Farm machinery selection in Iowa under variable weather conditions

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Farm Machinery Selection in Iowa Under Variable Weather Conditions

William Edwards and Michael Boehlje
Department of Economics

Special Report 85

Cooperative Extension Service and the Agriculture and Home Economics Experiment Station
Iowa State University of Science and Technology
Ames, Iowa ......................... March 1980
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The Cooperative Extension Service and Experiment Station conduct their programs and activities without discrimination as to race, color, sex, or national origin.
Since a wider range of sizes of machinery for crop production has become available, the problem of selecting the appropriate scale of machinery for a particular farming operation has become more complex. Larger machinery helps to reduce labor costs and can improve yields by allowing crops to be planted and harvested on more nearly optimal dates. Some or all of these benefits, however, may be offset by higher depreciation, interest, and other fixed costs. If yield losses due to untimely field operations are considered as a cost, then the problem of machinery selection can be analyzed with the objective of minimizing total expected machinery costs.

Year-to-year variation in the number and sequence of days suitable for fieldwork causes similar variability in timeliness costs and total machinery costs. Larger machinery reduces variability of costs by making it possible to complete planting and harvesting in a timely fashion even when suitable field days are limited. Farmers who wish to reduce the risk of high timeliness costs may wish to choose machinery sets larger than those that would minimize average total machinery costs.

A mathematical model was constructed to estimate planting and harvesting dates, yield reductions, and machinery costs for various machinery sets used in corn and soybean production on Iowa farms. By simulating 20 crop years from data on suitable field days gathered from 1958 to 1977, both the expected mean and variance of the total cost distribution were estimated. Values of several key parameters were tested to observe their effect on machinery costs, variance of cost, and the optimal machinery set. Farm size was varied by increasing crop acres from 100 to 1,000, in increments of 100 acres; the labor supply was increased in a constant proportion to crop acres.

Increasing the size of the machinery set for a fixed number of acres and labor hours caused fixed costs to increase while fuel, repair, labor, and timeliness costs decreased. Total costs per acre tended to decrease at first, then increase as machinery size increased for a specified acreage.

Varying the proportion of total crop acres devoted to corn production from 50 to 100 percent caused the least-cost machinery size to increase, particularly from 400 to 800 acres. It also caused total machinery costs per acre to increase, particularly timeliness costs, and increased the variability of these costs from year to year.

A rise in the expected gross revenue (yields or prices or both) from corn and soybeans caused the average size of the least-cost machinery sets to be slightly larger, primarily because timeliness costs were more critical. Overall costs were lower because of the greater tax savings.

When more labor and field hours per day were assumed to be available, the size of the machinery set that minimized total machinery costs at each acreage level was smaller. The extended hours caused timeliness costs, total costs, and the variability of total costs all to be lower than when field and labor hours were more restricted.

There was very little difference between the sizes of the least-cost machinery sets in northern, central, and southern Iowa due to available field days. Differences in available field days among the three areas had little effect on the average values of any of the machinery cost components, but total costs in southern Iowa were more variable than in the other two regions.

Evidence from a sample of Iowa farmers was used to test the hypothesis that Iowa farmers tended to have machinery of the least-cost size. On the average, the size of the actual machinery sets reported by the farmers in the sample was 0.60 acre per hour, only 0.03 acre per hour smaller than the estimated size of the least-cost machinery sets for their farming operations. The smaller farms (100-300 acres) tended to have machinery somewhat larger than the least-cost size, while for the larger farms (800-1,000 acres), the opposite was true.

The amount of labor available for fieldwork did not seem to affect whether a farm's actual machinery capacity was larger or smaller than the least-cost size. The same was true for differences in expected gross revenue per acre. The close agreement between the sizes of the actual and least-cost machinery sets suggests that working longer hours or other short-term adjustments can be made to compensate for years in which the number of suitable field days is less than average.

The variability of total machinery costs as estimated in this study was relatively small except when the smallest machinery sets are used at the largest acreage levels. This result owes partly to the fact that costs were calculated on an after-tax basis, which incorporates the effect of the progressive marginal tax rates. Because the primary source of high mean costs, timeliness cost, also was the main source of variation in total costs, the lowest-cost sets in some instances also had the least variability. This was especially true at the greater acreage levels. This means that, although it may be possible to include consideration of variability as well as level of costs in selecting machinery, choosing machinery sets on a least-cost basis typically will not result in a machinery set that presents a high degree of risk.

If the standard deviation of the total cost distribution can be estimated, the most practical way of incorporating cost variability into machinery selection probably is to determine which machinery sets have total average costs not significantly higher than those of the least-cost set and to choose the largest of these sets. Another workable method is to rank the sets according to their maximum expected cost (upper confidence limit). Both these criteria require only one item of information related to an individual's risk preference—the degree of confidence to be used in comparing the average costs or in estimating the maximum costs. Other criteria require information regarding marginal substitution rates between risk and returns or a maximum affordable cost, both of which may be difficult to elicit from the typical producer.

SUMMARY
Farm Machinery Selection in Iowa
Under Variable Weather Conditions

by William Edwards and Michael Boehlje

Machinery costs have long been a major portion of the cost structure on most midwestern farms. Table 1 shows that machinery costs have varied from 37 to 48 percent of total farm costs on Iowa farms between 1950 and 1978. The costs of Table 1 are from farm record summaries and include fuel, lubrication, repairs, depreciation, and machine hire. In dollar terms, average machinery costs per rotated acre have increased rapidly in the past few years, but crop yields and prices also have increased. As seen in Table 1, machinery costs as a percentage of the average gross value of corn per acre have actually changed very little in the past 28 years.

The range in sizes of farm machinery available has increased considerably during this 28-year period. Although machinery of the sizes in use 20 years ago can still be purchased, most manufacturers have expanded their lines to include larger models as well. The question of what size of machinery is best suited to a particular farming operation has become more important but for several reasons has been especially difficult to answer.

First, machinery costs depend, not just on one machine or operation, but on a whole system of machines with power provided by one or more tractors or self-propelled units. The performance of one machine may be affected by the characteristics of another machine; for example, when harvesting corn, any of the combining, hauling, or drying operations may limit the rate at which harvesting is completed.

Second, some machinery-related costs are not "out-of-pocket" costs and may not be easily recognized or calculated. Depreciation is one example. Another is timeliness cost—the indirect costs or lower crop yields that occur because planting and harvesting are not completed during the optimal time periods. Estimation of yield-related machinery costs by farmers is further complicated by the effects that other random occurrences such as rainfall, insects, frost, and temperature have on crop yields. This makes it difficult to isolate the effects due solely to timeliness of operations and machinery size. Completion dates also are affected by labor hours available, number of tillage operations carried out, and number of acres farmed, all of which are different for each producer.

Third, there is no universal agreement on what criteria should be used to determine which machinery sets are "best." The most common criterion is minimization of total machinery costs, including ownership costs, operating costs, labor, and timeliness costs. Most discussions of machinery selection have emphasized the trade-offs between the fixed or ownership costs of farm machinery and the value of yield losses that result from planting and harvesting crops on dates other than the optimal ones. These yield losses decrease the farmer's gross income from crops. Their value can be considered as an additional machinery-related cost and can be added to the fixed, operating, and labor costs to arrive at a total machinery cost. Minimizing total machinery costs then becomes equivalent to maximizing profits from production, if all factors except machinery size are held constant (Burrows and Siemens, 1974).

Estimates of timeliness costs usually have been based on average weather expectations or some selected level of probability in which fewer than average suitable field days are assumed (Kletke and Griffin, 1976; McIsaac and Lovering, 1976; Boisvert, 1976; Burrows and Siemens, 1974; Tulu et al., 1974). Although the cost factor probably is the most important element in machinery selection, reduction of risk and minimization of income variation also must be considered. Year-to-year fluctuations in weather cause the number and distribution of days suitable for fieldwork to be highly variable. A machinery set that minimizes costs one year may be much too large or much too small the next year.

Many farmers recognize the need to protect against large losses from late planting and harvest-

Table 1. Farm machinery costs in Iowa, 1950-1978.

<table>
<thead>
<tr>
<th>Year</th>
<th>Machinery cost per rotated acre</th>
<th>Machinery costs as a percent of total farm expenses</th>
<th>Machinery cost per acre as a percent of gross value of corn per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>$19</td>
<td>43%</td>
<td>26%</td>
</tr>
<tr>
<td>1955</td>
<td>20</td>
<td>48%</td>
<td>31%</td>
</tr>
<tr>
<td>1960</td>
<td>22</td>
<td>46%</td>
<td>37%</td>
</tr>
<tr>
<td>1965</td>
<td>25</td>
<td>38%</td>
<td>37%</td>
</tr>
<tr>
<td>1970</td>
<td>34</td>
<td>37%</td>
<td>34%</td>
</tr>
<tr>
<td>1975</td>
<td>69</td>
<td>40%</td>
<td>29%</td>
</tr>
<tr>
<td>1978</td>
<td>77</td>
<td>37%</td>
<td>28%</td>
</tr>
</tbody>
</table>


*Machinery costs include depreciation, fuel, lubrication, repairs, and machine hire.
ing in years in which weather is highly unfavorable and use this as a rationale for owning machinery that is larger than necessary for most years. However, the question has not been answered as to how much extra capacity is needed, or the true cost of this bad weather "insurance." By utilizing weather records, a probability distribution for machinery costs can be estimated, and the risk-reducing potential of various machinery sets can be evaluated. The degree of risk reduction achieved can then be compared with the corresponding increases in long-run total costs.

Some machinery selection models have been constructed in which the optimal machinery set is the one that allows all machinery operations to be completed by a certain date for a given number of years out of 10. This "all or nothing" approach, however, ignores the fact that timeliness losses increase gradually as the date of completion of planting or harvesting is delayed, at least for the most important midwestern crops (Fulton, 1975; Iowa Cooperative Extension Service, 1977).

Another important factor in machinery selection is the impact of machinery investments on income tax payments. Rapid depreciation methods and investment credit allowances effectively reduce the cost of machinery ownership but rarely have been considered in estimating least-cost combinations of farm machinery.

The purpose of this study is to provide for the professional agricultural consultant or educator, or the interested producer, an explanation of the factors that should be considered in the machinery selection decision and the results of empirical analysis of the impact of these factors on machinery selection for farms with various size, geographic, and other characteristics. This study will attempt to incorporate the concepts just discussed in the context of an Iowa corn and soybean producer. The specific objectives of the study are:

1. Construct a model that accurately estimates machinery-related costs under a broad range of assumptions.
2. Estimate the effects that variations in parameters, such as acres farmed, amount of labor available, crop yields and prices, type of crops grown, and location within Iowa, have on total machinery costs (including timeliness costs and tax savings), and identify representative sets of machinery that minimize total machinery costs for various combinations of values for these parameters.
3. Demonstrate the use of several criteria for choosing the optimum scale of machinery that consider variability of machinery costs as well as their long-run average level and compare the results from the criteria and the practicality of implementing each one.
4. Compare the estimated optimal machinery sizes with those actually possessed by a sample of Iowa farmers.
5. Discuss the implications of the results for farmers' machinery selection decisions.

**THEORETICAL CONCEPTS**

**Least-Cost Selection**

For any given number of acres, there exists a range of sizes of machinery that can be used. If it is assumed that the objective of the producer is to maximize profits (i.e., reduction of risk is not important), then he would wish to employ the scale of machinery for which total machinery costs are minimized. Total machinery costs have been defined to include the value of yield losses due to late planting or harvesting.

Increasing machinery size without changing the number of acres in crop production affects different cost components in different ways. For example, fixed costs such as depreciation and investment costs, property taxes, insurance, and housing depend primarily on the original cost, current value, or size of each machine and are not greatly affected by the number of acres over which the machine is used each year. As machinery size increases, the initial investment and annual fixed costs increase proportionally, as shown in Figure 1.

![Figure 1. Effect of increasing machinery size on machinery costs.](attachment:image)

*Operating costs* include expenditures for fuel, lubrication, and repairs. Larger tractors pulling larger machines burn more fuel per hour and have higher repair costs, but they can complete field operations in less time, so have fewer hours of annual use for a constant number of acres. These two effects largely offset each other, so that operating costs per acre are largely unaffected by machinery size (Edwards, 1979). However, reductions in hours of annual machine use due to greater machinery size do cause labor costs to decrease proportionately. *Timeliness costs* also can be reduced substantially by increasing machinery size until the maximum potential yields are achieved.

As seen in Figure 1, finding the least-cost machinery size is a matter of analyzing the trade-offs between rising fixed costs and declining labor and timeliness costs. The total of all machinery costs typically declines, then begins to rise, as machinery
size increases. The lowest point on the total cost curve corresponds to the least-cost machinery size.

Income tax implications of machinery costs also must be considered. Deducting machinery costs from taxable income lowers the amount of income tax due. The dollars of taxes saved can be subtracted from total machinery costs to arrive at total after-tax machinery costs. If all machinery costs are assumed to reduce taxable income, then subtracting tax savings will not substantially affect the shape of the total cost curve but will lower each point on the curve by an amount proportional to the marginal income tax rate of the producer.1

**Variability as a Consideration**

Crop production, like nearly every farming enterprise, exhibits a distribution of possible outcomes that can be characterized by an expected mean value and variance. Specifically, the timeliness component of machinery costs depends to a large degree on the expected number of days suitable for fieldwork for each calendar period. These values are highly variable from period to period and year to year. If farmers can be assumed to prefer less uncertainty to more uncertainty, then they will be willing to accept a lower expected return in exchange for less variability of that return (Anderson et al., 1977).

A probability distribution of total cost for each machinery set can be described by two values. The expected mean is the average level of total costs that the machinery set is expected to achieve over a long period. The variance or standard deviation measures the expected degree of variability of total costs from year to year. Several different criteria can be employed to evaluate which set gives the most desirable combination of level and variability of total machinery costs.

**Expected cost, variability frontier**

Some combinations of expected total machinery costs and variability costs may be more acceptable to the producer than others. If all possible combinations are considered, however, there will most likely be some that are equally acceptable. A set of combinations that are all equally acceptable can be joined by a continuous line called an "indifference curve," i.e., the decision-maker is indifferent as to which combination he chooses (Van Horne, 1968). In Figure 2, four such theoretical indifference curves are shown by curves $I_1$, $I_2$, $I_3$, and $I_4$. Because the farmer is assumed to prefer lower to high costs and less variability to more, the indifference curves closest to the origin (o) comprise the most desirable combinations.

Since each machinery set has an expected total cost (mean) and degree of variability (standard deviation), these values can be plotted on the same set of axes. Points $a$ through $h$ in Figure 2 represent eight hypothetical machinery sets. Some sets, such as those represented by points $c$ and $f$, may have both a higher expected cost and a higher level of variability than at least one other machinery set (points $d$ and $e$, respectively) and never logically would be the first choice of the producer. Van Horne (1968) terms these sets "inefficient." The remaining sets are termed the "efficient" sets and can be joined by a curve, which is referred to as an efficiency frontier. When it is not possible to test all feasible sets, then connecting the points representing the sets that are tested and found efficient provides an estimate of the true efficiency frontier.

The most desirable machinery set can be determined by comparing the efficiency frontier and the indifference curves. The point on the efficiency frontier that is tangent to the indifference curve closest to the origin indicates the most desirable, or optimal set. In Figure 2, this is point $e$. All other points represent machinery sets with less desirable combinations of expected total costs and variability.

**Semivariance**

It can be argued that cost deviations below the mean (that is, years in which machinery costs are lower than average) are advantageous to the farmer and should not be looked upon with disfavor. By considering only variations in total machinery costs above the mean, another measure of variability can be calculated, which Markowitz (1959) terms the "semivariance."

The expected mean and square root of the semivariance can be estimated and graphed for each machinery set under consideration in the same manner as for the expected mean and standard deviation. The efficiency frontier and optimal machinery set are then determined in a fashion similar to that just discussed. For clarity, efficiency frontiers derived by using variance will be referred to as $E$, $V$ frontiers, while those derived by using semivariance will be referred to as $E$, $S$ frontiers.

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1 Although a farmer's own labor is not tax deductible, additional time spent on field operations may reduce income from other farm enterprises and thus reduce total taxable farm income.
Cost, variance minimization

Several machinery sets may have nearly identical expected mean costs. One simple way of choosing an optimal machinery set is to reduce the sets under consideration to all those with mean costs not significantly higher than the lowest mean and then to choose the set with the smallest variance from among this group. In this manner, cost variability is minimized, given the condition that no statistically significant increase in expected mean costs is allowed.

Upper confidence limit (minimax)

Another criterion is to select machinery sets such that the probability of a very high cost in any one year can be minimized. The object is to avoid one disastrous year, which could jeopardize the continuation of the farm business.

From the mean and standard deviation, the highest total machinery cost likely to occur can be estimated with a specified degree of confidence. The machinery set that has the lowest expected maximum cost is then chosen as the optimal one (McInerney, 1967).

Maximum affordable loss

Another strategy similar to the upper confidence limit involves estimating the probability that the total cost for each machinery set will exceed a certain level. Presumably, this level would be the maximum cost that the farm business could withstand in 1 year. The optimal machinery set is the one with the lowest probability of exceeding this maximum affordable loss (Anderson et al., 1977).

METHODOLOGY

The most precise method for estimating the performance of each machinery set would be to test the sets under a variety of conditions and measure the results. This would prove difficult if not impossible to do on a large scale, especially when year-to-year variations in climatic conditions are to be considered. An alternative is to construct a mathematical model that embodies the important physical relationships of the system to be studied.

Three steps were involved in developing a model that could simulate performance and costs of various machinery complements. The first step was to specify the relationships between machinery costs and a number of parameters describing the economic and climatic conditions under which the machinery was being used. These relationships were expressed mathematically and were derived from empirical data or from equations previously calculated and verified by other authors.

The second step was to combine these relationships into a mathematical model that simulated the relevant aspects of the complete crop production system. The third step involved testing selected values for those variables, including alternative machinery sets, that represent the decision environment faced by producers. Only then were alternative decision criteria evaluated, hypotheses tested, and generalizations made.

With use of a simulation model, a number of possible situations are tested, and their predicted outcomes compared (Anderson et al., 1977). This differs from an optimization model, in which only the optimal situation (e.g., machinery set) is identified. Feasible combinations of expected cost and variability can be generated with an optimization model also, by minimizing total costs subject to a constraint on variability. However, special techniques must be used to allow for the indivisibility of machine units and the increasing rate of yield loss due to late planting. It was decided that testing a number of common machinery sets in a simulation model would be the most efficient way to generate the necessary data for applying the decision criteria.

The general structure of the simulation model is as follows. First, values are read and edited describing the general production environment, including weather parameters. Next, data describing the alternative machinery sets to be tested are read and edited. The first machinery set then is tested by using the first set (year) of suitable field days and the smallest farm size.

Performance of fall and spring field operations is simulated, completion dates for harvesting and planting are estimated, and yield losses are calculated. Then other costs, both fixed and variable, are estimated, as well as income tax savings.

This procedure is repeated 10 times. Each time the farm size is increased by a specified increment. This is done for each set of suitable field days. The data for the next machinery set are then read, and the whole process is repeated until no more sets remain. At this point, a detailed summary of the costs for each machinery set under each set of suitable field days and for each level of crop acres is printed. These estimates can then be used to determine the optimal machinery set(s) according to one or more of the criteria discussed.

The following discussion will briefly review the key and unique components of the model used. For a more detailed discussion of the methodology, see Edwards (1979).

Machinery Sets

Although information about actual farm machinery inventories is scarce, a 1976 statewide survey of Iowa farmers did include questions about sizes of tractors, planters, and combine heads (Hoiberg and Huffman, 1978). Nearly a third of the tractors reported in use by the respondents were less than 50 horsepower, and another one-third were from 50 to 80 horsepower. Although sales of large tractors of 150 horsepower or more are increasing, they made up less than 2 percent of all tractors in use by the farmers surveyed.

More than two-thirds of the row-crop planters reported in use were only four rows wide. Six-row and eight-row planters were the next most common.
Four-row corn heads also were the most common, accounting for more than half of the corn heads reported in the 1976 survey. Nearly a third were two rows wide, and most of the rest were three-row or six-row heads. The width of grain heads (such as used for soybeans) in use also was reported. More than 60 percent of the grain heads were 13-15 feet wide.

Although there is commonly thought to be a trend toward larger machinery in Iowa, the results of this survey show that a broad range of machinery sizes is still in use. The machinery sets selected for evaluation in this study were intended to represent the broad range of machinery sizes being used by Iowa farmers at present. The types and sizes of machines chosen are listed in Table 2.

All crop machinery was categorized into two subsets: one for tillage machines and one for planting, weed control, and harvesting machines. The machines in the first subset were grouped primarily on the basis of p.t.o. horsepower required at normal operating speed (except for harrows), and machines in the second subset were grouped according to width and number of rows for which they were designed. The combine size was determined by the horsepower requirement of the corn head, and the size of the grain head was, in turn, determined by the size of the combine. From these subsets, 10 combinations of complete machinery sets were chosen for testing. Table 3 shows the composition of these combinations. Table 4 lists the field operations assumed for corn and soybean production.

Initial list prices were estimated from information published by the National Farm and Power Equipment Dealers Association (1977) and from price lists furnished by several farm machinery manufacturers in late 1977. Purchase prices were estimated at 90 percent of list price to allow for the 10-percent investment tax credit for which most farm machinery purchases qualify. Operating speeds and field efficiencies were estimated by Ayres and Williams (1976a). The equations used to calculate repair costs and wear-out life were used by Ayres and Boehlje (1976) and others (American Society of Agricultural Engineers, 1975).

For all machines, total hours of annual use were computed by multiplying the capacity of the machine in hours per acre times the total number of acres over which it was used and times the number of times it was used over each acre. Hours of annual use for tractors and combine units were equal to the total of the annual hours of use of each machine pulled or powered by that power unit. The factors used to calculate the remaining value after each year of machine life are published by the American Society of Agricultural Engineers (ASAE) (1975) and used by Ayres and Boehlje (1976) and Kletke (1975).

**Crop Production Parameters**

Several parameter values were specified to describe the general production and economic environment in which the machinery sets were tested. These values are summarized in Table 5.

**Farm Size**

The 10 machinery sets were tested over 10 different farm sizes. The range of farm sizes was simulated by increasing the number of crop acres

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### Table 2. Size and composition of machinery subsets.

<table>
<thead>
<tr>
<th>Size of tillage machines</th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
<th>Extra Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>Second tractor</td>
<td>55 h.p.</td>
<td>65 h.p.</td>
<td>75 h.p.</td>
<td>85 h.p.</td>
</tr>
<tr>
<td>Moldboard plow</td>
<td>4 x 16&quot;</td>
<td>5 x 16&quot;</td>
<td>6 x 16&quot;</td>
<td>7 x 16&quot;</td>
</tr>
<tr>
<td>Chisel plow</td>
<td>9.5&quot;</td>
<td>11&quot;</td>
<td>13.5&quot;</td>
<td>15&quot;</td>
</tr>
<tr>
<td>Tandem disk</td>
<td>14&quot;</td>
<td>17&quot;</td>
<td>21&quot;</td>
<td>24&quot;</td>
</tr>
<tr>
<td>Field cultivator</td>
<td>15&quot;</td>
<td>21&quot;</td>
<td>27&quot;</td>
<td>34&quot;</td>
</tr>
<tr>
<td>Spikeloth harrow</td>
<td>21&quot;</td>
<td>26&quot;</td>
<td>31&quot;</td>
<td>36&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size of planting, weed control and harvesting machines</th>
<th>4-row</th>
<th>6-row</th>
<th>8-row</th>
<th>12-row</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planter</td>
<td>4 x 30&quot;</td>
<td>6 x 30&quot;</td>
<td>8 x 30&quot;</td>
<td>12 x 30&quot;</td>
</tr>
<tr>
<td>Rotary hoe</td>
<td>4 x 30&quot;</td>
<td>6 x 30&quot;</td>
<td>8 x 30&quot;</td>
<td>12 x 30&quot;</td>
</tr>
<tr>
<td>Cultivator</td>
<td>4 x 30&quot;</td>
<td>6 x 30&quot;</td>
<td>8 x 30&quot;</td>
<td>12 x 30&quot;</td>
</tr>
<tr>
<td>Combine</td>
<td>75 h.p.</td>
<td>100 h.p.</td>
<td>125 h.p.</td>
<td>145 h.p.</td>
</tr>
<tr>
<td>Corn head</td>
<td>2 x 30&quot;</td>
<td>3 x 30&quot;</td>
<td>4 x 30&quot;</td>
<td>6 x 30&quot;</td>
</tr>
<tr>
<td>Soybean head</td>
<td>10&quot;</td>
<td>13&quot;</td>
<td>15&quot;</td>
<td>20&quot;</td>
</tr>
<tr>
<td>Grain wagons (2)</td>
<td>185 bu.</td>
<td>250 bu.</td>
<td>350 bu.</td>
<td>450 bu.</td>
</tr>
<tr>
<td>Auger</td>
<td>700 bu./hr.</td>
<td>1000 bu./hr.</td>
<td>1400 bu./hr.</td>
<td>2300 bu./hr.</td>
</tr>
<tr>
<td>Dryer</td>
<td>100 bu./hr.</td>
<td>150 bu./hr.</td>
<td>200 bu./hr.</td>
<td>375 bu./hr.</td>
</tr>
</tbody>
</table>

---

### Table 3. Machinery set combinations and designations.

<table>
<thead>
<tr>
<th>Tillage subset</th>
<th>4-row</th>
<th>6-row</th>
<th>8-row</th>
<th>12-row</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>4S</td>
<td>6S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>4M</td>
<td>6M</td>
<td>8M</td>
<td></td>
</tr>
<tr>
<td>Large</td>
<td>6L</td>
<td>8L</td>
<td>12L</td>
<td></td>
</tr>
<tr>
<td>Extra large</td>
<td>8X</td>
<td>12X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

### Table 4. Machinery operations assumed and times over each acre.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Corn</th>
<th>Soybeans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moldboard plow</td>
<td>1.03/</td>
<td>1.03/</td>
</tr>
<tr>
<td>Chisel plow</td>
<td>1.0</td>
<td>1.03/</td>
</tr>
<tr>
<td>Tandem disk</td>
<td>1.0</td>
<td>1.03/</td>
</tr>
<tr>
<td>Field cultivator</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Spikeloth harrow</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Planter</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Rotary hoe</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Cultivator</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Combine</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Wagon and auger</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Dryer</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>

*Plowing is assumed to be done in the fall, if time allows, following harvest of the indicated crop.*
and field labor hours available. By using data from a sample of Iowa farmers, relationships were estimated between crop acres and field labor hours in spring and fall:

\[
\begin{align*}
\text{SLH} &= 6.6 + 1.9A \quad r^2 = 0.58 \quad (1) \\
\text{FLH} &= 9.5 + 1.5A \quad r^2 = 0.59 \quad (2)
\end{align*}
\]

where:

\[
\begin{align*}
\text{SLH} &= \text{spring labor hours per day} \\
\text{FLH} &= \text{fall labor hours per day} \\
A &= \text{number of crop acres in hundreds of acres}
\end{align*}
\]

In this manner, two of the resources in crop production, land and labor, were allowed to increase simultaneously while a third, machinery capacity, was held constant.

Suitable Field Days

The most uncontrollable and unpredictable variable affecting completion dates of field operations is the number of suitable field days available during different periods of the year. Weather conditions in Iowa are highly variable and show little consistency from week to week or year to year.

The Iowa Crop and Livestock Reporting Service (1958-1977) has collected data on suitable field days since 1958 from approximately 300 observers distributed throughout the state. Observations are recorded weekly and summarized for each of nine crop reporting districts in the state, as well as used to calculate a statewide average. Table 6 summarizes the average number of suitable field days over the state for 1958 through 1977. It was assumed that future weather patterns could be expected to have similar means and standard deviations, but not necessarily occur in the same sequence.

Date of Completion of Field Operations

Earliest possible beginning dates for soybean and corn planting and harvesting were determined on the basis of weekly weather and crop report bulletins released by the U.S. Department of Agriculture (1958-1977). Data on suitable field days (Iowa Crop and Livestock Reporting Service, 1958-1977) along with estimates of the accomplishment rates of various harvesting machines (Ayres and Williams, 1976a,b) were utilized to determine the dates of completion for corn and soybean harvesting. The model allowed tillage operations to be started in the fall and finished in the spring, with the remaining field time then allocated to the planting of corn and soybeans. The amount of labor available in the spring and fall also was incorporated in the analysis to reflect the impact of both labor constraints and suitable field days on completion dates and yield losses.

In general, completion dates were estimated by calculating the total number of field hours needed to complete a machine operation (or set of operations) over a given number of acres and dividing by the number of field hours available per day. The result is the number of field days needed. The completion date is the date by which the cumulative total of suitable field days in a given year is equal to or

---

2 Detailed information about crop enterprises, labor availability, and machinery in use was obtained from 382 participants in the Iowa Cooperative Extension Service crop planning workshops (CROP-OPT) from 1975 to 1977.
greater than the number of field days needed. For more detail, see Edwards (1979).

**Yield Losses**

Actual yields harvested by individual farmers vary tremendously among farms and from year to year, depending on such factors as rainfall, temperature, subsoil moisture, planting and fertilization rates, seed varieties, and so forth. By using a mathematical model to simulate production, variables unrelated to machinery capacity were held constant so that differences in estimated yields could be attributed solely to machinery-related factors. The difference between estimated yield and maximum possible yield was then used to calculate the timeliness cost.

Agronomic research has shown that corn and soybean yields vary according to the date of planting and harvesting, as does the moisture content of the grain at harvest. Yield losses and moisture levels were estimated from data published by the Iowa Cooperative Extension Service (1977), as shown in Figures 3-6. Yield loss and grain moisture estimates were derived from experimental results representing various varieties tested at several sites in Iowa (Iowa Cooperative Extension Service, 1974).

In the actual simulation model, regression equations were estimated by using the data just noted for percentage yield reduction as a function of planting date and for percentage yield reduction and moisture level (corn only) as functions of planting date and harvesting date. These equations are shown in Appendix A. All equations used to estimate yield losses and moisture content of grain represent conversions of tabular values to equation form and were not derived from the original experimental results.
Planting yield losses were calculated by multiplying the average percentage loss over the entire planting season by the assumed potential yield. Harvest yield losses were estimated by multiplying the average percentage loss over the entire harvesting season by the potential yield after planting losses were deducted. Timeliness cost is then equal to the product of the total yield loss of each crop and its respective assumed price.

Cost Relationships

Fixed and variable costs were estimated by using standard formulas with the following modifications. Because differences exist in the time of occurrence of some machinery costs, a present-value approach was used to estimate the annual total cost for each machinery complement. Each cost component was estimated for each year of a machine’s anticipated life. These costs were discounted to calculate a present value, then amortized as an ordinary annuity over the life of the machine to give an annual equivalent cost (Smith, 1973). The annual equivalent costs were then summed over all machines in the complement. Income tax savings were calculated in the same manner except that the deducted expenses were summed over all machines before tax savings were calculated, discounted, and subtracted.

Income tax effects

It was assumed that all machinery was depreciated as rapidly as possible, with the total amount of machinery cost deducted in any one year not to exceed remaining taxable farm income, and depreciation not to exceed the amount allowable utilizing the declining balance method and the additional first-year depreciation option.

Investment credit was considered by subtracting 10 percent from the list price of each machine to estimate its net purchase price. All machines were assumed to be owned for 7 years or more. This was long enough to avoid any recapture of investment credit. Recaptured depreciation, however, was calculated and added to taxable income for the final year of each machine’s life.

Recaptured depreciation is the excess of the market value of a used machine when it is sold over the depreciated value of that machine claimed for income tax purposes. Adding this to taxable income adjusts the salvage value of each machine to an after-tax basis.

The net effect of all machinery costs on income tax liability was calculated by subtracting the estimated federal income, Iowa income, and self-employment taxes due with all machinery costs deducted from the total taxes due with no machinery costs deducted. This was done for each year of machinery ownership. Taxable income before deducting machinery costs was estimated by:

\[
TI = AC \times (YC \times PC - 72) + AS \times (YS \times PS - 41) - (50 \times NA)
\]

where:

- \(TI\) = taxable income
- \(YC\) = yield of corn in bushels per acre
- \(YS\) = yield of soybeans in bushels per acre
- \(PC\) = price of corn in dollars per bushel
- \(PS\) = price of soybeans in dollars per bushel
- \(NA\) = total acres of corn and soybeans

The figures of $72 and $41 represent estimates of nonmachinery deductible costs for growing corn and soybeans, respectively (Stoneberg et al., 1977). The $50 charge represents an interest cost plus property taxes for a landowner with partial equity in his land, or a rental charge to a nonowner (unpublished farm-record data for the Iowa Farm Business Associations). Taxable income from sources other than corn and soybean production was assumed to be offset by personal deductions, exemptions, and credits.

Income tax due was then estimated by the following equations:

\[
T_1 = 0.003764 TI^{1.1444} \\
T_2 = 0.0004774(TI - T_1)^{1.4848} \\
T_3 = 0.079 SEI \\
TAX = T_1 + T_2 + T_3
\]

where:

- \(T_1\) = federal income tax due
- \(T_2\) = state (Iowa) income tax due
- \(T_3\) = self-employment tax due (1977 rate was 7.9%)
- \(TI\) = taxable income
- \(SEI\) = taxable income up to a maximum of $16,500 (1977 limit)
- \(TAX\) = total income tax due

Equations 4 and 5 were estimated by the use of regression techniques on the 1977 federal income tax table for joint returns and the 1977 Iowa income tax rate table, respectively. Tax due was assumed to be zero when taxable income was equal to or less than zero. Each year’s tax savings was then calculated as the difference in total income tax due before and after machinery costs were deducted from taxable income. Tax savings for each year of machinery ownership were then discounted to a present value, summed, and converted to an annual equivalent cost.

Total costs

The annual equivalent values of all costs that are not constant for each year were added to the annual values of those costs assumed to be constant with respect to year of ownership (fuel, lubrication, labor, and timeliness). From this, the annual equivalent income tax saving was subtracted, and the result was divided by the number of crop acres to calculate an annual equivalent after-tax total cost per acre for a given machinery complement, as shown by the following equation:

\[
TCA = (AEC + TIH + F + REP + LAB + TPC - TSV) - \frac{NA}{NA}
\]
where:

- **AEC** = annual equivalent cost of the initial purchase cost of each machinery complement
- **TIH** = annual equivalent cost of property taxes, insurance, and housing costs for machinery
- **F** = annual fuel and lubrication cost
- **REP** = annual equivalent cost of machinery repairs
- **LAB** = annual machinery labor cost
- **TPC** = annual timeliness penalty cost
- **TSV** = annual equivalent income tax saving due to machinery
- **NA** = number of crop acres

From the set of total cost per acre values estimated for each year's weather assumptions, a mean and standard deviation were calculated. These describe the probability distribution of total costs for each machinery set, which is the basis for determining the optimal set.

### SELECTING THE EXPECTED LEAST-COST MACHINERY SET

In this section, minimization of the total of all machinery-related costs will be considered as the only objective in selecting among alternative machinery sets. In a later section, the analysis will be extended to include year-to-year variability of total costs. Several of the key parameter values identified earlier will be varied, one at a time, to measure their effect on the size of the machinery set that minimizes expected total costs and on the total machinery costs for each set. The parameters to be varied are: the division of total crop acres between corn and soybeans, expected gross revenue per acre from crops, labor and field hours available per day (Table 7), and field days available by location within the state of Iowa (detailed later in Table 12). The ranges of values assumed for the parameters were derived from data obtained from a sample of Iowa crop farmers and encompass 90 percent of the population represented by the sample (see footnote 2).

#### Initial Assumptions

The initial set of assumptions or parameter values for which the 10 machinery sets were evaluated is shown in Table 5. Each of the 10 machinery sets was tested at 10 levels of farm size, ranging from 100 to 1,000 crop acres, and for 20 sets of suitable field days representing each year from 1958 through 1977. Table 8 shows, for each farm size, the average annual total cost per acre, including timeliness costs, for all 10 machinery sets.

In some cases, several different machinery sets had nearly the same total per-acre costs. For each farm size, the lowest estimated total cost per acre was tested against the estimated costs for each of the other machinery sets at that farm size to determine whether or not the difference was statistically significant. In Table 8, the 10 machinery sets are listed in order from smallest to largest. The least-cost machinery set and the other sets for which the total cost per acre was not significantly higher statistically than that of the least-cost set are underlined.

The smallest machinery set (four-row small) had the lowest average total cost of any machinery set from 100 to 400 acres, and the largest set tested (twelve-row extra large) was the least-cost set at 1,000 acres. If machinery sets smaller than the four-row small (4S) or larger than the twelve-row extra large (12X) had been tested, it is possible that these sets could have been least-cost at the extremes of the range of crop acres. At 500 acres, the four-row medium (4M) set had the lowest average cost, and at 600 acres, the six-row large (6L) set was the least-cost set.

For acreage levels 700 through 900, more than one machinery set was accepted as least-cost, meaning that the higher fixed costs of the larger set were just offset by the higher labor and timeliness costs of the smaller optimal sets. At 700 acres, the six-row large (6L), the eight-row large (8L), and the eight-row extra large (8X) sets were all least-cost. The lowest-cost sets at 800 acres were the 6L and 8X, and at 900 acres, the 8X and 12X sets minimized total machinery costs.

The penalty for not choosing the least-cost machinery set is the difference in total cost per acre for each machinery set and the least-cost set at that

---

3 A standard t-test for testing deviations between paired observations was used (Snedecor and Cochran, 1967, page 93).

4 For brevity, machinery sets will be identified according to the designations shown in Table 3, where 4, 6, 8, or 12 refers to the row size of the planter and S, M, L, or X refers to the small, medium, large, or extra large tillage machines, respectively.

---

### Table 7. Ranges of parameter values assumed for estimating least-cost machinery sets.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Low Assumptions</th>
<th>Initial Assumptions</th>
<th>High Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proportion of crop acres</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planted to corn</td>
<td>50%</td>
<td>61%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Gross revenue per crop acre</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield - bushels per acre</td>
<td>95</td>
<td>115</td>
<td>132</td>
</tr>
<tr>
<td>Price - $ per bushel</td>
<td>2.10</td>
<td>2.35</td>
<td>2.59</td>
</tr>
<tr>
<td>Gross revenue - $ per acre</td>
<td>195.50</td>
<td>270.25</td>
<td>341.88</td>
</tr>
<tr>
<td>Soybeans:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield - bushels per acre</td>
<td>31</td>
<td>36</td>
<td>40</td>
</tr>
<tr>
<td>Price - $ per bushel</td>
<td>5.00</td>
<td>6.09</td>
<td>7.09</td>
</tr>
<tr>
<td>Gross revenue - $ per acre</td>
<td>155.00</td>
<td>219.24</td>
<td>283.60</td>
</tr>
<tr>
<td><strong>Labor and field hours available</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Per suitable field day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Spring labor:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum hours</td>
<td>.0</td>
<td>6.6</td>
<td>13.9</td>
</tr>
<tr>
<td>Additional hours per 100 acres</td>
<td>1.7</td>
<td>1.9</td>
<td>2.1</td>
</tr>
<tr>
<td><strong>Fall labor:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum hours</td>
<td>3.5</td>
<td>9.5</td>
<td>15.3</td>
</tr>
<tr>
<td>Additional hours per 100 acres</td>
<td>1.3</td>
<td>1.5</td>
<td>1.7</td>
</tr>
<tr>
<td><strong>Planting hours</strong></td>
<td>6.0</td>
<td>11.0</td>
<td>16.0</td>
</tr>
<tr>
<td><strong>Harvesting hours</strong></td>
<td>6.5</td>
<td>11.0</td>
<td>15.5</td>
</tr>
</tbody>
</table>
Table 8. Expected mean total machinery costs per acre under the initial parameter value assumptions ($).\(^{a/}\)

<table>
<thead>
<tr>
<th>Machinery set</th>
<th>Farm size (crop acres)</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
<th>600</th>
<th>700</th>
<th>800</th>
<th>900</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Four-row small</td>
<td>213.52</td>
<td>102.87</td>
<td>68.57</td>
<td>50.92</td>
<td>43.77</td>
<td>42.48</td>
<td>56.85</td>
<td>76.69</td>
<td>91.15</td>
<td>103.58</td>
<td></td>
</tr>
<tr>
<td>Four-row medium</td>
<td>224.93</td>
<td>106.66</td>
<td>70.98</td>
<td>51.57</td>
<td>42.91</td>
<td>39.90</td>
<td>46.05</td>
<td>64.66</td>
<td>76.00</td>
<td>86.66</td>
<td></td>
</tr>
<tr>
<td>Six-row small</td>
<td>254.70</td>
<td>118.45</td>
<td>77.56</td>
<td>55.59</td>
<td>44.43</td>
<td>38.10</td>
<td>33.57</td>
<td>33.35</td>
<td>36.50</td>
<td>41.77</td>
<td></td>
</tr>
<tr>
<td>Six-row medium</td>
<td>271.35</td>
<td>123.29</td>
<td>80.36</td>
<td>58.16</td>
<td>44.25</td>
<td>37.30</td>
<td>32.32</td>
<td>29.82</td>
<td>28.99</td>
<td>30.52</td>
<td></td>
</tr>
<tr>
<td>Six-row large</td>
<td>277.88</td>
<td>125.12</td>
<td>81.13</td>
<td>58.01</td>
<td>44.08</td>
<td>36.67</td>
<td>31.35</td>
<td>27.80</td>
<td>26.11</td>
<td>25.55</td>
<td></td>
</tr>
<tr>
<td>Eight-row medium</td>
<td>310.12</td>
<td>138.01</td>
<td>87.31</td>
<td>62.01</td>
<td>47.10</td>
<td>38.66</td>
<td>32.74</td>
<td>28.19</td>
<td>24.54</td>
<td>21.66</td>
<td></td>
</tr>
<tr>
<td>Eight-row large</td>
<td>316.47</td>
<td>139.81</td>
<td>87.98</td>
<td>61.87</td>
<td>46.74</td>
<td>38.01</td>
<td>31.93</td>
<td>26.88</td>
<td>23.09</td>
<td>20.05</td>
<td></td>
</tr>
<tr>
<td>Eight-row extra large</td>
<td>324.49</td>
<td>143.38</td>
<td>90.27</td>
<td>63.13</td>
<td>47.37</td>
<td>37.84</td>
<td>31.75</td>
<td>26.55</td>
<td>22.52</td>
<td>19.43</td>
<td></td>
</tr>
<tr>
<td>Twelve-row large</td>
<td>362.22</td>
<td>161.09</td>
<td>98.94</td>
<td>68.43</td>
<td>51.72</td>
<td>39.70</td>
<td>32.63</td>
<td>27.34</td>
<td>22.69</td>
<td>19.03</td>
<td></td>
</tr>
<tr>
<td>Twelve-row extra large</td>
<td>370.18</td>
<td>164.96</td>
<td>100.54</td>
<td>69.61</td>
<td>51.73</td>
<td>39.80</td>
<td>32.41</td>
<td>27.13</td>
<td>22.43</td>
<td>18.59</td>
<td></td>
</tr>
</tbody>
</table>

\(^{a/}\) Underlined values indicate the machinery sets having the lowest average total costs for each farm size, at the .05 level of confidence.

level of crop acres. For very small and very large acreages, the potential penalty was high. On the other hand, at 600 acres, for example, even choosing the most costly of the machinery sets tested would result in an expected increase of only $5.81 per acre over the least costly set.

**Effects of Machinery Size on Costs**

Table 9 compares the costs per acre of the smallest and largest machinery sets tested at 100 and 1,000 acres. When machinery size increased for each acreage level, fixed costs increased also. Fuel costs per acre were nearly constant for all the machinery sets, but repair and labor costs per acre decreased as machinery size increased because fewer hours of field time were required. Increasing machinery size also reduced timeliness costs, particularly at the larger acreage levels. For example, at the 1,000-acre level, the four-row small set had yield losses of $147 per acre, while losses of only $12 per acre were projected from using the twelve-row extra large machinery set.

Tax savings at 100 acres were equal for all machinery sets because machinery costs were high enough for every set to offset all taxable income, resulting in a projected income tax liability equal to zero. At greater acreages, tax savings were directly proportional to pretax costs.

The effect of machinery size on total cost per acre varied with farm size. For example, at 100 acres, average total cost per acre increased over the whole range of machinery sizes tested (from small to larger

Table 9. Expected mean machinery cost components per acre under the initial assumptions.

<table>
<thead>
<tr>
<th></th>
<th>Four-row small set, 100 acres</th>
<th>Twelve-row extra large set, 100 acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed costs</td>
<td>$233.79</td>
<td>$398.47</td>
</tr>
<tr>
<td>Fuel and lubrication</td>
<td>12.33</td>
<td>11.46</td>
</tr>
<tr>
<td>Repairs</td>
<td>1.84</td>
<td>.92</td>
</tr>
<tr>
<td>Labor</td>
<td>9.25</td>
<td>4.19</td>
</tr>
<tr>
<td>Timeliness</td>
<td>1.83</td>
<td>.66</td>
</tr>
<tr>
<td>Tax savings (-)</td>
<td>45.33</td>
<td>45.33</td>
</tr>
<tr>
<td>Total</td>
<td>213.32</td>
<td>370.18</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>.67</td>
<td>.75</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Four-row small set, 1000 acres</th>
<th>Twelve-row extra large set, 1000 acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed costs</td>
<td>$24.31</td>
<td>$40.70</td>
</tr>
<tr>
<td>Fuel and lubrication</td>
<td>7.67</td>
<td>7.96</td>
</tr>
<tr>
<td>Repairs</td>
<td>9.31</td>
<td>4.42</td>
</tr>
<tr>
<td>Labor</td>
<td>9.25</td>
<td>4.73</td>
</tr>
<tr>
<td>Timeliness</td>
<td>147.22</td>
<td>12.36</td>
</tr>
<tr>
<td>Tax savings (-)</td>
<td>93.21</td>
<td>51.57</td>
</tr>
<tr>
<td>Total</td>
<td>103.58</td>
<td>18.59</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>.36</td>
<td>1.61</td>
</tr>
</tbody>
</table>
(ones) while, for 1,000 acres, it decreased over the whole range. In general, at the intermediate acreage levels, total costs per acre first declined as machinery size increased, then rose.

For some farm sizes, machinery size had little effect on total machinery costs per acre. As noted, at 600 crop acres, there was less than $6 difference per acre in total costs among all 10 machinery sets.

The average total cost for the least-cost machinery set under the initial assumptions decreased as the number of crop acres increased (Table 8). This indicates that the long-run average cost curve for machinery use in grain production was still declining at 1,000 acres. Of course, this assumes a constant level of management skills and capital availability at all acreage levels, which may not always be true.

**Effect of Crop Mix, Gross Revenue, Field Hours, and Location**

Table 10 shows the minimum total machinery cost per acre at each acreage level when different values were assigned to several of the key parameters. Table 11 compares the size of the least-cost machinery sets for the various parameters. The effects of varying each parameter will be discussed in detail.

**Crop mix**

Increasing the proportion of crop acres planted to corn from 50 to 100 percent caused slight increases in per-acre fuel, repair, and labor costs. Timeliness costs also increased, particularly at the larger acreages because early planting is more critical for corn than for soybeans. Variability of costs also was greater when all acres were planted to corn. Total machinery costs per acre were higher as well ($30 vs. $19 at 1,000 acres, for example) primarily because of higher timeliness costs.

The overall size of machinery needed to minimize total costs was affected by the change in crop mix, as shown in Figure 7. With 100 percent corn, the least-cost machinery set was larger for acreages between 400 and 800 acres. The size of the least-cost tillage machinery, in particular, increased as a larger proportion of total acres were in corn. This was less evident for planting and harvesting machinery. In fact, the sets with twelve-row planting and six-row harvesting equipment (12L, 12X) were not least-cost even at 1,000 acres when no soybeans were planted. In contrast, these sets were frequently least-cost when the enterprise mix included only 50 percent corn.

To test whether adequate planter size was more critical than adequate harvesting capacity with 100 percent of the acreage in corn, a machinery set with the extra-large tillage equipment, a twelve-row
Table 11. Designation of the least-cost machinery sets under ranges of parameter values tested.

<table>
<thead>
<tr>
<th>Farm Size (crop acres)</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
<th>600</th>
<th>700</th>
<th>800</th>
<th>900</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial assumptions</td>
<td>4S</td>
<td>4S</td>
<td>4S</td>
<td>4S</td>
<td>4M</td>
<td>6L</td>
<td>6L,M</td>
<td>6L</td>
<td>8X</td>
<td>12X</td>
</tr>
<tr>
<td>50% corn</td>
<td>4S</td>
<td>4S</td>
<td>4S</td>
<td>4S</td>
<td>4M</td>
<td>6L</td>
<td>6L</td>
<td>6L</td>
<td>6L</td>
<td>12X</td>
</tr>
<tr>
<td>100% corn</td>
<td>4S</td>
<td>4S</td>
<td>4S</td>
<td>4M,6L</td>
<td>6L</td>
<td>6L</td>
<td>6L</td>
<td>8X</td>
<td>12X</td>
<td></td>
</tr>
<tr>
<td>Low gross revenue</td>
<td>4S</td>
<td>4S</td>
<td>4S</td>
<td>4S</td>
<td>4M</td>
<td>6L</td>
<td>6L</td>
<td>6L</td>
<td>6L</td>
<td>12L</td>
</tr>
<tr>
<td>High gross revenue</td>
<td>4S</td>
<td>4S</td>
<td>4S</td>
<td>4S</td>
<td>4M</td>
<td>6L</td>
<td>6L</td>
<td>6L</td>
<td>6L</td>
<td>12L</td>
</tr>
<tr>
<td>Low labor and field hours</td>
<td>4S</td>
<td>4S</td>
<td>4M</td>
<td>6L</td>
<td>6L</td>
<td>6L</td>
<td>6L</td>
<td>8X</td>
<td>12X</td>
<td></td>
</tr>
<tr>
<td>High labor and field hours</td>
<td>4S</td>
<td>4S</td>
<td>4S</td>
<td>4S</td>
<td>4M</td>
<td>6L</td>
<td>6L</td>
<td>6L</td>
<td>6L</td>
<td>12L</td>
</tr>
<tr>
<td>Northern Iowa</td>
<td>4S</td>
<td>4S</td>
<td>4S</td>
<td>4S</td>
<td>4M</td>
<td>6L</td>
<td>6L</td>
<td>6L</td>
<td>6L</td>
<td>12L</td>
</tr>
<tr>
<td>Central Iowa</td>
<td>4S</td>
<td>4S</td>
<td>4S</td>
<td>4S</td>
<td>4M</td>
<td>6L</td>
<td>6L</td>
<td>6L</td>
<td>6L</td>
<td>12L</td>
</tr>
<tr>
<td>Southern Iowa</td>
<td>4S</td>
<td>4S</td>
<td>4S</td>
<td>4S</td>
<td>4M</td>
<td>6L</td>
<td>6L</td>
<td>6L</td>
<td>6L</td>
<td>12L</td>
</tr>
</tbody>
</table>

The weighted average expected gross revenue per acre from corn and soybeans was varied from $182 to $319. Table 7 shows the price and yield assumptions used to calculate gross revenue. Added bushels also caused fuel, labor, and repair costs to be slightly higher. The increase in gross revenue, however, caused the marginal tax rate and the income tax savings to be greater at each acreage level, and total costs were actually less than when lower prices and yields were assumed. At 1,000 acres, the minimum total after-tax cost per acre was only $13 under the high gross revenue assumptions compared with $34 under the low gross revenue assumptions (see Table 10). Variability of total costs was greater under the higher gross revenue assumptions because of the increased timeliness costs.

Higher timeliness costs that occur with higher gross revenues also resulted in increased size of the least-cost machinery sets (Table 11). A greater investment could be justified to reduce yield losses. Figure 8 illustrates the sizes of the least-cost sets under the low, initial, and high gross revenue assumptions.

**Labor and field time**

Great variation exists among farms in the number of hours of labor available for fieldwork each day and, to a lesser degree, in the number of hours per day that planting and harvesting can be carried out. The initial assumptions regarding labor and field time availability were given by equations 1 and 2. Two other levels of availability were tested. Under the **low** labor and field time assumptions, labor hours per day...
varied from 1.7 (100 acres) to 17 (1,000 acres), with 6.0 field hours per day assumed for planting and 6.5 field hours per day assumed for harvesting. The high assumptions specified a range of 16.0 labor hours per day at 100 acres to 34.9 labor hours per day at 1,000 acres, 16.0 field hours per day for planting and 15.5 field hours per day for harvesting (Table 7). All labor hours were valued at $3.50 per hour, although a farmer might prefer to value his own labor at an increasingly higher rate as the number of hours worked per day increases.

As shown in Figure 9, increasing the number of labor and field hours per day significantly reduced the size of the machinery sets (fewer acres per hour) needed to minimize costs at each acreage level. For example, the smallest machinery set tested (4S) was least-cost through 600 acres when the high levels of field and labor hours were assumed, but only through 200 acres under the low level assumptions. At the other extreme, as shown in Table 11, the largest set tested (12X) was least cost from 600 acres through 1,000 acres when hours were limited, but only at the 1,000-acre level when field and labor time was extended.

Table 10 shows that total costs per acre were considerably higher when the low level of labor and field hours per day was assumed and each acreage level. For example, the smallest machinery set tested (4S) was least-cost through 600 acres when the high levels of field and labor hours were assumed, but only through 200 acres under the low level assumptions. At the other extreme, as shown in Table 11, the largest set tested (12X) was least cost from 600 acres through 1,000 acres when hours were limited, but only at the 1,000-acre level when field and labor time was extended.

As shown in Figure 9, increasing the number of labor and field hours per day significantly reduced the size of the machinery sets (fewer acres per hour) needed to minimize costs at each acreage level. For example, the smallest machinery set tested (4S) was least-cost through 600 acres when the high levels of field and labor hours were assumed, but only through 200 acres under the low level assumptions. At the other extreme, as shown in Table 11, the largest set tested (12X) was least cost from 600 acres through 1,000 acres when hours were limited, but only at the 1,000-acre level when field and labor time was extended.

Figure 9. Least-cost machinery sizes for three levels of labor and field hours available per day.

Table 10 shows that total costs per acre were considerably higher when the low level of labor and field hours per day was assumed and each acreage level. For example, the smallest machinery set tested (4S) was least-cost through 600 acres when the high levels of field and labor hours were assumed, but only through 200 acres under the low level assumptions. At the other extreme, as shown in Table 11, the largest set tested (12X) was least cost from 600 acres through 1,000 acres when hours were limited, but only at the 1,000-acre level when field and labor time was extended.

Location

A comparison of different regions within the state of Iowa (Table 12) revealed that northern Iowa has the fewest suitable field days before April 25, on the average, but that southern Iowa has the fewest suitable days during planting and harvesting periods as well as the greatest variability in number of suitable field days. As shown in Figure 10, the average size of the least-cost machinery sets was slightly larger in southern Iowa than in the central region, at least from 400 to 800 acres. In general, the least-cost machinery size and average machinery costs were not greatly affected by location within the state, but variability of total machinery costs was slightly greater in the southern region. It should be noted, however, that, in certain areas of Iowa, the steepness of the slopes being farmed, location of terraces, and size of fields may put practical limits on the size of machinery that can be used.

A similar analysis of the western, central, and eastern areas of Iowa showed even less variation in the number of suitable field days and, hence, least-cost machinery sizes.

Figure 10. Least-cost machinery sizes for three regions in Iowa.

Tax Effects

After-tax total machinery costs were equal to pretax costs minus income tax savings due to investment credit and deduction of machinery costs. Variability of total costs from year to year was lowered by including tax savings because of the progressive marginal income tax rates. Consideration of
tax savings, however, had no significant effect on the sizes of the least-cost machinery sets, at least under the initial assumptions.

**Least-Cost Sizes**

As summarized in Table 11, the 4S machinery set (with the smallest tillage implements and tractors tested plus a four-row planter and two-row combine) was the least-cost machinery set under all conditions from 100 to 300 acres, except at 300 acres when labor was restricted. This also was the least-cost set at 400 acres except for the 100-percent corn and low-labor situations.

The 4S set and the four-row set with the medium subset of tillage implements (4M) were least cost at 500 and 600 acres under the "nonrestrictive" assumptions, i.e., 50 percent corn, low gross revenue, and high labor supply. The six-row large (6L) and eight-row extra large (8X) sets were most often the least-cost sets from 500 to 700 acres when all acres were planted in corn or high prices and yields were assumed. At these acreage levels, however, the cost differences among nearly all the sets were small.

The 8X set was least cost at 900 acres under all conditions. At 1,000 acres, the largest set tested, the 12X set, was almost optimal always.

**EXPECTED LEAST-COST VERSUS ACTUAL MACHINERY CAPACITY**

To compare the least-cost machinery capacities just discussed with the actual machinery capacities possessed by Iowa farmers, a sample was drawn from a group of farmers who participated in a series of crop planning workshops sponsored by the Iowa State University Cooperative Extension Service in 1975, 1976, and 1977 (see footnote 2). The sample contains the same proportion of farmers from northern, central, and southern regions of the state as the population of Iowa farmers.

It was not practical to simulate conditions for each individual farm in the sample to determine the size of the least-cost machinery set for that farm. Instead a linear regression equation was estimated, by using the results from the simulation analysis, for the least-cost machinery size as a function of several key variables. The size of the machinery set (the dependent variable) was measured by the number of field hours required to complete all machinery operations over 1 acre. The independent variables included were acres of crop land, gross revenue per acre, average labor hours per day (spring and fall), and proportion of acres devoted to corn. Data points were obtained from the least-cost machinery sets identified under the initial assumptions, high and low gross revenue assumptions, high and low labor and field hours per day assumptions, and 50- and 100-percent corn assumptions, which have been summarized previously. Only the coefficients for crop acres and labor hours were significant at the 0.10 level.

The following equation was estimated from the simulation data:

$$\text{HRA} = 2.138 - 0.00233A + 0.0415 \text{HRD} \quad (r^2 = 0.90)$$

where:

- $\text{HRA}$ = size of the least-cost machinery set in hours per acre
- $A$ = number of crop acres
- $\text{HRD}$ = average hours of labor available per day in spring and fall

Information supplied by the farmers in the sample about their farming operations was used in equation 9 to estimate the size of the expected least-cost machinery set for each operation. Additional data concerning the time required to perform field operations on each farm were used to estimate the size of the actual machinery set in use. Estimates of the expected and actual machinery size are summarized in Table 13; the size measure for the machinery sets was inverted, i.e., measured in acres (over which all operations could be completed) per hour, so that a larger value indicates a larger machinery set, and vice versa.

A comparison of expected and actual acres per hour showed that the farmers in the sample were, on the average, using machinery sets very close in size to the estimated least-cost size. The average size of the machinery sets (measured by hours per acre) in use on the sample farms was 0.60 acre per hour, and the average size of the least-cost sets for the same farms based on the simulation results was 0.63 acre per hour. This difference was not significant at the 0.01 level.

Further analysis was done to determine if some types of farms had, on the average, machinery sets closer to the least-cost size than others. Table 13 shows the size of the actual and estimated least-cost machinery sets for farms of different acreages. The smaller farms tended to have machinery of larger than least-cost size, and the larger farms tended to have machinery smaller than the least-cost size indicated by the simulation analysis. The difference between the average and least-cost machinery sizes was statistically significant at the 0.05 level for farms in the 150-249, 250-349, 750-849, and 850-949 acre size groups.

Possible explanations for the excess machinery capacity observed on the smaller farms are a lack of availability of smaller-sized machinery, a desire to reduce the chances of larger timeliness losses, and plans for future expansion of the land base. In some cases, the power requirements for machinery used in livestock operations on smaller farms may have made it more feasible to own larger crop machinery.

There was no observable relationship between the size of the labor supply on the farms included in the sample and whether the machinery set on each farm was larger or smaller than the least-cost size. This suggests that, although not all farms had machinery sets of exactly the least-cost size, farms with a relatively small labor supply were no farther away from the least-cost machinery set than were farms with more labor available. Likewise, when
Table 13. Actual and expected least-cost machinery set sizes, by number of crop acres.

<table>
<thead>
<tr>
<th>Number of crop acres</th>
<th>Average size of actual machinery set, acres per hour</th>
<th>Average size of least-cost machinery set, acres per hour</th>
<th>Difference, acres per hour</th>
<th>Number of farms</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 - 149</td>
<td>.52</td>
<td>.43</td>
<td>.09</td>
<td>5</td>
</tr>
<tr>
<td>150 - 249</td>
<td>.51</td>
<td>.45</td>
<td>.06*</td>
<td>22</td>
</tr>
<tr>
<td>250 - 349</td>
<td>.53</td>
<td>.49</td>
<td>.04*</td>
<td>30</td>
</tr>
<tr>
<td>350 - 449</td>
<td>.57</td>
<td>.56</td>
<td>.01</td>
<td>21</td>
</tr>
<tr>
<td>450 - 549</td>
<td>.62</td>
<td>.63</td>
<td>-.01</td>
<td>23</td>
</tr>
<tr>
<td>550 - 649</td>
<td>.68</td>
<td>.68</td>
<td>.00</td>
<td>22</td>
</tr>
<tr>
<td>650 - 749</td>
<td>.71</td>
<td>.74</td>
<td>-.03</td>
<td>14</td>
</tr>
<tr>
<td>750 - 849</td>
<td>.69</td>
<td>.85</td>
<td>-.16*</td>
<td>18</td>
</tr>
<tr>
<td>850 - 949</td>
<td>.51</td>
<td>.98</td>
<td>-.47*</td>
<td>9</td>
</tr>
<tr>
<td>950 - 1049</td>
<td>.85</td>
<td>1.25</td>
<td>-.40</td>
<td>2</td>
</tr>
<tr>
<td>TOTAL</td>
<td>.60</td>
<td>.63</td>
<td>-.3</td>
<td>166</td>
</tr>
</tbody>
</table>

*Significant at .05 level.

farms were grouped according to expected gross revenue per acre, the differences between the actual and least-cost sizes were not significant for any of the three levels.

The evidence presented indicates that, in general, the farmers in the sample did not have excess machine capacity. As noted earlier, many analysts argue that farmers maintain excess machine capacity to reduce the risks of not getting cropping operations done in a timely fashion. In many years, however, short-run adjustments can be made that effectively increase machinery capacity, such as reducing the number of field operations, increasing the number of field hours per day, changing the mix of crops, or leasing or custom hiring extra machinery. This may make it unnecessary to own machinery larger than that needed for minimizing costs simply to reduce the chances of suffering high timeliness losses in a given year.

**MACHINERY SELECTION CONSIDERING RISK**

The hypothesized importance of considering variability as well as mean level of costs in machinery selection is illustrated by Figure 11. Estimated total costs for each year from 1958 through 1977 are shown for two example machinery sets, the 6M and the 12X machinery complements, for 700 crop acres. Although these two sets were not least-cost at 700 acres (see Table 8), their average costs were less than $1.00 (3 percent) higher per acre than those of the least-cost set(s). The difference in mean value of total cost per acre for these two sets was not statistically significant at the 0.01 significance level. Yet, as seen from the graph, the cost of the six-row set was considerably higher or lower than the cost of the twelve-row set in most years, depending on the number of suitable field days available in each particular year. A risk-averse individual would choose the twelve-row set over the six-row set in this case because he could reduce the variability without significantly increasing long-run expected costs.

As indicated earlier, total machinery costs were adjusted to an after-tax basis by estimating the total amount of income tax due before and after deducting machinery costs and subtracting these tax savings from pretax machinery costs. High machinery costs produced high tax savings, and low machinery costs produced low tax savings. The progressive nature of the marginal tax rates magnified this effect. Thus,
Table 14. Standard deviation of total cost distribution under initial assumptions.

<table>
<thead>
<tr>
<th>Farm Size (crop acres)</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
<th>600</th>
<th>700</th>
<th>800</th>
<th>900</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Four-row small</td>
<td>.67</td>
<td>1.50</td>
<td>2.82</td>
<td>3.04</td>
<td>4.57</td>
<td>9.54</td>
<td>26.00</td>
<td>34.56</td>
<td>35.89</td>
<td>36.33</td>
</tr>
<tr>
<td>Four-row medium</td>
<td>.57</td>
<td>1.22</td>
<td>1.72</td>
<td>3.04</td>
<td>3.43</td>
<td>7.51</td>
<td>16.16</td>
<td>30.09</td>
<td>35.03</td>
<td>37.86</td>
</tr>
<tr>
<td>Six-row small</td>
<td>.57</td>
<td>1.35</td>
<td>1.95</td>
<td>3.21</td>
<td>3.63</td>
<td>7.80</td>
<td>16.88</td>
<td>28.82</td>
<td>34.34</td>
<td>37.07</td>
</tr>
<tr>
<td>Six-row medium</td>
<td>.64</td>
<td>1.09</td>
<td>1.41</td>
<td>1.57</td>
<td>1.97</td>
<td>2.26</td>
<td>3.60</td>
<td>6.36</td>
<td>9.34</td>
<td>13.81</td>
</tr>
<tr>
<td>Six-row large</td>
<td>.58</td>
<td>1.27</td>
<td>1.24</td>
<td>1.38</td>
<td>1.77</td>
<td>1.88</td>
<td>2.82</td>
<td>4.84</td>
<td>7.14</td>
<td>9.99</td>
</tr>
<tr>
<td>Eight-row medium</td>
<td>.57</td>
<td>1.27</td>
<td>.78</td>
<td>1.15</td>
<td>1.69</td>
<td>2.10</td>
<td>2.87</td>
<td>3.48</td>
<td>4.09</td>
<td>4.09</td>
</tr>
<tr>
<td>Eight-row large</td>
<td>.58</td>
<td>1.32</td>
<td>1.16</td>
<td>1.02</td>
<td>1.39</td>
<td>1.73</td>
<td>2.18</td>
<td>2.63</td>
<td>3.23</td>
<td>3.23</td>
</tr>
<tr>
<td>Eight-row extra large</td>
<td>.59</td>
<td>1.44</td>
<td>.56</td>
<td>1.68</td>
<td>1.86</td>
<td>1.26</td>
<td>1.44</td>
<td>1.90</td>
<td>2.26</td>
<td>2.90</td>
</tr>
<tr>
<td>Twelve-row large</td>
<td>.62</td>
<td>.70</td>
<td>.54</td>
<td>.78</td>
<td>.92</td>
<td>1.29</td>
<td>1.49</td>
<td>1.73</td>
<td>1.91</td>
<td>1.91</td>
</tr>
<tr>
<td>Twelve-row extra large</td>
<td>.64</td>
<td>.55</td>
<td>.47</td>
<td>1.24</td>
<td>.73</td>
<td>1.10</td>
<td>1.19</td>
<td>1.51</td>
<td>1.61</td>
<td>1.61</td>
</tr>
</tbody>
</table>

adjusting total machinery costs for tax savings considerably reduced year-to-year variability.

Table 14 shows the standard deviation for each machinery set evaluated from 100 to 1,000 acres. Except at the 100-acre level, where variation was very small, the standard deviation was inversely related to the size of the machinery set. The primary source of variation in total costs was the timeliness cost component, and as machinery size increased, timeliness costs became smaller and less variable.

Differences in the optimal choice of a set of machinery when risk as well as mean cost is included in the selection criteria occurred mostly for farms with 200 to 800 acres. At 100 acres, differences in mean costs among machinery sets were very large while differences in the standard deviations were very small, so that the least-cost machinery set (4S) would be chosen at the optimum under nearly any circumstances. Likewise, at 900 and 1,000 acres, the 12X machinery set had both the lowest mean cost and the lowest standard deviation and would be considered optimal under any criterion that assumed a negative marginal utility for both costs and variability.

Five methods for incorporating risk into the machinery selection decision were tested, and the practicality of using each one with individual producers was evaluated.

**Expected Cost, Variance Frontiers**

Expected cost, variance (E, V) frontiers for several acreage levels were constructed by plotting the combinations of the mean and standard deviation for total costs for each machinery set. Figure 12 illustrates E, V frontiers for 200 through 700 acres. Those sets having a lower mean and (or) a lower standard deviation than each of the other sets at each acreage level were termed "efficient" sets and were connected by a solid line to project the shape of the E, V frontier.

As noted earlier, the optimal machinery set for each acreage level would be represented by the point on the respective E, V frontier that touches the cost,
variance indifference curve lying closest to the origin. Although the actual shapes of a farmer's indifference curves are difficult to determine, for a risk-averse individual, they can be expected to slope down and to the right (see Figure 2). Given this shape, several machinery sets seem more likely to be chosen as optimal than others. In particular the 4M, 6L, 8X, and 12X sets would be optimal, assuming a broad range of negative slopes for the indifference curves.

**Expected Cost, Semivariance Frontiers**

Expected cost, semivariance (E, S) frontiers were constructed in a manner similar to the E, V frontiers except that semivariance, which considers only cost deviations above the mean, was used as the measure of cost variability. Inasmuch as the cost distributions for all the machinery sets were skewed in the same direction and to approximately the same degree, this method gave practically the same results as the E, V frontier method. In general, employing either the E, V or E, S criterion to select machinery would result in the choice of machinery sets of the same size or larger than those chosen when only the means of the cost distributions are considered.

**Cost, Variance**

As noted earlier, statistical tests were used to decide whether or not the expected mean cost of each machinery set was significantly higher than that of the set with the lowest mean cost. In this manner, several sets may be determined to minimize costs for the same farm size. Choosing the least-cost set with the smallest standard deviation results in a reduction in the degree of risk with no significant increase in expected costs.

Figure 13 compares the sizes of the optimal machinery sets under this criterion with the average size of the least-cost sets at each acreage level. Where more than one machinery set was least cost (700, 800, and 900 acres), the average size of the least-cost sets was slightly smaller than the size of the least-cost set with the smallest variability (i.e., the largest least-cost set).

This strategy of selecting the least-cost sets and choosing the one with the lowest variability is relatively simple to apply because it merely requires estimating the expected cost and standard deviation for each machinery set. The only selection parameter that must be specified is the level of statistical significance used for identifying the least-cost sets. For lower significance levels, more machinery sets would tend to be least-cost because differences in long-run average costs would have to be larger to be statistically significant.

**Upper Confidence Limit**

The upper confidence limit (minimax) criterion involves calculating the maximum total cost expected for each machinery set at a designated level of statistical significance or confidence. The set with the lowest upper confidence limit or expected maximum cost is then chosen as the optimal set. The goal is to maximize the chances of survival of the business rather than minimize total machinery costs.

Figure 13 shows the sizes of the optimal machinery sets under this criterion at a 0.90 confidence level. At each acreage level, the standard deviation decreased as machinery size increased. At the smaller acreage levels, however, particularly from 100 to 400 acres, the mean increased enough to offset the decreasing standard deviation so that the smallest machinery set, the 4S equipment, had the lowest upper limit on total costs. At the larger acreage levels (500 and above), the timeliness costs for the smaller machinery sets increased, causing both the mean and standard deviation to increase, thus making the upper confidence limits for the small machinery sets much greater than for the large sets. The overall effect was for the size of the optimal machinery set to increase as the number of acres increased, just as when only total costs were considered.

At each level except 500 and 800 acres, the optimal set under the upper confidence limit criterion was also one of the least-cost sets so that the difference in average total costs or "risk premium" (difference between the cost of the least-cost and the optimal set) was not statistically significant. At the 500-acre level, the risk premium was $1.12 per acre, and at 800 acres it was $0.58 per acre. When the confidence level was raised to 0.99, slightly larger machinery sets were found to be optimal at the 300-, 600-, and 700-acre levels. The risk premiums were greater at this confidence level, but still ranged only from $0.00 to $2.41 per acre.

Choosing a machinery set by minimizing the worst possible result protects the farm business against a disastrous year. This procedure requires only an estimate of the mean and standard deviation for each machinery set, plus a designated level of confidence for estimating the upper limits for total machinery costs.
Maximum Affordable Cost

The upper confidence level criterion can be restructured so as to fix the maximum total machinery cost affordable and estimate the probability of exceeding it for each machinery set. At each acreage level, the set with the lowest probability is then chosen as the optimum.

By using the mean costs and standard deviations from Tables 8 and 14, it was found that, unless the maximum affordable cost is assumed to be close to the mean cost for a particular machinery set (within $5 to $10 per acre under the conditions assumed), the probability of exceeding it approaches zero or one. When this is true for most of the machinery sets at a particular acreage level, the information provided by calculating the probabilities is of little use. Most or all of the sets will be equally acceptable or unacceptable and will exceed the maximum affordable cost either in most years or not at all.

The degree to which weather risk should be considered in machinery selection depends on how much flexibility the operator has to deal with unfavorable suitable field day patterns. If additional hired workers or custom operators are readily available, or if the farmer's own crop labor hours can be extended, then choosing machinery on strictly a least-cost basis may be the most advisable strategy to follow. If, however, labor hours cannot be easily extended or extra machinery capacity acquired on a short-term basis, then risk reduction should be considered also.

The producer's financial position also is important. An operator with high cash flow commitments and (or) little unused borrowing capacity has more reason to guard against a high-cost year than an operator with more financial reserves. The upper confidence limit and maximum affordable cost criteria in particular emphasize avoiding one disastrous year.

The most practical methods of incorporating risk into the decision criteria are to choose the largest machinery set from among those estimated to be least cost, or to choose the set with the lowest maximum cost.

More detailed information from a broader and more representative sample of farmers is needed to more accurately test whether or not their machinery selection decisions really do correspond closely to that projected under a least-cost criterion. Information about farmers' attitudes towards risk, especially regarding the occurrence of fewer than normal suitable field days, and what measures are used to reduce this risk would facilitate a much better understanding of the decision-making process used in machinery selection.

Some aspects of the simulation model used to estimate machinery costs could be specified more accurately if more detailed farm-level data were available. Examples include marginal tax rates, possible short-run adjustments to the set of tillage operations carried out, and the effect of soil type on the number of suitable field days available. Other parameters, which were not tested but could be significant, are the hourly labor cost and adoption of "reduced" or "minimum" tillage practices.

In this study, all machinery cost components were summed and treated equally. Some types of costs, however, may have different implications for risk than others, such as cash versus noncash costs or indirect costs such as timeliness costs and income tax savings.

Consideration of only 10 possible machinery sets also placed some limitations on the usefulness of the information generated, particularly in two areas. One was in estimating the mean, variance and mean, semivariance frontiers, where only a partial set of points on each frontier could be identified. The other was in analyzing the effects that varying key parameters had on the least-cost sizes of different types of machines, such as tillage, planting, and harvesting implements. For these purposes, some type of optimizing model that can be varied parametrically might be useful, where many combinations of sizes of tractors, combines, and tillage machines could be specified at once.
APPENDIX A

1. Assumed yield loss due to late planting of corn or soybeans

\[ \text{PYL} = 0.0193 D^2 + 0.0986 D \]

where:

- \( \text{PYL} \) = planting yield loss, percent
- \( D \) = number of days from April 29 (corn) or May 9 (soybeans) to planting date, with \( D = 0 \) if planting occurs on or before April 29 (corn) or May 9 (soybeans)

2. Average assumed yield loss over the entire planting period, due to late planting of corn or soybeans

\[ \text{AYL} = 0.00643(d_2^3 - d_1^3) + 0.0493(d_2^2 - d_1^2) \]

where:

- \( \text{AYL} \) = average planting yield loss, percent
- \( d_2 \) = days after April 29 (corn) or May 9 (soybeans) on which planting was finished
- \( d_1 \) = days after April 29 (corn) or May 9 (soybeans) on which planting was started

3. Assumed yield loss due to late harvesting of corn

\[ \text{HYLC} = (0.306 \text{HC} - 0.167 \text{D} - 1.01)^{0.665} \]

where:

- \( \text{HYLC} \) = harvest yield loss, percent
- \( \text{HC} \) = date of harvesting corn, days after Oct. 1, with \( \text{HC} = 0 \) if harvesting occurs before Oct. 1
- \( \text{D} \) = date of corn planting, days after April 29, with \( \text{D} = 0 \) if planting occurs before April 29

4. Assumed yield loss due to late harvesting of soybeans

\[ \text{HYLS} = 1.25 H - 0.0125 (H \times D) - 20 \]

where:

- \( \text{HYLS} \) = harvest yield loss, percent
- \( H \) = date of harvesting soybeans, days after Oct. 1, with \( H = 0 \) if harvesting occurs before Oct. 1
- \( \text{D} \) = date of soybean planting, days after April 29, with \( \text{D} = 0 \) if planting occurs before April 29

5. Assumed moisture level at harvest for corn

\[ \text{MLC} = (7.3 + 0.2 \text{D}) e^{(0.186 - 0.0016 \text{D})(7.01 H)} \]

where:

- \( \text{MLC} \) = moisture level of corn in percent, \( \text{MLC} \geq 18.0 \)
- \( H \) = date of harvesting corn, days after Oct. 1, with \( H = 0 \) if harvesting occurs before Oct. 1
- \( \text{D} \) = date of corn planting, days after April 29, with \( \text{D} = 0 \) if planting occurs before April 29

REFERENCES


