.36	612.94
	C/DWS		86.73	0	0	122.44	0	0
	C/AH		0	0	0	0	0	0
	SS-NR		241.28	273.86	864 13			
	SS-R							
	C/SS		440.94	570.23	585 16	427.40	598.36	612.94
	GS/SS		0	0	0	0	0	0
0	DS-NR		634 85	531 71	0			
	DS-R		86 73	0	0	122.44	0	0
	DW-NR		634.85	531 71	0			
	DW-R		86 73	0	0	122.44	0	0
	GS-NR		0	0	0			
	GS-R		0	0	0	0	0	0
	AH-NR		32.00	26 65	81 44			
	AH-R		0	0	0	0	0	0
	C-NR		133 69	288 47	396 19			
	C-R							
	C/SS		440 94	669.55	717 43	427.40	612.96	769 77
	C/DWS		158 12	0 08	0	207.94	97 01	0
	C/AH		0	0	0	0	0	0
	SS-NR		339 65	324 45	888.58			
	SS-R							
	C/SS		440.94	669.55	717 43	427 40	612.96	769 77
	GS/SS		0	0	0	0	0	0
1	DS-NR		634.85	594.55	0			
	DS-R		158.12	0 08	0	207.94	97 01	0
	DW-NR		634.85	594.55	0			
	DW-R		158 12	0 08	0	207.94	97 01	0
	GS-NR		0	0	0			
	GS-R		0	0	0	0	0	0
	AH-NR		116 06	70.81	81 44			
	AH-R		0	0	0	0	0	0
	C-NR		25.98	141.89	201.43			
	C-R							
	C/SS		440 94	669.55	867.97	491 73	728.99	940 49
	C/DWS		251 12	105.97	0	256.48	115.37	0
	C/AH		0	0	0	0	0	0
	SS-NR		512.84	447 80	1045.82			
	SS-R							
	C/SS		440 94	669.55	867.97	491.73	728.99	940 49
	GS/SS		0	0	0	0	0	0
2	DS-NR		634.85	625.29	161.55			
	DS-R		251.12	105.97	0	256.48	115.37	0
	DW-NR		634.85	625.29	161.55			
	DW-R		251 12	105.97	0	256.48	115.37	0
	GS-NR		0	0	0			
	GS-R		0	0	0	0	0	0
	AH-NR		228.21	261.36	168.96			
	AH-R		0	0	0	0	0	0
	C-NR	Acre	280 01	378 02	0			
	C-R							
	C/SS		441.88	785 04	1036 97	488 19	868.52	1140 01
	C/DWS		279 78	124.25	0	304.93	137.45	0
	C/AH		0	0	0	0	0	0
	SS-NR		424.59	420.53	1169 66			
	SS-R							
	C/SS		441.88	785 04	1036.97	491 73	868.52	1140 01
	GS/SS		0	0	0	0	0	0
3	DS-NR		634.85	631.21	390 75			
	DS-R		279 78	124.25	0	304.93	137.45	0
	DW-NR		634.85	631.21	390 75			
	DW-R		279 78	124.25	0	304.93	137.45	0
	GS-NR		0	0	0			
	GS-R		0	0	0	0	0	0
	AH-NR		284.52	316.52	266 66			
	AH-R		0	0	0	0	0	0
	C-NR		368.24	477 19	17.21			
	C-R							
	C/SS		440.94	892.20	1036.97	486 68	1034 02	1279.27
	C/DWS		286 12	141.20	221 65	315.29	163 64	132.47
	C/AH		0	0	0	0	0	0
	SS-NR		381 04	411.99	1159 08			
	SS-R							
	C/SS		441.88	892.20	1036 97	488.19	1034 02	1279.27
	GS/SS		0	0	0	0	0	0
4	DS-NR		708 44	796 00	757 01			
	DS-R		286.12	141.20	221 65	315.29	163 64	132.47
	DW-NR		708.44	796 00	757 01			
	DW-R		286.12	141.20	221.65	315.29	163.64	132.47
	GS-NR		0	0	0			
	GS-R		0	0	0	0	0	0
	AH-NR		252.52	289.87	185.52			
	AH-R		0	0	0	0	0	0
	C-NR		368.24	477 19	17.21			
	C-R							
	C/SS		441.88	892.20	1036.97	488 19	1034 02	1279.27
	C/DWS		286.12	141.20	221 65	315.29	163 64	132.47
	C/AH		0	0	0	0	0	0
	SS-NR		381 04	411.99	1159 08			
	SS-R							
	C/SS		440.96	892.20	1036.97	486.68	1034 02	1279.27
	GS/SS		0	0	0	0	0	0
5	DS-NR		894 13	932.52	757 01			
	DS-R		286.12	141.20	221 65	315.29	163 64	132.47
	DW-NR		0	0	0			
	DW-R		0	0	0	0	0	0
	GS-NR		0	0	0			
	GS-R		0	0	0	0	0	0
	AH-NR		168.46	245 71	185.52			
	AH-R		0	0	0	0	0	0

Source: Shrestha, Table 6.1, p. 189-194.

Year 0=1984,..., Year 5=1989; the suffixes NR and R indicate no-rotation and rotation cropping schemes, respectively; C=corn; SS=single crop soybeans; DS=double-crop soybeans; DW=double-crop wheat; GS=grain sorghum; AH=alfalfa hay; C/SS=corn/single-crop soybean rotation; C/DWS=corn/double-crop wheat soybean rotation; C/AH= corn/alfalfa hay rotation; GS/SS=grain sorghum/single-crop soybean rotation, CT=conventional tillage; MT=minimum tillage; and NT=no-tillage.

Table 4. Optimal Investment Plans Under Various Cash-Withdrawal Scenarios and Tillage Systems With a Rotation Cropping Scheme.

Year	Investment Activity	Unit	Cash Withdrawal			No Cash Withdrawal		
			CT	MT	NT	CT	MT	NT
	BUYTE	Number	3.39 (0.14)[a]	2.20 (0)	0.17 (0.29)	3.61	2.41	0.27
	BUYCE	Number	0	0	0	0	0	0
0	BUYCL	Acre	205.33 (217.25)	290.47 (246.71)	320.31 (310.55)	249.68	346.72	375.88
	SAVEM	$1000	0	0	0	0	0	0
	BUYTE	Number	0.22 (0.57)	0.73 (0.32)	0.49 (0.31)	0	0.30	0.58
	BUYCE	Number	0 (0.07)	0.07 (0)	0.14 (0)	0.01	0.13	0.23
1	BUYCL	Acre	142.77 (157.00)	198.80 (181.58)	264.55 (205.68)	171.00	223.21	313.65
	SAVEM	$1000	0	0	0	0	0	0
	BUYTE	Number	0.31 (0.80)	0.21 (0.37)	0.56 (0.09)	0.80	0.89	0.63
	BUYCE	Number	0.10 (0)	0.17 (0)	0.24	0.18	0.21	0.27
2	BUYCL	Acre	186.01 (177.63)	211.77 (198.05)	301.09 (211.55)	225.74	268.74	341.44
	SAVEM	$1000	0	0	0	0	0	0
	BUYTE	Number	0.12 (0.25)	0.89 (0.33)	0.63 (0)	0.25	1.07	0.74
	BUYCE	Number	0.05 (0.05)	0.21 (0.04)	0.27	0.07	0.26	0.32
3	BUYCL	Acre	183.53 (222.09)	267.53 (269.94)	338.00 (249.61)	229.48	323.23	399.04
	SAVEM	$1000	0	0	0	0	0	0
	BUYTE	Number	0	0.82 (0.15)	0.31 (0)	0	1.27	0.70
	BUYCE	Number	0.01	0.20	0.35 (0.25)	0.01	0.31	0.43
4	BUYCL	Acre	203.22 (207.41)	310.88 (250.05)	443.29 (291.44)	257.11	383.39	543.46
	SAVEM	$1000	0	0	0	0	0	0
	BUYTE	Number	0	0	0	0	0	0
	BUYCE	Number	0 (0.12)	0 (0.01)	0	0	0	0
5	BUYCL	Acre	26.84 (17.19)	37.36 (71.06)	35.63 (54.81)	47.63	56.00	45.05
	SAVEM	$1000	0	0	0	0	0	0

Source: Shrestha, Table 6.2, p. 201-203. Note: Year 0 = 1984,...,Year 5 = 1989; BUYTE = buy tractors and tillage equipment; BUYCE = buy combines and harvest equipment; BUYCL = buy cropland; and SAVEM = save money; CT = conventional tillage; MT = minimum tillage; and NT = no-tillage.

[a]Values in parentheses are for no-rotation cropping scheme, if different from the values for rotation cropping scheme.

Table 5. Objective-Function Values From Six-Year Production-Investment Plans Under Various Objective Functions, Cash-Withdrawal Scenarios, and Tillage Systems With a Rotation Cropping Scheme.

		Discounted Salvage-Value Excluding Net Cash Balance			Terminal Net Worth		
Cash-Withdrawal Scenario	Tillage System	Amount ($)	%Change Due to a Shift from CT to MT	%Change Due to a Shift from MT to NT	Amount ($)	%Change Due to a Shift from CT to MT	%Change Due to a Shift from MT to NT
	CT	721415.76			2152269 00 (2153663.00)[a]		
			21.47			19 66 (9 05)	
CW	MT	876327.56			2575363 00 (2348483 00)		
				6.63			12.81 (3.70)
	NT	934425.35			2905389.00 (2435433.00)		
	CT	726157.90			2219959 00		
			21.33			21.38	
NCW	MT	881070.00			2694664.00		
				6.63			13 42
	NT	939496.10			3056304.45		

Source: Shrestha, Table 6.9, p. 222.

Note: CW = cash withdrawal; NCW = no cash withdrawal; CT = conventional tillage;

MT = minimum tillage; and NT = no tillage.

[a]Values in parentheses are for no-rotation cropping scheme.

Table 6. A Comparison of Acreage Allocation to Crops Under Alternative Tillage Technologies.

Study and Date	Tillage System	Percent of Total Cropland Allocated to[a] Corn	Corn Silage	SC Soybeans	DC Wheat-Soybeans	SC Wheat	Grain Sorghum	Alfalfa Hay	Red-clover Hay
Debrah, 1981[b]	CT	70	0	20	NM[e]	10	NM	NM	NM
	NT	57	0	10	33	NM	NM	NM	NM
Hall and Taneja; 1985[c]	CT	29	NM	0	50	NM	NM	NM	21
	NT	24	NM	0	68	NM	NM	NM	8
Shrestha, 1986[d]	CT	15	NM	26	47	NM	0	12	NM
	MT	21	NM	24	43	NM	0	13	NM
	NT	8	NM	62	20	NM	0	10	NM

[a]SC = single crop; DC = double crop.

CT = conventional tillage; MT = minimum tillage; NT = no-tillage.

[b]Reported results are averages for ten energy price indices.

[c]Reported results are totals for four classes of land.

[d]Reported results are totals for six years obtained with the use of a no-rotation cropping scheme.

[e]NM = not modeled

Table 7. **Logit, Logist, Probit, and OLS Estimates of Minimum-Tillage Adoption in Kentucky.**

Model	Constant	Explanatory Variable[a] Land Slope	Education	Income	Inf-Index	Lab-Index
Logit	-1.68*	0.93*	0.06*	0.04*	0.10*	0.01
	(0.25)[b]	(0.16)	(0.02)	(0.01)	(0.02)	(0.01)
Logist	0.72*	1.87*	0.11*	0.08*	0.19*	-0.02
	(0.12)	(0.32)	(0.03)	(0.03)	(0.04)	(0.02)
Probit	-1.65[c]	1.00[c]	0.05[c]	0.04[c]	0.10[c]	-0.01[c]
	-1.94[d]	1.11[d]*	0.06[d]*	0.05[d]*	0.11[d]*	-0.01[d]
	(0.28)	(0.18)	(0.02)	(0.01)	(0.02)	(0.01)
OLS	-0.06	0.35*	0.02*	0	0.03*	-0.01**
	(0.07)	(0.05)	(0.01)	0	(0.01)	0

Source: Mohammad, Table III, p. 47.

[a]Numbers are rounded to two decimal places.

[b]Numbers in parentheses are standard errors.

[c]Probit analysis after 2 iterations.

[d]Maximum-likelihood estimates of probit model after 6 iterations.

*Asymptotic significance at 1 percent.

**Asymptotic significance at 10 percent.

Table 8. Impacts of Alternative Tillage systems on the Economy of Western Kentucky.

Scenario	Sub Sector	Tillage System	Final Demand	Output	Income	Employment
			----------$ 1, 000----------			(Persons)
1	Corn	CT	1, 557	2, 649	308	38
		MT	1, 557	2, 360	206	25
		NT	1, 557	2, 113	101	20
	Soybeans	CT	2, 323	4, 489	645	81
		MT	2, 323	3, 888	421	52
		NT	2, 323	3, 528	290	34
2	Corn	CT	-15, 724	-26, 748	-3, 112	-389
		MT	11, 688	17, 719	1, 546	187
		NT	4, 036	3, 551	261	53
	Soybeans	CT	-4, 177	-8, 073	-1, 160	-146
		MT	2, 235	3, 892	422	52
		NT	1, 852	2, 813	336	28
3	Corn	CT	--	-190, 430	-22, 156	-2, 747
		MT	--	106, 379	9, 286	1, 123
		NT	--	56, 694	2, 698	546
	Soybeans	CT	--	-229, 494	-32, 973	-4, 147
		MT	--	63, 699	6, 903	848
		NT	--	122, 599	10, 072	1, 200
4	Corn	CT	--	-110, 947	-12, 908	-1, 601
		MT	--	63, 879	5, 576	674
		NT	--	31, 329	1, 491	301
	Soybeans	CT	--	-117, 254	-16, 847	-2, 119
		MT	--	32, 510	35, 318	433
		NT	--	62, 553	5, 143	613

Source: Adutwum, Tables 5.3 and 5.4 (p. 83), 5.6 (p. 87), 5.8 (p. 91), 5.10 (p. 95), 5.11 (p. 97), 5.13 (p. 101), and 5.15 (p. 105).
Note: CT = conventional tillage; MT = minimum tillage; NT = no-tillage.

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