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Impacts of Reduced Tillage on Operating Inputs and Machinery Requirements

Many advances in crop production have resulted from the development of alternative production systems requiring changes in the types and quantities of factors used. For example, reduced tillage production systems substitute herbicide applications for tillage operations. Reduced tillage practices may involve a significant change in the types and quantities of inputs, including machinery, used in crop production.

In this paper we present some work regarding alternative tillage systems for wheat production in Oklahoma. We include a section describing the physical and economic environment which has prompted our efforts in this area. Other sections describe our approach to estimating resource requirements of alternative systems.

Winter Wheat Tillage Problems in the Southern Great Plains

Continuous winter wheat production in the Southern Plains presents some unique tillage problems. Weeds must be controlled from the time the crop is harvested in June until the next crop is seeded in the fall. If weeds are not controlled they will mine the available soil moisture and nutrients and jeopardize crop yields. Typically, clean tillage is used to control weeds and prepare the seedbed for the next crop. Between plowing, in June or July, and fall seeding, tillage operations are required after each significant rain to control weeds.

Stubble mulching is an alternative tillage method. It relies on a sweep, or v-blade, which can control summer weeds and leave residue on the soil. But, it does not necessarily reduce the number of tillage operations. Generally, as with conventional clean tillage, a trip across the field is required after each substantial rain during the summer fallow period. Stubble mulching also has resulted in consistently lower net returns (equivalent cost with lower yields) (Chandler and Santelmann). For stubble mulching to succeed in providing adequate weed control, the crop must be planted late in the fall. However, supplementary winter wheat grazing, which is an important source of pasture in the Southern Plains, requires early fall seeding. Thus, most producers use clean tillage including either a moldboard or chisel plow operation.

Several factors have contributed to increasing producer interest in tillage reduction. The price of fuel has risen relative to the price of agricultural chemicals (figure 1). Also, effective herbicides and effective stubble drills have been introduced. Most reduced tillage systems substitute a stubble drill for a conventional drill and herbicides for tillage operations. Herbicides are rarely used with conventional tillage wheat production in the Southern Plains. Thus, adoption of reduced tillage requires access to a suitable sprayer and a stubble drill, neither of which are typically in a producer's machinery inventory.

Study Objectives and Procedures

An interdisciplinary research team composed of agronomists, plant pathologists, entomologists, agricultural engineers, and agricultural economists was established at Oklahoma State University to define and evaluate alternative wheat production systems. One objective was to identify potentially cost effective systems to be evaluated in field trials. The team assisted in defining 22 wheat

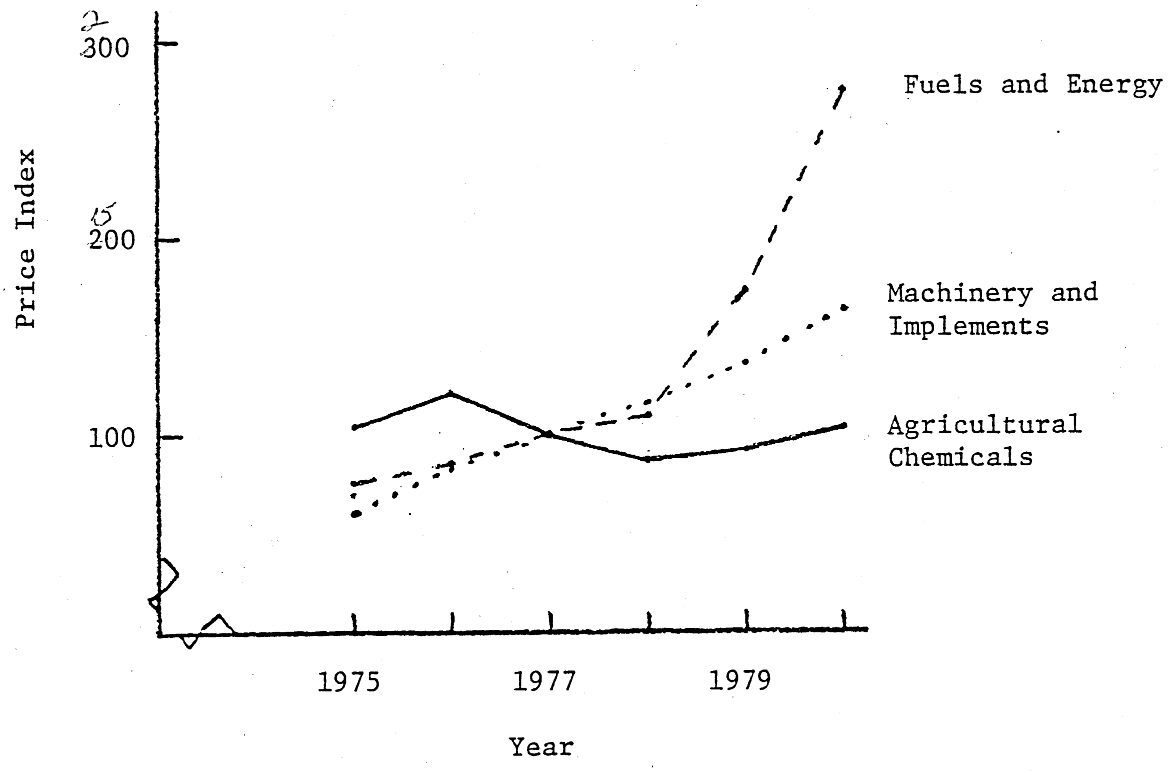

Figure 1. Indexes of prices paid for fuels, machinery, and chemicals. (Source: USDA, Annual Price Summary, June 1981)

systems (Handke). No yield data are currently available for the experimental systems. Quantities and types of production factors, including herbicides, were estimated from only limited field testing. Ultimately, as field trials generate forage and grain yield data, net returns can be estimated.

Figure 2 presents a diagrammatic sketch of the steps described in this paper. Estimates of necessary field operations and operating inputs form the basis for estimates of costs. A 1,240 acre wheat farm in Garfield County, Oklahoma, was used as a case farm. Typically, 95 percent of the cropland in Garfield County is seeded to wheat.

Consistent estimates of tractor and implement requirements, usage levels, and available field work days are essential for a cost evaluation of alternative tillage systems. Field operations (eg. plow, disk), number of times over, and start and ending dates for completion, were defined by agronomists. Tractor operations for four of the systems are included in table 1. The "plow" system is typical for the study area. It includes six soil disturbing operations. The "two-till" and "one-till" systems combine herbicides with two and one tillage operations, respectively. The "zero-till" system relies completely on herbicides for weed control. The stubble drill, which is used to sow the wheat in the two-till, one-till, and zero-till systems, has fluted colters which till a narrow band of soil prior to seed placement. However, we do not consider this to be a tillage operation.

A field work day simulator, developed by Reinschmiedt, was used to estimate available field work days for Garfield County. An 80 percent timeliness level with 10-hour work days was assumed. The

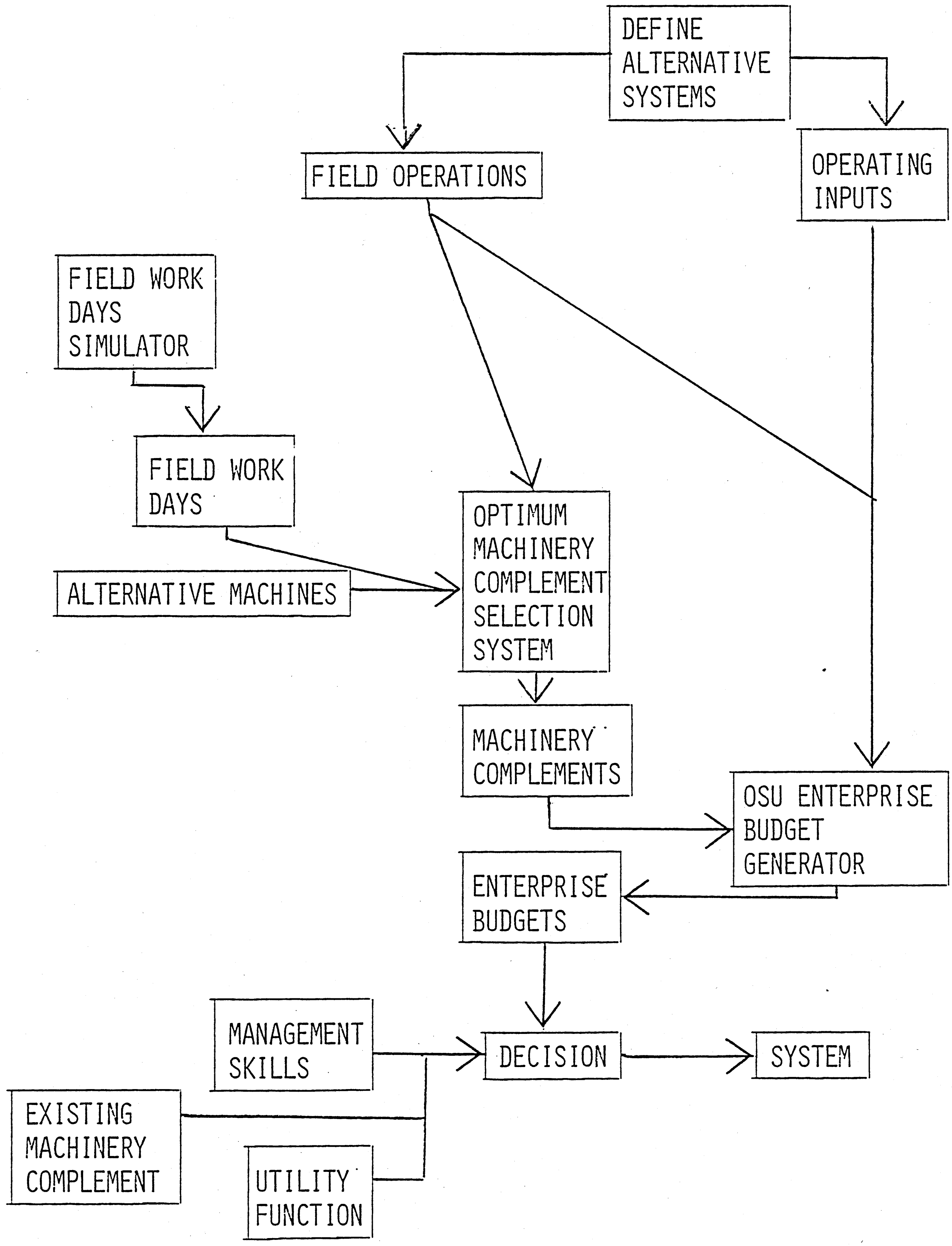

FIGURE 2. STEPS FOR ANALYSIS

Table 1. Tractor Operations for Alternative Wheat Production Systems

Field Operation	Time Period[a]	System: Plow	System: Two-till	System: One-till	System: Zero-till
Spray herbicide	Feb. 2 - March 1	XX[b]	XX	--	XX
Aerial herbicide application[c]	Apr. 1	--	--	XX	XX
Sweep and Spray herbicide	June 2	--	XX	--	--
Off-set Disk	June 2 - July 1	XX	--	--	--
Moldboard Plow	June 2 - July 1	XX	--	--	--
Spread Dry Fertilizer	Aug. 1	XX	--	--	--
Off-set Disk	Aug. 1	XX	--	--	--
Knife in NH_3	Aug. 2 - Sept. 1	XX	--	--	--
Sweep and Knife-in NH_3	Aug. 2 - Sept. 1	--	XX	XX	--
Spread Liquid Nitrogen	Aug. 2 - Sept. 1	--	--	--	XX
Spray herbicide	Aug. 2 - Sept. 1	--	XX	XX	XX
Field Cultivate	Sept. 2	XX	--	--	--
Spray herbicide	Sept. 2	--	--	--	XX
Conventional Drill	Sept. 2	XX	--	--	--
Stubble Drill	Sept. 2	__	XX	XX	XX

[a]Months are divided into half-month periods. A "1" denotes the first half of the month and a "2" denotes the second half.

[b]XX indicates that an operation is performed.

[c]This herbicide is applied with a custom hired airplane.

simulator generated the number of work days available in each half month period.

Tractors of 70, 81, 91, 111, 131, 156, 180, and 229 horsepower were considered as well as a wide range of implements. For example, eight possible tandem disks, ranging in width from 12.7 to 40.3 feet were considered. The implements were matched to tractor sizes. Maximum implement width for a tractor is a function of tractor horsepower, horsepower conversion, draft, and field speed (Bowers, Jones and Bowers). Estimates for these variables were provided by agricultural engineers (Bowers, 1981). Maximum implement widths for each tractor size were estimated from the engineering equations and validated by comparing with actual sales in Garfield County.

Machinery Complement Selection

The machinery cost estimation procedure of the Oklahoma State University Enterprise Budget Generator (Kletke) was used to estimate tractor and implement cost (depreciation, insurance, taxes, interest (opportunity cost), repairs, fuel, lubrication). The Oklahoma State University Optimum Machinery Complement Selection System (OMCSS) was used to solve for the least-cost machinery complement for each production system (Griffin, Hininger). OMCSS uses the integer programming package of MPSX (IBM) to select the tractor-implement combinations which will minimize the total cost of performing the specified field operations in the allotted time.

Table 2 indicates the least-cost number and size of tractors selected, as well as the number of hours the tractors will be used to complete the work on the 1,240 acre farm. The "plow/one-till" system is a 50/50 combination of the plow and the one-till systems.

Table 2. Tractor sizes and annual hours of tractor use by tillage system

	Annual Tractor Hours Tractor Size (Horsepower)[a]				
System	70	81	91	111	180
Plow		445	489		469
Two-till					455
One-till	124			312	
Zero-till	188				98
Plow/One-till	332:186[b]			623	

[a]Tractor of size 131, 156, and 229 horsepower were not selected as part of the optimal complements for these systems.

[b]The plow/one-till system requires two 70 horsepower tractors.

Half of the acreage (620 acres) would be plowed each year. Three tractors are "optimal" for the plow system and the plow/one-till system. However, smaller tractors are required for the latter. The one-till system and zero-till system both require two tractors. The two-till system requires one 180 horsepower tractor used 455 hours per year. The optimal machinery complements are very dependent upon the time constraints. For example, the zero-till system requires two tractors because a spray operation and drilling are scheduled in the same time period but in different trips.

Quantities and Cost of Inputs

The optimal least-cost machine combinations and the other operating inputs defined by the agronomists (e.g. herbicides, fertilizers, seed, and seed treatment) were necessary inputs for budgeting. The Oklahoma State University Enterprise Budget Generator (Kletke) was used to generate enterprise budgets for each of the 22 systems. Some of the results from five of the systems which were included in the study are presented in table 3. (For a detailed description of all systems and additional estimates see Handke.)

Table 3 includes estimates of labor, herbicides, tractor fuel, operating capital, machinery investment, and costs across the five systems.

Labor

The machinery labor estimates in table 3 reflect the time required to complete the field operations listed in table 1. Machinery hours are a function of machine sizes which were calculated by OMCSS. The wage rate is an important OMCSS input. We

Table 3. Estimates of labor, herbicide, fuel, and capital requirements and costs per acre by tillage system

	System				
	Plow	Two-till	One-till	Zero-till	Plow/One-till
Machinery Labor (hours/acre)	1.25	0.40	0.39	0.25	1.01
Herbicide ($/acre)	1.27	11.34	15.21	21.06	8.24
Tractor Fuel (gallons/acre)	6.39	3.16	1.68	1.19	4.08
Annual Operating Capital ($/acre)	40.31	44.90	51.10	59.33	46.11
Average Machinery Investment ($/acre)	74.58	53.76	49.14	54.23	66.62
Operating Plus Machinery Capital ($/acre)	114.89	98.66	100.24	113.56	112.73
Total Operating Cost ($/acre)	84.19	87.30	91.30	102.66	89.10
Machinery Fixed Cost ($/acre)	22.52	16.67	15.12	16.50	20.53
Total Operating Plus Machinery Cost ($/acre)	106.71	103.97	106.42	119.16	109.63

assumed a wage rate of $4 per hour. For information regarding labor-machine size substitution see Hininger.

Since our objective was to investigate tillage practices, we assumed custom harvesting and custom hauling which are typical for the area. Thus, the estimates do not include any harvest labor. These estimates also do not include time required for management or for scouting for early detection of pests and diseases. Additional management and scouting time may be required for the reduced tillage systems.

The zero-till system requires only 20 percent as much preharvest machinery labor as the plow system, and the one-till and two-till systems only one-third as much. Only 310 hours of preharvest machinery labor would be required to farm the 1,240 acres with the zero-till system. The same acreage would require 1,550 hours if the plow system were used. Thus, reducing tillage operations will reduce the amount of labor required. However, labor must be available during critical periods for all systems.

<u>Herbicide</u>

Herbicide costs are also reported in table 3. The percentage increase in herbicide costs in moving from the conventional plow system to the reduced tillage systems is high when compared with other crops in other regions (Crosson, p. 9). Although a cost of $1.27 per acre is included for the plow system, herbicides are not typically used. Perhaps since herbicides have not been used, chemical companies have not been aggressive in seeking clearance. For example, the one-till and zero-till systems depend upon oryzalin which has not been cleared for use on wheat in Oklahoma. It has been used under an experimental use permit. The two-till system requires cyanazine which was cleared for use in 1981.

All systems include a spring application of a broadleaf herbicide. The two-till and one-till systems require three herbicides. The zero-till system requires four separate applications. The cost of the chemicals is $21.06 per acre for the zero-till system. This is substantial when compared with the $1.27 per acre for the plow system.

Tractor Fuel

The reduced tillage systems require three to five gallons less tractor fuel per acre than the plow system (table 3). These estimates are consistent with those provided by Crosson (p. 7). They do not include the energy embodied in the herbicides and machinery.

Annual Operating Capital

The budget generator was employed to estimate annual operating capital requirements for operating inputs including fuel, lubrication, machinery repairs, herbicides, seed, fertilizer, seed treatment, and other cash expenses. As herbicides are substituted for tillage operations, more annual operating capital is required. With diesel fuel priced at $1.20 per gallon, the fuel, lubricants, and repair cost savings of the reduced tillage systems are less than the additional cost for the herbicides. The zero-till system requires almost 50 percent more annual operating capital than the plow system.

The one-till and zero-till systems both require an application of oryzalin in April of the year preceeding harvest. This results in a fourteen month carrying period. Thus, the annual operating capital requirements across systems reflect the timing as well as the cost of herbicide applications.

Machinery Investment

The reduced tillage systems require the use of a stubble drill which costs 2.5 to three times as much per linear foot as a conventional drill. This added cost is more than offset by the reduced number of tillage implements and tractors of the reduced tillage systems relative to the plow system.

Machinery investment requirements are critically tied to the timing of field operations. For example, the two-till system requires only one tractor. Tillage operations are required in late June and late August-early September. Late September is free for drilling. On the other hand, the zero-till system requires a late September spraying operation as well as drilling in the same time period but in different trips across the field. And, the least-cost complement for completing these operations includes two tractors.

The plow system requires an average tractor and implement investment of approximately $92,000 for the 1,240 acre farm compared to $61,000, 34 percent less, for the one-till system. This reduction in machinery investment assumes a complete substitution of the one-till system for the plow system. The producer would not retain the implements necessary for conventional tillage. The combination plow/one-till system assumes that half of the farm is plowed each year. In this case only a 10.7 percent reduction in machinery investment is indicated. It is assumed that a producer would trade an existing conventional drill for a stubble drill and that the stubble drill would be used for the entire acreage with the plow/one-till system. If this assumption had not been made, OMCSS may have selected a combination of conventional and stubble drills for the plow/one-till system.

Operating Plus Machinery Capital

The sum of annual operating capital and machinery investment provides an estimate of the total nonland capital requirements. The capital requirements are similar across systems. For example, the two-till system requires the smallest amount of capital ($98.66/acre), but that amount is 86 percent of that required by the plow system ($114.89/acre).

Estimates indicate that intermediate term financing would decline relative to short term financing as herbicides are substituted for tillage operations. Short term cash flow planning may become increasingly important.

Costs

July 1981 prices were used for all tractors, implements, and operating inputs. The estimated total operating plus machinery costs for the plow, two-till, and one-till systems are very close. The zero-till system suffers from the unfortunate timing of field operations, the cost of the additional herbicide application, and the requirement for liquid nitrogen rather than anhydrous ammonia. It costs almost 12 percent more than the plow system and is the most costly system.

The reduction in the cost of the fuel (at $1.20 per gallon), labor (at $4 per hour), and machinery for the two-till and one-till systems relative to the plow system is almost completely offset by the cost of the herbicides. If the prices of fuel, labor, and machinery increase relative to the price of herbicides, the one-till and two-till systems will become relatively less costly. However, at budgeted prices the reduced tillage systems do not have a significant cost advantage.

Machinery Investment Issues

The relatively small cost advantage of the experimental systems when coupled with the uncertainty resulting from the lack of yield data, suggests that immediate widespread adoption of reduced tillage systems for wheat production in the Southern Plains is not likely. A producer could switch from the plow system machinery complement to the two-till system machinery complement by disposing of two tractors, three moldboard plows, two field cultivators, an offset disk, an anhydrous ammonia applicator, and a conventional drill and acquiring a sweep (v-blade) and stubble drill. Table 4 contains estimates of annual cost for the plow and two-till systems by year of machinery complement life. The estimates assume that all tractors and implements are purchased simultaneously and have a life of ten years on the farm. After the second year of ownership, costs per year are very similar. The reduction in the machine values over-time (ownership costs) are offset by increased repair cost. After the third year of plow system life, the average cost of the two-till system exceeds the marginal annual cost of the plow system. If salvage values and income tax consequences of trading are ignored, and yield and yield variability assumed to be equivalent across systems, the plow complement should be held if it is greater than three years old (Faris, Perrin).

If yields and estimates of net returns are significantly greater for the reduced tillage systems, a machinery investment decision aid which considers the existing and desired machinery

Table 4. Marginal Annual Operating Plus Machinery Cost of Plow and Two-Till Systems by Year of Machinery Complement Life ($/acre)

Year of Life	System	
	Plow	Two-till
1	137.17	127.40
2	105.19	102.06
3	104.50	101.68
4	103.90	101.42
5	103.39	101.14
6	103.03	101.10
7	102.74	101.11
8	102.48	101.13
9	102.40	101.21
10	102.30	101.45

complements would be useful. For individual producers, a present value of expected cash flows approach could be used to estimate the economic consequences of alternative trading strategies. However, this approach would require a considerable amount of machine specific data. For example, equity, salvage value, loan terms, income tax status, and repair cost estimates would be needed for each year of life for each machine. In addition, the appropriate marginal income tax rate and discount rate would be required. A number of simplifying assumptions may be necessary to reduce the data requirements to a manageable level.

Because of the uncertainty surrounding the experimental systems, a complete substitution of a reduced tillage system for the existing system may not be a realistic assumption. Many producers may be reluctant to dispose of their conventional tillage equipment prior to "experimenting" with the new systems. Thus, a transition period during which the existing machinery complement is supplemented with the services of a stubble drill is likely. There are several circumstances that may justify the cost of the services of a stubble drill and the implementation of reduced tillage on a limited scale. For example, a reduced tillage system may enable producers to convert pastureland which they would be reluctant to plow frequently into crop production. Also, acquisition of a stubble drill may enable a producer to expand acreage without additional tractors. The economic consequences of both of these situations could be analyzed in a partial budgeting framework.

Limitations

The estimates presented herein are specific to one location and one size of farm that produces only one crop. Costs for other locations, alternative farm sizes, and multiple crop farms should be investigated.

Research is needed to generate yield and yield variability information for the alternative systems. Potential differences in fertilizer requirements across systems should also be investigated. Additional research may be necessary to determine weed and disease incidence across systems.

Environmental consequences of reduced tillage have been ignored. Benefits which accrue in terms of reduced soil loss should be weighed against the potential impacts of increased herbicide usage.

If alternative production systems generate greater net returns, a decision aid which analyzes machinery investment decisions would be useful. Purchase as well as lease strategies should be considered. Leasing may be an effective means for introducing stubble drills into a region.

Summary

This paper arose from insights gained by agricultural economists working as part of an interdisciplinary team involved in a systematic evaluation of a new and developing production technology. An approach for estimating operating inputs and machinery requirements for alternative tillage systems was presented. A team of scientist provided information regarding operating inputs, field operations, herbicide applications, and timing of operations. A simulation model was used to estimate field work days. A machinery selection program which relies on integer programming was used to select least-cost machinery complements for an Oklahoma wheat farm. Costs were estimated for a conventional plow system as well as for experimental two-till, one-till, and zero-till systems.

The reduced tillage systems require 69 to 80 percent less preharvest machinery labor, 50 to 82 percent less tractor fuel, and 27 to 34 percent less average machinery investment than the plow system. But, they require 11 to 47 percent more annual operating capital and their herbicides cost 793 to 1,558 percent more than that estimated for the plow system. Total operating costs were estimated to be 4 to 22 percent greater for the reduced tillage systems. However, machinery fixed costs are 26 to 33 percent less with the experimental systems. The total operating plus machinery costs of the two-till system were estimated to be 2.6 percent less than that for the plow system. However, the zero-till system costs 12 percent more than the plow system.

The cost of a stubble drill relative to a conventional drill, and the requirement to complete field operations in constrained time periods, prohibit a sizable reduction in machinery investment when switching completely from the plow to a reduced tillage system. If the producer elects to maintain the option for conventional tillage (e.g. plow/one-till), the reduction is even less. However, the reduction in annual hours of use may be substantial. For example, the zero-till system requires a 180 horsepower tractor for only 98 hours per year.

The development of effective herbicides, tolerant wheat varieties, and improved stubble drills, coupled with the decline in the relative prices of herbicides, may trigger many changes. Migrant combines and trucks dominate the harvest scene in the Southern Plains. Will we begin to see migrant tractors? Will interregional leasing firms be established? Tractors could be moved from the Corn Belt to the Southern Plains in June and returned in October. Will 1,240 acre farms be custom sprayed and custom seeded as well as custom harvested?

Perhaps the major contribution of interdisciplinary analysis of emerging technology is the identification of research needs. Agricultural economists on the team have gained an improved perception of biological research. Our associates from the other disciplines have developed an improved understanding of the manner is which specific technology must be analyzed as part of a farming system.

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