LNC94-063

Paper

Appendix 1-a

REDUCED-COST BENEFITS FROM MULTIPLE CROP SYSTEMS[1]

by

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[1] Paper presented at American Agricultural Economics Association Meeting, San Diego, California, August 7-10, 1994.

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This material is based upon work supported by the U.S. Department of Agriculture under Agreement No. 43-3AEK-3-80075. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the view of the U.S. Department of Agriculture.

REDUCED-COST BENEFITS FROM MULTIPLE CROP SYSTEMS

Abstract

An integer programming model of machinery, labor, and crop selection was used to analyze reduced costs for diversified cropping arising from reduced timeliness pressure in critical time periods. The results showed large cost savings from multi cropping compared to single cropping. The model endogenized opportunity interest costs.

REDUCED-COST BENEFITS FROM MULTIPLE CROP SYSTEMS

Introduction

In cropping agriculture a number of potential economic benefits arise from growing multiple crops. If multiple cropping involves rotations, positive yield interactions among crops can increase gross returns compared to any crop grown singly. Also, with rotations, fewer inputs are sometimes required (such as fertilizer and insecticides), weed control costs may be reduced, and machine operating costs may be reduced because of better soil tilth. Whether in rotation or not, two other economic benefits can result from multiple crop systems. One is risk reduction resulting from diversification. The other is reduced labor and/or machinery ownership costs because of reduced labor and machine timeliness pressure in certain time periods. This last factor and its quantification is the focus of this paper.

Two factors are important in considering machinery cost impacts in multiple crop systems compared to single crop systems. For some multiple crop systems, more machines may be required simply because of more crops. For example, a grain harvesting head is required if soybeans are added to a corn system. Countering this, however, is that because each crop requires operations in a particular time period or "window," growing multiple crops may reduce timeliness pressure and may allow a smaller machinery set to be used. How significant these benefits are is largely unknown particularly for different crop mixes.

In considering this issue, machine ownership costs are the major cost reduction source which may result from crop diversification. However, labor cost reductions may also be important because labor and machinery are important substitutes and diversification may reduce labor requirements in the same way as machinery. In this analysis, machinery selection is selected simultaneously with the labor and crop mix (except where a particular crop is "forced").

How accurately ownership costs for machinery are estimated and incorporated into choice is obviously important to quantifying the above-described influences. Often machinery ownership costs are budgeted on an annual basis assuming a particular use per year thus defining the lifetime of the machine. Yet, in optimization models, the resulting actual use per year from model results may vary considerably from the use assumption used in constructing the cost creating a potentially serious bias problem. Whenever an objective function for an activity is output dependent, biased results may occur. Further, a fixed machine cost results in pressure for the model to use machines more per year and potentially affect the optimum machine set and crop mix. Here, machine ownership costs for depreciation, repairs, and interest on repairs are first developed on a per hour of use basis. Also, interest on investment varies with use per year because the replacement period is affected and thus the time period over which interest is charged. In this study a method is developed to linearly approximate that force so that interest on investment costs are not biased. A comparison of results is made to results when depreciation and interest on investment costs are constructed as per year costs (traditional) to test biases arising from that method.

The cost interactions resulting from crop diversification from reduced machinery and labor would not be expected to be identical across varying farm sizes. Also, the impact of one crop on another would be expected to be different if no other crop is present (first-crop impact) compared to if another is present (second-crop impact). Should there be significant cost interactions from multiple crop systems, some serious questions need to be raised about the manner in which single and multiple crop cost budgets are constructed. Further, there are other implications related to policy which would need consideration.

Objectives

The primary objectives of this paper are to 1) estimate reduced-cost machinery and labor benefits from multiple crop or diversified crop systems at various farm sizes and 2) to partition the above estimated cost benefits into second-crop and third-crop benefits.

Secondary objectives arise from the need for a correct specification of machine ownership costs in integer programming models. These are 3) to develop a method of incorporating a linear approximation to the cost of interest on investment such that model solutions do not result in machine use at variance with that use used in the cost estimation process. Given this bias-free procedure, the final objective is 4) to compare the degree of bias on model choices which result from the traditional method (assumed use per year) in budgeting depreciable assets.

General Procedure

The analysis proceeded in seven steps.

1. An integer programming model optimizing machinery, labor, and the crop mix was constructed for an eastern Nebraska setting. In particular six timeliness periods (two spring and four harvesting) were incorporated into the model with a number of machine sizes available for various machine types. Four crops could be selected but no yield interactions among crops were included.

2. Machine ownership costs for depreciation, repairs, and interest on repairs were constructed on a per hour of use basis. For interest on invested capital a procedure was developed to accurately reflect interest cost decreases per hour of use (increased cost in total) as use increases per year (fewer years of life).

3. For each of nine farm sizes, returns above costs (for costs not included in the model) for each crop were adjusted such that the solution objective function for complete specialization of each crop was zero.

4. The model was then optimized without crop constraints with objective functions above zero a result of multi crop cost benefits.

5. For one farm size, second-crop cost benefits were estimated for three crops by

forcing in one half of the first crop and one-half of the second crop. Next, third-crop cost benefits were estimated in a similar manner.

6. A second model was constructed for four farm sizes in which depreciation and interest on investment were estimated on an annual basis using alternative assumed hours of use per year (years of life) and organization and objective functions from the above model estimated.

7. The resource and crop results from the traditional model in (6) were forced into the initial model described in (4) to determine the bias of models using costs of depreciable assets estimated in the traditional manner.

Intensity Based Vs. Assumed Hour Based Costs For Depreciable Assets

As previously mentioned, in optimization models where the objective function for an input changes as the input use changes, a problem can occur unless a process exists to correctly specify the linkage of the cost to use. If not, the resultant input use may vary considerably from that use originally assumed in developing the cost. In such a case little confidence can be placed in the optimization process.

In this problem there are four aspects of machine ownership costs which require attention to maintain a bias-free model. These are 1) depreciation, 2) repairs, 3) interest on repairs, and 4) interest on investment.

Depreciation

Use is generally regarded as highly related to a machine's remaining value. While remaining value functions may not be linear with use (usually perceived as convex) such as assumption is not unrealistic for estimating an average cost per hour over a machine's lifetime. Thus, original costs less salvage value are divided by lifetime hours of use.

Repairs

Cumulative repair function estimates are published for various machine classes (ASAE). While these are not linear, a linear assumption is not unrealistic because only an average is desired in annual-based models. Thus, cumulative repair costs are divided by hours of use.

Interest on Repairs

Assuming repairs are paid at year's end and assuming the repair function is linear rather than convex, interest on repairs is simply the annual interest cost on annual average repairs. Another way of viewing this is that for any use per year, interest on repair costs are a constant series over the life of the machine. Thus, this cost aspect can simply be placed in a per hour of use basis.

Interest on Investment

Assuming machine life (H) in hours and initial machine cost (V_o), depreciation (d) on an hourly basis is

1) $d = (V_o - SV)/H$ where SV represents salvage value

The depreciation cost per year is

2) $D = dX$ where X is the hours of use per year

In capital budgeting the annualized interest charge can be shown to be approximated by

3) $$I = \frac{(V_o - SV + D)}{2} i$$

where i is the annual interest rate. Substituting (2) into (3) one obtains

4) $$I_D = i\frac{(V_o - SV)}{2} + \frac{id}{2} X$$

The interest on investment cost consists of a fixed component (the first term) which is independent of the intensity of use and a variable component which increases with use (X). Thus, the economic pressure for greater machine use due to the resultant reduction of average interest costs is properly modelled if a linear approximation to the remaining value function is satisfactory.

Setting and Model Detail

Eastern Nebraska is the setting for the analysis. Four crops were considered, corn, soybeans, grain sorghum, and oats. For each crop, machinery operations were specified in six or less critical time periods. These time periods included two spring tillage and planting periods, an oat harvesting period, and early, medium, and late fall harvesting periods. Historical weather records were used to estimate the average number of 10-hour days available for field work for each period. For this analysis it was assumed that because of risk only 75 percent of those days would be available providing more confidence that machine capacity will be adequate.

In 1993 a machinery dealer provided new costs and estimates of field performance for three tractors, three disks, three field cultivators, two planters, two grain drills, and three combines - each with corn and grain head alternatives. These were included in the model as integer choices. Model costs were estimated for these as previously described. An integer variable was included for labor in one-half person units. A $14,000 charge for each unit was included. Land was rented at 58 dollars per acre and forced in for specified farm sizes. Machine operating costs were included in machine operating variables. Other costs such as seed, fertilizer, and pesticides unique to each crop were subtracted from gross returns for each crop. Thus, all costs were estimated and included in the model. Commodity programs were not examined in the model.

For a given farm size the model selected the optimum mix of crops, machinery set, and labor unit. As discussed previously, two input capacity forces had particular impact on resource (and output) decisions. These were set-up charges on the integer labor variable and the fixed charge component for machine selection due to interest on investment. Both lead to pressures to utilize these variables to full capacity.

Results

The analysis is presented in two parts - the first relating to objectives (1) and (2) and the second related to objectives (3) and (4).

Cost Benefits From Diversification

In Table 1 the benefits of multi crop systems are presented by farm size. Because the objective function for full specialization of each crop was set at zero, the objective functions presented represent multi crop benefits. At 160 acres the benefit is nearly $55/acre for all acres. At 1600 acres this benefit is reduced to approximately $18/acre. For other farm sizes the benefits per acre lie between these, however they vary considerably. These benefits are rather dramatic. The assignment of these benefits cannot be assigned to any crop of the mix. This is a jointness setting and the assignment of benefits has long been recognized as theoretically impossible.

It should be pointed out that soybeans performed almost identically to grain sorghum, thus results would be nearly the same if soybeans replaced grain sorghum whenever grain sorghum entered the solution. The optimum relative crop mix varies rather dramatically from one farm size to another. In some cases, for example 320 acres, these benefits arise with less than one-fifth of the acreage in a second crop. Obviously a relatively small level of diversification can dramatically reduce timeliness pressure in critical periods.

At larger farm sizes larger machinery and more labor units were predictably used. Interesting machinery-labor substitutions occurred. For example, from 320 to 480 acres more labor but smaller machinery was optimal. These choices are not separate from output mix changes.

In Table 2 for a 960 acre farm, the results of forcing 1) proportional acreages of the second crop to the first, and 2) the third crop to the first and second are presented. The first-crop benefits are greatest for corn to oats (or oats to corn) and least (zero) for soybeans to grain sorghum. Third crop effects are positive or zero depending on the preceding two crops. Third crop effects required the first two crop levels to be reduced from 320 acres to 240 acres each. It can be noted that a simple four crop system (160 acres of each) resulted in a $11,213 benefit over any single crop grown at 640 acres. Except for soybeans to grain sorghum, first-crop effects are large ($9,230 to $12,060). These estimates, of course, are at particular crop mix levels.

Considering these results in the light of commonly grown cropping systems, it must be remembered that this analysis was directed only at cost benefits. No crop yield interactions were included. Further, the gross returns for each crop were set at levels such that multi cropping benefits could be quantified. These internal cost benefits exist regardless of what gross returns would be used in an overall optimization analysis.

Model Bias From Assumed Use Costs of Depreciable Assets

For this section, specified returns over operating costs for each crop were estimated and used rather than the previously described returns. These are 175, 160, 155, and 120 dollars per acre for corn, soybeans, grain sorghum, and oats respectively. For the four farm sizes the model's objective functions under use-based cost budgeting of depreciable assets were $-1,888, $6,807, $12,555, and $22,300. These results should be viewed as parallel to the results of Table 1 except the objective functions for each crop are slightly different. Objective functions using various assumed machine use per year (traditional) are presented as actual.

The actual objective functions for the traditional models are always less for the 320 acre farm, less at 30-year and less budgeting periods for the 640 acre farm, and less at a 20-year period or less for the $60 acre and 1280 acre farms. The results suggest that if one is interested only in the performance of traditional or assumed-use models with respect to the overall objective function, long budgeting periods are required. While this provides one perspective of the effect of traditional budgeting, a more appropriate perspective is where these traditional model solutions are forced through the use-based model. By so doing, a perspective of the degree of model bias can be seen. The objective functions from this process are termed adjusted and can be compared to the actual objective functions of the use-based models. It can be noted that in only one case (1280 acres and a forty year budgeting period) is there no significant bias to traditional cost budgeting.

The results from this analysis suggest that if traditional machinery ownership costs are to be used in optimization models, rather long budgeting periods are necessary to approximate accurate model objective functions. Yet organizational biases from models using traditional cost budgets are so great that little confidence should be placed on their accuracy, regardless if one can secure an accurate objective function.

Conclusions

In a 1993 survey of Nebraska agricultural producers (reference omitted) it was found that diversified producers have significantly smaller machinery compared to nondiversified farmers. The research from the analysis in this paper is from a different perspective but is entirely consistent with those survey findings. The benefits of multi crop systems in midwestern agriculture resulting from reduced machinery and labor costs are estimated to range from \$18 to \$55 per acre for farm sizes of 80 to 1600 acres. While the largest part of this increase arose from two-crop interactions, in some cases third-crop interactions yielded sizable cost benefits. In estimating these impacts an effort was made to construct machinery ownership costs such that they would perform in a bias-free manner (machine use under model results consistent with that use used to budget costs). To do this, except for interest on investment, this involved a use-based cost expression. For interest on investment, a two part expression was developed (a fixed and variable component) to accurately reflect costs. Testing alternative assumed-use models against the model used in this analysis demonstrated considerable bias of assumed-use budgeting.

The implication of this analysis is that system benefits are very important in cropping agriculture. Thus, either from a farm management standpoint or from a policy standpoint, much more attention needs to be directed to system economics as opposed to single crop economics. It also demonstrates that cost of production for a particular crop commodity becomes an elusive concept when inputs can be used at different points in time within a production period to produce two or more outputs.

Table 1. Positive Objective Functions, Crop Mix, and Machinery-Labor Choices for Optimum Solutions of Nine Farm Sizes.

Acreage	Positive[1] Objective Function $	Crop[2] (acres)	Machine-Labor[3]
160	8,760	C 127 GS 33	T3; D3; F3; P2; C3, c, g; 1L
320	9,199	GS 259 O 61	T3; D3; F3; P2; Dr1; C3, g; 1L
480	8,758	C 365 O 115	T2; D2; F2; P2; Dr2; C3, c, g; 2L
640	12,370	C 234 GS 236 O 169	T3; D3; F3; P2; Dr1; C3, c, g; 2L
800	18,800	C 548 O 252	2T2; D2; F2; P2; Dr2; C3, c, g; 3L
960	19,842	C 572 GS 5 O 382	2T3; D3; F3; P2; Dr1, Dr2, C3, c, g; 3L
1280	22,939	C 763 GS 5 O 512	2T3; D3; F3, P2; Dr1, Dr2; C3, c, g; 4L
1440	27,113	C 688 GS 752	T2, 2T3; D2, D3; F3; 2P2; C3, c, g; 5L
1600	28,402	C 763 GS 55 O 781	T1, 2T3; D3; F1, F3, P2, Dr1, Dr2; C3, c, g; 5L

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[1] Zero returns occur when each crop is grown alone at that acreage. Thus, these returns are positive interactions.

[2] C = corn, GS = grain sorghum, O = oats.

[3] Respectively this should be interpreted as follows: T = tractor, D = disk, F = field cultivator, P = planter, Dr = grain drill, C = Combine with c = corn head and g = grain head, L = labor in one-half person units. Sizes follow the designation except for Drills where Dr1 is a 25 ft. drill and Dr2 is a no-till drill. A number preceding the designation refers to multiple units. Sizes of tractors are 85, 145, and 200 hp., disks 10, 21, and 27 ft., planter 4R and 8R, field Cultivator 15, 24, and 34 ft., and combines 4R, 6R, and 8R.

Table 2. Returns ($) Above Single Crop Returns For a 640 Acre Farm From Forced Proportional Cropping Under All Combinations of Two and Three Crops for the 640 Acre Farm Size.[1]

Initial Crop	Second Crop		Third Crop	
Corn[3]	Oats	12,060	Soybeans (Grain Sorghum)[2]	12,370
	Soybeans (Grain Sorghum)	9,230	Oats	12,370
			Grain Sorghum (Soybeans)	9,230
Oats	Corn	12,060	Soybeans (Grain Sorghum)	12,370
	Soybeans (Grain Sorghum)	9,750	Corn	12,370
			Grain Sorghum (Soybeans)	9,750
Soybeans (Grain Sorghum)	Corn	9,230	Oats	12,370
			Grain Sorghum (Soybeans)	9,230
	Oats	9,750	Corn	12,370
			Grain Sorghum (Soybeans)	9,750

[1] 160 acres of all four crops results in a comparable objective function of $11,213.

[2] The results for grain sorghum and soybeans are equal.

[3] The objective function for each crop grown singly for 640 acres is zero.

Table 3. Actual Objective Functions for Four Farm Sizes Using a Use-Based Model and Assumed-Use Models of Various Machine Life and Adjusted Objective Functions Where the Crop, Machine, and Labor Results of the Assumed-Use Models are Forced Through the Use-Based Model.[1]

			Assumed-Use Machinery Costs				
Farm Size	Objective Function	Use Based	Five Year	Ten Year	Twenty Year	Thirty Year	Forty Year
320	Actual	-1,888	-71,844	-35,466	-17,276	-9,790	-5,233
	Adjusted	-1,888	-9,747	-9,747	-9,747	-3,077	-3,077
640	Actual	6,807	-81,502	-31,496	-4,025	5,147	9,704
	Adjusted	6,807	-10,281	4,710	4,710	4,710	4,710
960	Actual	12,555	-79,048	-23,912	5,743	15,631	20,572
	Adjusted	12,555	-7,609	8,723	8,723	8,723	8,723
1280	Actual	22,300	-94,924	-22,614	14,432	26,799	33,082
	Adjusted	22,300	6,711	16,587	16,587	16,587	22,300

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[1] Assuming the following respective returns over operating costs, corn $175, soybeans $160, grain sorghum $155, and oats $120.

References

ASAE, ASAE Standards 1992. Standards, Engineering Practices and Data adopted by the American Society of Agricultural Engineers. St. Joseph, Missouri. 1992.