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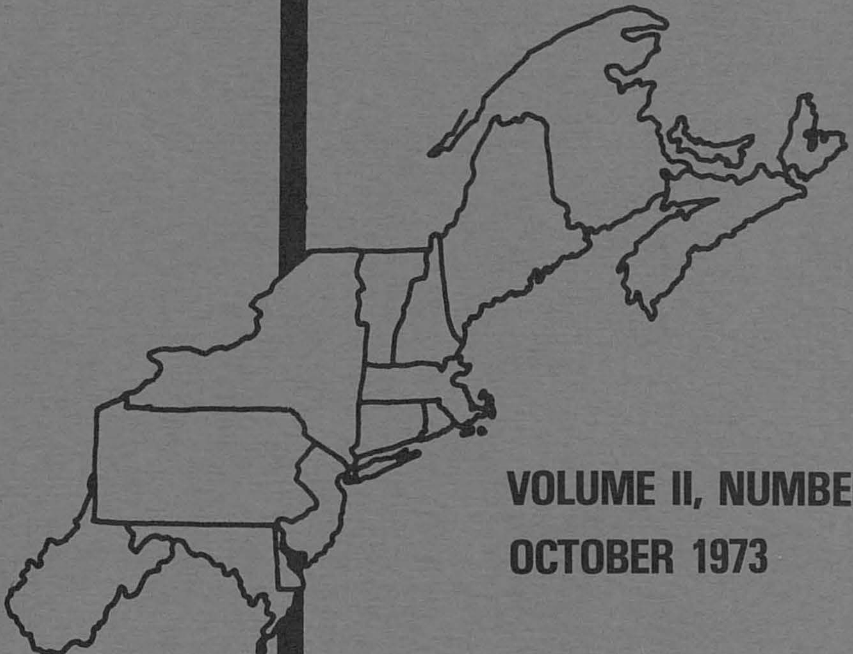

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OPTIMUM FARM FIELD MACHINERY SYSTEMS WITH APPLICATION TO FARM PLANNING

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Field machinery is an integral part of a farm that produces crops and has to be taken into consideration in farm planning. This machinery presents the farm manager or analyst with problems that differ from other working or fixed farm resources. The reason is that field machinery consists of a set of machines which is an interdependent system, particularly in terms of size, performance and cost factors related to capacity. Maintaining control over the problems of matching machines for size or power and properly timing each field operation by crop or rotation is a difficult and time consuming task with current methods.

The purpose of this paper is to illustrate the application of a least-cost (optimum) machinery system algorithm developed by Hunt [2] to the problem of computing machinery cost and labor data for farm planning. The algorithm not only solves the machinery system problem, but it also provides machinery cost and labor data that are based on machine investment requirements, performance data, and field crop operations cost. In addition, any discrepancies between the cropping program of the optimum farm plan and the cropping program used in the optimum machinery system algorithm is readily apparent. When these discrepancies occur, an adjusted optimum machinery system can be developed using the cropping program of the optimum farm plan as its basis.

Optimum machinery system algorithm

The algorithm defined by Hunt [2, 3, 4] is still undergoing change. A detailed description of data requirements and computational procedures is contained in the above references and thus need not be presented in detail. However, a few general comments are needed.

The data requirements of the algorithm include selected agronomic, engineering and economic data needed to define an optimum machinery system for a specific cropping program. In brief, the following data are required.

1. The cropping program must be defined to include the list of crops in the cropping program, crop acreage of each crop and gross receipts per acre for each crop.
2. The cultural practices and method of harvesting each crop of the cropping program must be specified. For example, the corn silage crop may include plowing, discing twice, harrowing, planting, cultivating, spraying and harvesting.
3. A list of the machines required by the cropping program, cultural practices and method of harvesting must be specified. Additional data for the machines include field efficiency, machine speed, machine draft, maximum working width available, service life, trade-in age, repair and maintenance cost, tractor or self-propelled powered, and investment per foot of working width [1]. Investment requirements for tractors are entered as dollars per horsepower.
4. Cultural practices and method of harvesting are combined with machinery list to define what may be called operational data. For example, plowing 25 acres of corn ground and plowing 20 acres of alfalfa ground would be two separate operations.
5. The algorithm provides for the consideration of self-propelled powered machines with attachments as an alternative to tractor powered pull-type machines, auxiliary engines as an alternative to the tractor providing all power to the machine, and custom hiring as an alternative to owning field machinery.
6. Machine and tractor labor cost per hour, where applicable, are included.
7. A minimum initial estimated horsepower requirement for the farm must be provided along with a horsepower increment. The horsepower increment is used to increase the initial estimated horsepower requirement 36 increments. (Hereafter, these increments will be referred to as incremental horsepower levels.) The algorithm computes a machinery system for each of the 36 incremental horsepower levels in search of the optimum machinery system. (Hunt's algorithm of 9 increments was increased to 36 to explore a wider range of horsepower levels.)
8. The maximum horsepower per tractor desired or available in the market must be specified.

Now a few comments regarding procedure. The algorithm assumes a long-run planning horizon; thus, all costs are variable. Overhead cost, except repair and maintenance cost, are distributed on a basis of per foot of width for machines and per horsepower for tractors. Labor cost is included in total annual system cost. Fuel and oil costs are computed as a function of horsepower requirements; and repair and maintenance costs are computed as a function of time and initial investment, which is the normal procedure used by agricultural engineers.

Linear assumptions are made regarding all costs. Non-linear functions, particularly with regard to investment per foot of working width or per horsepower unit would be desirable and could be added to the algorithm.

The algorithm will handle power requirements and labor requirements to transport and process crops. In the study described in this paper, these requirements were handled external to the algorithm.

Only direct production field labor was considered. Thus, overhead or non-direct production labor requirements, such removing machinery to the field or down-time in the field, were accounted for in the study in areas other than the optimum field machinery algorithm

An annual cost function is computed by the algorithm for each machine with width as the independent variable. The optimum width of a machine is defined as the lowest point on the annual cost function. If the power requirement of a machine at optimum width exceeds the incremental horsepower level for the farm, then width is re-computed to match the incremental horsepower level under consideration.

The maximum horsepower per tractor available in the market and the incremental horsepower level of the farm are used in computing the number of tractors required in total and in particular for each field operation. For example, if the horsepower required by a machine (plowing corn ground) exceeds the maximum horsepower per tractor available in the market but is less than the incremental horsepower level on the farm, then the number of tractors required in excess of one is computed. Machine numbers are adjusted accordingly.

The optimum working width computed for each machine will probably not be compatible with widths available in the market or with width of other machines in the system where compatible widths are desired. A small change in annual cost for a machine is defined for the purpose of computing a range in width about the optimum. This range provides the latitude needed to describe a system of machines with widths that are available and compatible.

A cost that is equivalent to insuring against loss of product value resulting from improperly timing a field operation, called timeliness cost,1/is computed. In other words, it is a penalty cost of doing an operation at other than the optimum time. This cost, at present, is not highly defined; nevertheless, it is included as a recognized cost of growing crops.

Timeliness cost (C) is a function of a timeliness factor (T), gross crop value per acre (V), number of annual crop acres for the crop in question (A) and the number of times that an operation is divided for timeliness (D). As used in this paper, the timeliness factor represents a reduction in crop value for each hour of operation required to complete a particular operation outside the optimum time

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1/The term timeliness cost is used in the literature; but, perhaps a more descriptive term would be untimely cost.

period. Since the value of a crop is determined at harvest, timeliness cost is applicable for all operations that affect the harvested value of a crop. Thus, if a crop can be harvested at three points in time or three optimum time periods, for example, then in general the timeliness cost of all operations leading up to harvest could be divided three times for timeliness.

Where an operation is divided only once for timeliness (D=1), C = TVA. However, in the case of baling alfalfa hay where three cuttings are made, the baling operation is divided three times for timeliness; thus C = TVA/3. In effect including timeliness cost in the algorithm tends to increase the optimum size of a machine for a given operation. To illustrate the calculation of timeliness cost (C) per hour of operation for baling hay, let T = .001/hr., V = 200/acre, A = 25 acres and D = 3. In this example C = $1.67.

Application

The revised algorithm was used to determine optimum machinery systems in a study of large dairy farms [5]. The machinery list used in the study is shown in Table 1. Machinery systems were determined for four farm sizes (50, 100, 200 and 400 acres) and three crop rotations (continuous corn silage, corn silage/alfalfa hay, and corn silage/alfalfa haylage).

An optimum system was determined for each cropping program by farm size: a total of 12 systems. To define each of the 12 systems a range in incremental horsepower levels per farm from 15 to 540 horsepower at 15 horsepower increments was explored to locate the optimum system. The total annual cost per acre for each combination of four farm sizes, three cropping programs and alternative machinery systems is shown in Table 2.

Machinery systems

Alternative machinery systems were studied for each crop rotation by farm size listed above. The algorithm was used to evaluate alternative machines within each system as well as to determine the global optimum system given the alternative being considered.

PTO pull-type forage harvesters rather than self-propelled forage harvesters were included in the optimum machinery systems for the continuous corn silage rotation by farm size (See Tables 1 and 2). Plowing and discing ground were the primary determinants of horsepower requirements for this system; thus, it was more economical to use this available tractor horsepower to pull forage harvesters rather than use self-propelled harvesters and have idle available horsepower. The machinery system for continuous corn silage is shown in Table 3.

Table 1
Machinery Systems for Corn Silage Alfalfa Haylage and Alfalfa Hay

	Field Crops		
	Corn	Alfalfa	
Machines	Silage	Haylage	Hay
Moldboard Plow	X	X	X
Disc Harrow	X	X	X
Spring Tooth Harrow	X	X	X
Cultipacker		X	X
Row Planter	X		
Seeder		X	X
Sprayer	X	X	X
Row Cultivator	X		
Mower		X	X[c]
Conditioner			X[c]
PTO Mower-Conditioner			X[c]
SP Mower-Conditioner			X[c]
Rake		X	X
PTO Baler w/Thrower			X
PTO Silage Harvester	X[a]		
PTO Haylage Harvester		X[b]	
SP Haylage Harvester		X[b]	
SP Silage Harvester	X[a]		

a/ Alternative forage harvesters for corn silage.

b/ Alternative forage harvesters for alfalfa haylage.

c/ Alternative mowers and conditioners for alfalfa hay.

PTO pull-type and self-propelled forage harvesters were considered as alternative harvesting methods for the corn silage/alfalfa haylage rotation by farm size (See Tables 1 and 2). The PTO pull-type harvester was the least-cost method on the 100 acre farm and the self-propelled harvester was the least-cost method on the 400 acre farm as shown in Table 2. The findings were different than those reported for harvesting continuous corn silage. The base self-propelled unit could be used for harvesting both silage and haylage with a relatively low additional investment in a haylage cutting head. The acreages on 100 acre farms were not sufficiently large for the self-propelled harvester to compete with the PTO harvester; however, the difference in annual cost per acre was smaller than the difference reported for the continuous corn silage rotation on the 100 and 400 acre farms (See Table 2).

Table 2
Total Annual Cost Per Acre for Alternative
Field Machinery Systems by Rotation and Acreage

Rotation[a]	Code[b]	Crop Land Acres			
		50	100	200	400
		$	$	$	$
CCCCCC	A	45[c]	36	33	32
CCCCCC	B	52	41	37	36
CCCAAA	AC	57	45	39	36
CCCAAA	BC	60	48	41	35
CCCHHH	ACD	61	51	45	43
CCCHHH	BCD	65	55	48	44
CCCHHH	AE	64	54	47	44
CCCHHH	AF	63	52	45	43

a/ CCCCCC = continuous corn silage, CCCAAA = corn silage/alfalfa haylage, CCCHHH = corn silage/alfalfa hay

b/ A = PTO forage harvester, B = self-propelled forage harvester
C = PTO mower, D = PTO conditioner, E = PTO mower-conditioner
F = self-propelled mower-conditioner

c/ Fixed and variable annual cost per acre for alternative field machinery systems used in the analysis.

Several alternative machinery systems were considered with the corn silage/alfalfa hay rotation by farm size (See Tables 1 and 2). These included PTO pull-type and self-propelled mower-conditioners and individual PTO pull-type mowers and conditioners. Optimum systems included the PTO harvester, and separate mower and conditioner rather than the other available alternative (See Table 3). Again, this choice among forage harvesting alternatives was consistent with the choice made with the continuous corn silage rotation.

Field machine size

The algorithm discussed in this paper, at its present stage of development, permits the calculation of a range in size about the optimum width for each machine over which the optimum system criteria are applicable. The machinery systems shown in Table 3 were specified using the range limits as a guide.

Table 3

Machine Systems for Growing a Continuous Corn Silage, Corn Silage/Alfalfa Haylage and Corn Silage/Alfalfa Hay, Rotation on 100 and 400 Acres of Land

		Continuous Corn Silage				Corn Silage/ Alfalfa/Haylage				Corn Silage/ Alfalfa/Hay			
		100 Acres		400 Acres		100 Acres		400 Acres		100 Acres		400 Acres	
Equipment	Size Unit	Quan.	Size	Quan.	Size	Quan.	Size	Quan,	Size	Quan.	Size	Quan.	Size
Tractor 1	hp	1	40	2	55	1	40	1	45	1	30	3	75
Tractor 2	hp							1	50				
Moldborad Plow	in	1	28	2	48	1	28	2	42	1	28	3	70
Disc Harrow	ft	1	10	2	12	1	10	2	10	1	6	3	14
Spring Tooth Harrow	ft	1	14	2	20	1	14	2	18	1	10	3	24
Cultipacker	ft					1	8	1	10	1	6	1	10
Row Planter	row	1	6	2	6	1	4	2	6	1	4	2	6
Alfalfa Seeder	ft					1	6	1	10	1	6	1	10
Sprayer	ft	1	24	2	28	1	28	2	28	1	28	3	28
Row Cultivator	row	1	6	2	6	1	4	2	6	1	4	2	6
Mower	ft					1	7	2	7	1	7	3	7
Conditioner	ft									1	9	3	9
Mower-Conditioner													
Rake	ft					1	9	2	9	1	9	3	9
Baler	ft									1	9	3	9
Forage Harvester													
Base Unit	ea	1[a]		2[a]		1[a]		1[b]		1[a]		2[a]	
Haylage Head	ft					1	6	1	16				
Silage Head	row	1	1	2	2	1	1	1	3	1	1	2	2
Forage Wagon	ton	2	6	12	6	2	6	7	6	2	6	7	6
Hay Wagon	ton									2	4	4	4

a/ PTO powered

b/ Self-propelled

To illustrate the job of specifying the size of each machine shown in Table 3 from the output provided by the algorithm, the row planter and cultivator will be used for the 400 acre farm with the corn silage/alfalfa hay rotation. The computed range in widths was 24.6 - 34.6 feet for the planter and 31.6 - 45.1 feet for the cultivator. Thus, two 6-row cultivators were included in the system. With 30 inch rows, the combined width for each two planters and cultivators was 30 feet. The planter is within the computed range; but the cultivator is slightly below the optimum machine width range.

Machinery specified according to size can be determined from each optimum machinery system. This step can be made whenever size specifications are desired. However, in applications where optimum machinery systems are computed in conjunction with optimum farm plans, it would only be necessary to make size specifications when size is a part of the desired results.

Long-run cost functions

A positive relationship exists between horsepower and acreage with respect to the optimum system; annual cost per acre is a function of horsepower and acreage. These data are shown in Table 4 for the corn silage/alfalfa hay machinery systems shown in Table 3.

The annual cost envelope for this function shows a 30 horsepower system as the optimum system for 50 and 100 acres, a 120 horsepower system for 200 acres, and 225 horsepower for 400 acres. It is suspected that with additional observations an envelope would result that is rather flat. Since the annual cost envelope is rather flat with respect to acres, an optimum farm plan using the assumed linear estimates of annual operating cost for a given cropping program would be applicable over a range in farm size. At least, one can determine the extent that the initial cost estimates deviate from those that would be applicable for the cropping program of the optimum farm plan. If the deviation is not within an acceptable tolerance range, then another field machinery system can be determined that yields cost estimates within the tolerance range.

Annual per acre cost functions with horsepower held constant and acreage varied have a "U" shape. Cost functions with acreage held constant and horsepower varied show the typical saw-tooth effect of adding a new tractor to the machinery system. However, these functions, in total, have a "U" shaped appearance. (See Table 4).

Other information

Other information, with further program development, can be made available on a routine basis. This information includes per acre machinery cost and direct labor requirements by crop. These data can be used to evaluate the optimum machinery system by making comparison with like data from other sources.

Table 4
Annual Cost Per Acre by Horsepower and
Acreage for Corn Silage/Alfalfa Rotation.[a]

	Acres			
hp	50	100	200	400
	$	$	$	$
30	62	51	51	63
60	72	56	52	62
90	82	62	56	64
120	86	60	46	45
150	94	64	48	45
180		68	51	46
210		72	50	43
240		75	52	43
270		79	54	44

Additional research

Risk and uncertainty are not directly recognized in computing an optimum machinery system. They are indirectly recognized through timeliness cost and machinery performance data. Additional research in the area of the timeliness factor would improve the algorithm.

Summary

Machinery systems computed in the manner described in this paper take into consideration power and machine size requirements in conjunction with machine performance. Optimum systems are computed for specific cropping programs, machines and field operations. Timeliness costs are included to add a cost factor equivalent to insuring against loss in product value due to untimely operations.

Present experience with the method indicates that the annual per acre cost function is relatively flat provided that available power and machinery size are matched to cropping program requirements. Thus, linear assumptions with respect to annual operating cost for a specified machine system can be used within limits without adversely affecting the acceptability of optimum farm plans. Should the optimum farm plan result in a cropping program with significantly different annual operating cost another machinery system can be computed for the cropping program in the farm plan.

A farm machinery analysis program of the type described in this paper can provide cost and labor data of the type used in farm planning. These data would be based upon acceptable agricultural engineering standards.

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