OPTIMAL MANAGEMENT STRATEGIES FOR ALFALFA PRODUCTION WITHIN A TOTAL FARM PLAN

David L. Debertin and Angelos Pagoulatos

Abstract

This paper examines the impacts of alternative management strategies for the production of alfalfa within the context of a total farm plan. A linear programming model is used to represent a 600-acre farm which can grow either grain crops or alfalfa. Alfalfa production competes with the grain crops for available land, labor, machinery, and field time over a calendar of tillage, planting, cutting, spraying, and harvesting activities. The profitability of an acre of alfalfa and the contribution of alfalfa to net returns for the farm varies quite widely depending on the particular alfalfa management strategy selected.

Key words: alfalfa, management, optimization, linear programming, total farm plan, production.

This paper measures the impacts of alternative management strategies for alfalfa production within a total farm planning model. The total farm planning model is used to measure the profitability of alternative management recommendations made by agronomists and others concerned with forage production. Alfalfa yields are greatly influenced by the particular management strategy implemented by the farmer, particularly the extent to which weeds and insects are controlled over the life of the stand. Second, forage crops such as alfalfa are important cash crops for some farmers, but are often only a secondary source of income. Available labor for implementing management practices for alfalfa must normally compete with uses in other enterprises that make contributions to the profitability of the total farm firm. Also, alfalfa is not a crop for which high tonnage can usually be obtained without much attention by the farm manager.

A detailed linear programming model of a 600-acre farm was used to assess impacts on profitability to the total farm firm of alternative management strategies in the production of alfalfa in competition with grain crops. The primary emphasis within the model is the calendar of events surrounding the production of corn, soybeans, and alfalfa. The model separates the events occurring in the production of each crop into periods as short as 9 days, and allocates labor, field days, tractor, tillage, and harvest equipment to specific crop enterprises within each period based on the net returns to the entire farm. The model used in this study was a modification of an earlier model that had been used by agricultural economists in working with corn and soybean farmers, but did not allow for forage production (Debertin et al., 1980). That model was modified for Kentucky conditions from a model developed in the 1960's at Purdue, and extensively used in Indiana for many years as the basis for a continuing extension education program in farm management (Debertin et al., 1981; Brink et al.).

Agricultural economists have recently become increasingly concerned with the comparative profitability of alternative strategies dealing specifically with management options related to pest control in forages and in other crops. Numerous "partial equilibrium" or "single commodity" research efforts have been directed toward specifying the management strategy that will result in the greatest profitability of the specific enterprise. Regev et al. used optimal control theory in an effort to identify a specific strategy for maximizing profits for alfalfa in the control of alfalfa weevils as a common property pest. Shoemaker used a multivariable dynamic optimization model to identify a strategy for the control of alfalfa weevils in which specific assumptions were made with respect to alfalfa prices and yields. Reichelderfer and Bender simulated plant/pest interaction and evaluated alternative pest control methods

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for Mexican bean beetles. However, the profitability of alternative management strategies for a specific crop cannot be fully evaluated except relative to the profitability of the total farm firm.

MODIFICATIONS FOR ALFALFA WITHIN THE TOTAL PLAN

The quality of alfalfa depends on soil fertility, the fertilization program, the degree of weed and insect control, rainfall and temperature patterns, and the timing of cutting. The variation in alfalfa quality can be extreme and prices paid for alfalfa may reflect this variation. At the same time, the marketing of alfalfa is not nearly as well organized as it is for the major grain crops. For example, the price discovery functions of the boards of trade or grain exchanges are not present. While alfalfa is sometimes shipped great distances, the bulkiness of the product means that markets, for the most part, will be localized and prices will be greatly impacted by the local supply/demand situation at any point in time.

To further complicate matters, the amount of each quality produced is a function of the specific set of management strategies implemented by the farmer. For example, a short delay in cutting could substantially reduce the hay quality. The thoroughbred horse industry of Central Kentucky provides a unique illustration of the linkages that exist between supply, demand, and quality. Alfalfa hay of the highest quality is much in demand as feed for expensive race horses. Local alfalfa of sufficient quality is not always available for the discriminating market. Much of this alfalfa is trucked in from northern Ohio at prices as high as $250 dollars per ton. The approach used in this analysis was to define a vector of three prices reflecting alternative quality grades for alfalfa, including a separate quality grade suitable for the race horses.

The machinery complement and land also present a number of problems. Certain machinery items (such as certain tractors) may be suitable for both alfalfa and grain production, while other machinery may be specific to alfalfa or to grain production. The model takes this into account. Land suitable for the growth of grain crops should also be suited for the growth of alfalfa, but some land not suited for grain crop production may be suited for alfalfa. Thus, the land variable is broken into two subcategories.

Finally, many herbicides and insecticides are unique to each crop, but alfalfa competes with grain crops for dollars available for the purchase of herbicides and insecticides. A fertilization program for alfalfa should be substantially different than for corn, but more like soybeans, since both plants are legumes. Only small amounts of nitrogen need be applied. Liming is more important than for most grain crops, since alfalfa is particularly sensitive to acid soils.

A CONCEPTUAL FRAMEWORK

The strategies available to a farmer with respect to the management of alfalfa and other crops can be represented by an array of options. Suppose, for example, that a farmer uses three categories of inputs in the production of alfalfa, wheat, corn, and soybeans. The three categories of inputs are "fixed" assets (F), "variable" assets (A), and time-related inputs such as labor, machinery time, and good field days (T). Components of conceptual model may be represented as follows.

i = the time periods involved in the production of grain or forage ($i=1,\ldots,q$). The calendar of events is broken into land preparation, planting, post planting, and harvesting activities for grain production and into cutting and other haymaking activities for alfalfa production. Time periods during crucial planting, cutting, and harvesting activities are as short as 9 days. The calendar includes 17 separate periods ($q=17$) so some periods are considerably longer than 9 days. Grain planting periods are usually 9 days long, while harvest periods are usually 2 to 3 weeks long.

k = activities related to grain production ($k=1,\ldots,g$) or alfalfa production ($k=g+1,\ldots,p$). A separate activity is defined for each possible combination for grain planting and harvesting and for each alfalfa management strategy. Wheat-soybeans double crop activities are treated separately from the corn and soybeans single crop activities. Alternative alfalfa production strategies each differ considerably with respect to labor, machinery, and good field time requirements within each period of the calendar.

j = each of the fixed factors involved in the production of grain or alfalfa $(j=1,\ldots,n)$ where j refers to fixed factors such as the availability of land, machinery, and tractors. The farm includes 500 acres of land suitable for corn, soybean, or alfalfa production and initially has available one 120 horsepower tractor, a combine suitable for the corn and soybean harvest, and a complement of haymaking equipment including two smaller tractors and equipment suitable for haymaking.

m = each of the variable factors used in the production of grain or alfalfa $(m=1,\ldots,h)$. These include inputs such as herbicides, insecticides, and fertilizers. For corn and soybean production, a base value was selected to represent the costs for each of these input categories. Alternative alfalfa management strategies differ considerably with respect to the chosen values.

Z_k = the level of the kth activity relating to grain production $(k=1,\ldots,g)$ or alfalfa production $(k=g+1,\ldots,p)$. Each grain production activity represents a crop planted in one possible production period and harvested in another possible period. Alfalfa production activities represent different management strategies.

T_{ik} = the total quantity of the ith time related factor of production required by the kth activity where $(i=1,\ldots,q)$ refers to labor and field time availability during each period within the calendar of events occurring within the production season. Field time availability is conditional on the availability of acceptable weather, tractors and machinery, and labor to operate the equipment. The farmer's own labor is used first, but the model allows for the hiring of part time labor on an hourly basis during each production period:

$$T_i = \Sigma T_{ik}, \text{ where: } k=1,\ldots,p.$$

F_{jk} is the total quantity of the jth fixed factor required by the kth activity where $(j=1,\ldots n)$ refers to land, tractors, harvesting equipment, or other machinery used in the production of grains or alfalfa:

$$F_j = \Sigma F_{jk} \text{ where: } k=1,\ldots,p.$$

A_{mk} is the total quantity of the mth variable factor required by the kth activity where $(m=1,\ldots,h)$ refers to herbicides, insecticides, or fertilizers used in grain or alfalfa production:

$$A_m = \Sigma A_{mk} \text{ where: } k=1,\ldots,p.$$

α_{ik}, β_{jk}, δ_{mk} are the quantities of each factor T_{ik}, F_{jk}, or A_{mk}, respectively, as required by one unit of the kth activity. P_k is the price per unit of the output from the kth activity. C_i is the imputed price per unit of the ith time related factor $(i=1,\ldots,q)$. G_{jk} is the cost of converting one unit of the jth fixed factor for use in the kth activity (Phouts).[1] D_m is the price per unit of the mth variable factor $(m=1,\ldots,h)$. M is money available for the purchase of variable factors.

The farm firm is assumed to maximize a profit function as defined by:

$$(1)\ \Pi = \sum_{k=1}^{g} P_kZ_k + \sum_{k=g+1}^{p} P_kZ_k - \sum_{i=1}^{q}\sum_{k=1}^{p} C_iT_{ik} - \sum_{j=1}^{n}\sum_{k=1}^{p} G_{jk}F_{jk} - \sum_{m=1}^{h}\sum_{k=1}^{p} D_mA_{mk}$$

subject to a number of constraints, including:

(a) the availability of time related factors of production within each period of the calendar of events:

$$(2)\ \sum_{k=1}^{p} \alpha_{ik}Z_k \leq T_i^0 \text{ where: } i=1,\ldots,q;$$

(b) the total availability of fixed factors such as land, machinery, and tractors:

$$(3)\ \sum_{k=1}^{p} \beta_{jk}Z_k \leq F_j^0 \text{ where: } j=1,\ldots,n;$$

[1]Phouts indicates that the transferring units of fixed factors of production of one product to that of another ordinarily entails a cost (p. 652) and that a multi-product firm cannot legitimately be regarded as a collection of single product firms, since each product is competing with the firm's other products for use of the available fixed factors (p. 651). Phouts' arguments are very relevant within an agricultural setting. Machines must be adapted to produce a different product (alfalfa versus grain), storage spaces and bins must be altered, buildings must be renovated, and so on. Phouts argues that these conversion costs are unique to multi-product firms and that they do not belong to the category of either fixed or variable costs. Further, though these conversion costs do not necessarily change continuously, they do change as the product mix of the firm is changed.

(c) the availability of variable factors of production such as herbicides, insecticides, and fertilizers[2]:

$$(4)\quad \sum_{k=1}^{p} \delta_{mk}Z_k \leq A_m^0 \text{ where: } m=1,...,h.$$

Expenditures on variable inputs cannot exceed the money available for their purchase:

$$(5)\quad \sum_{m=1}^{h} \sum_{k=1}^{p} D_m A_{mk} \leq M^0$$

where:

$\alpha_{ik}, \beta_{jk}, \delta_{mk}, C_i, Z_k \geq 0$ and
$P_k, G_{jk}, D_m > 0.$

A Lagrangian expression representing the constrained maximization problem is :

$$(6)\ L= \Pi+\lambda_1 (T_i^0-\sum_{k=1}^{p} \alpha_{ik}Z_k) + \lambda_2(F_j^0-\sum_{k=1}^{p} \beta_{jk}Z_k) + \lambda_3(A_m^0 - \sum_{k=1}^{p} \delta_{mk}Z_k) + \lambda_4(M^0 - \sum_{m=1}^{h} \sum_{k=1}^{p} D_m A_{mk}),$$

with the following Kuhn-Tucker first order optimization conditions:

$$
\begin{aligned}
(7)\ P_1 &\leq \lambda_1 \ \alpha_{i1} + \lambda_2 \ \beta_{j1} + \lambda_3 \ \delta_{m1} \\
&\vdots \\
P_k &\leq \lambda_1 \ \alpha_{ik} + \lambda_2 \ \beta_{jk} + \lambda_3 \ \delta_{mk} \\
&\vdots \\
P_p &\leq \lambda_1 \ \alpha_{ip} + \lambda_2 \ \beta_{jp} + \lambda_3 \ \delta_{mp}
\end{aligned}
$$

where: (k=1,...,p),

$$
\begin{aligned}
(8)\ P_1 Z_1-Z_1(\lambda_1 \ \alpha_{i1} + \lambda_2 \ \beta_{j1} + \lambda_3 \ \delta_{m1}) &= 0 \\
&\vdots \\
P_k Z_k -Z_k(\lambda_1 \ \alpha_{ik} + \lambda_2 \ \beta_{jk} + \lambda_3 \ \delta_{mk}) &= 0 \\
&\vdots \\
P_p Z_p -Z_p(\lambda_1 \ \alpha_{ip} + \lambda_2 \ \beta_{jp} + \lambda_3 \ \delta_{mp}) &= 0
\end{aligned}
$$

where: (k=1,...,p),

$$(9)\quad Z_k \geq 0 ,$$

$$(10)\ T_i^0 - \sum_{k=1}^{p} \alpha_{ik}Z_k \geq 0 ,$$

$$(11)\ F_j^0 - \sum_{k=1}^{p} \beta_{jk}Z_k \geq 0 ,$$

$$(12)\ A_m^0 - \sum_{k=1}^{p} \delta_{mk}Z_k \geq 0 ,$$

$$(13)\ M^0 - \sum_{m=1}^{h} \sum_{k=1}^{p} D_m A_{mk} \geq 0 ,$$

$$(14)\ \lambda_1, \lambda_2, \lambda_3, \lambda_4 \geq 0 ,$$

$$(15)\ \lambda_1 \ \partial L/\partial\lambda_1 = 0 ,$$

$$(16)\ \lambda_2 \ \partial L/\partial\lambda_2 = 0 ,$$

$$(17)\ \lambda_3 \ \partial L/\partial\lambda_3 = 0 , \text{ and}$$

$$(18)\ \lambda_4 \ \partial L/\partial\lambda_4 = 0.$$

Condition (7) requires that the marginal profit for the kth activity be no greater than its aggregate marginal imputed costs. Condition (8) requires that the firm stay within the capacity limitation of the resources available at that point in time. Conditions (7), (8), and (9) then become the complementary-slackness conditions stipulating that if the optimal solution calls for the production of the kth activity ($Z_k > 0$), the marginal gross profit must be exactly equal to the aggregate marginal imputed cost ($\partial L/\partial Z_k = 0$). Moreover, if the marginal gross profit optimally falls short of the aggregate imputed cost ($\partial L/\partial Z_k<0$),then that activity must not be produced ($\bar{Z}_k = 0$) (Chiang).

Conditions (10)-(13) require the firm to stay within the capacity limitations of every resource available to the farm firm. The complementary-slackness condition then ensures that if the ith, jth, or mth resource is not fully used in the optimal solution, its shadow price is equal to zero, and if it has a positive

[2]This represents specific cost per unit of the kth activity (for example, an acre of corn, soybeans, or alfalfa) for each of the major variable inputs such as fertilizer, herbicides, and insecticides within the mathematical programming model. These costs per acre assume specific variable input quantities and prices to hold.

shadow price, the condition automatically implies that the resource was fully utilized.

If the resource is not fully utilized in the optimal solution, then the imputed value for that resource must equal zero ($\lambda=0$). If the resource is fully utilized, then the imputed value will be positive ($\lambda>0$). These conditions ensure that an optimal solution has been found and allow for an evaluation of the stability of the model. Range analysis and parametric programming will be used to evaluate the sensitivity of the optimal solution (Chva'tal).

THE MODEL STRUCTURE

The model is based on a 600-acre representative West Central Kentucky farm engaged in alfalfa and grain crop production. Of the 600 acres, 500 acres were considered to be class I and suitable for row crop (corn-soybeans) or alfalfa production. The remaining 100 acres were suitable for alfalfa or pasture. In addition, a wheat-soybean double-crop enterprise common to the grain producing regions of Kentucky and the production of silage was allowed. Alfalfa land could be rented out at an assumed rental rate of $40 per acre.

The basic model provides a detailed representation of grain and alfalfa production by breaking the production season into periods. Table 1 provides an overview of the model structure. Labor, tractor, and haying and harvest equipment field times are broken down similarly. The alfalfa management strategies differ from each other with respect to resource requirements. The model allowed for four other cropping activities: corn, single-crop soybeans, double-crop wheat-soybeans, and silage. Each of the grain crops was modeled in land preparation, planting, post planting, harvesting, and drying phases. The stand of alfalfa was assumed to be in place. Costs of establishment were deducted over the assumed life of the stand using an interest rate of 10 percent. The completed model consisted of 185 activities and 116 constraints.

Each planting and harvesting combination represented a separate activity for each grain crop. Each management strategy represented a separate activity in the production of alfalfa. For the grain crops, six different planting periods could be combined with 3 different harvesting periods for a total of 18 possible planning and harvesting combinations. Each planting and harvest period had a unique yield assigned to it. Alfalfa pest control and cutting activities competed with grain tillage, planting, and harvest activities at appropriate points in the calendar of events.

Management strategies for alfalfa production were constructed with cooperation from agronomists and entomologists at the University of Kentucky. These management strategies differed with respect to: (1) the amount of alfalfa that was produced, (2) the proportions of each quality of alfalfa produced, (3) frequency of cuttings and hence, tractor, field time, and labor requirements within the calendar of events, (4) insect control and labor and insecticide requirements, (5) weed control and labor and herbicide requirements, (6) fertilization and liming requirements, and (7) the life expectancy of the stand. Because of a better fertilization program and weed and insect control, the life expectancy of the stand varied according to specific management strategy (I = 7 years; II = 5 years; and III = 4 years). These life expectancies were consistent with agronomists' recommendations.Table 2 summarizes key characteristics of each alfalfa management strategy.

Agronomists had previously worked with agricultural economists at the University of Kentucky in delineating coefficients for alternative management strategies dealing with grain crop and silage production. This was a continuation of work done earlier at Purdue. The management strategies for grain production involve primarily pre-plant tillage, planting, post-plant tillage, and harvesting dates. The optimal strategy with respect to when each event takes place on the calendar is determined inside the model. Fertilizer, herbicide, and seed expenditures are consistent with that needed to achieve a particular yield based on unpublished recommendations by agronomists at Purdue University and the University of Kentucky. Although new strategies for grain production could be specified by altering yield and specific variable cost figures, strategies for grain production are consistent with the base plan values used in the model in extension use in Kentucky and Indiana (Debertin et al., 1976; McCarl et al.).

The three management strategies for alfalfa production describe points along the complete range of options available to the alfalfa

TABLE 1. FEATURES OF ALFALFA-GRAINS MODEL FOR A 600-ACRE REPRESENTATIVE FARM, WEST CENTRAL KENTUCKY, 1983

I. Calendar of events:	Good field hours available
i. Land preparation:	
March 15-April 4	21
April 5-April 15	27
ii. Land preparation, planting, and/or post plant operations for grains, alfalfa cutting, and other haying activities:	
April 16-April 25	52
April 26-May 4	41
May 5-May 13	49
May 14-May 22	55
May 23-May 31	49
June 1-June 9	68
June 10-June 18	47
iii. Post plant tillage for grains, wheat harvest, double crop soybean planting, alfalfa cutting, and other haying activities:	
June 19-June 27	47
June 28-July 22	199
July 22-September 12	350
iv. Corn and soybean harvest, alfalfa cutting, and other haying activities, fall plowing, and related fall land preparation:	
September 13-September 26	90
September 27-October 17	137
October 18-November 7	120
November 8-November 28	108
November 29-December 12	54

II. Resources broken down by event calendar:

Good available field time for tillage, planting, post planting alfalfa cutting, and haying activities and grain harvesting and Fall land preparation activities (good work days x hours per day),

Available tractor time for above activities,

Available time for haying and harvest equipment, and

Own and full- and part-time hired labor availability (hired labor 75 percent as efficient as own labor).

III. Coefficients that vary according to event calendar:

Yields per acre,
Tonnage of alfalfa per acre,
Moisture content of grains,
Fertilizer costs per acre,
Herbicide costs per acre, and
Credit and miscellaneous costs per acre.

IV. Key activities:

Alfalfa production-class I land for three management strategies.
Alfalfa production-class II land for three management strategies.
Corn production for each possible planting and harvest period.
Soybean production for each possible planting and harvest period.
Wheat-soybeans double crop-two possible wheat planting periods.
Tillage, planting, post-plant tillage, and harvest activities for each grain crop.
Silage planting and cutting.
Corn and soybean grain drying.
Alfalfa, corn, soybean, wheat, and silage selling activities.
Land rental.

V. Key model coefficients:

Prices:	
Alfalfa	\$50, \$85, or \$125 per ton
Corn	\$2.75/bu. (wet); \$3.00/bu. (dry)
Soybean	\$6.10/bu. (wet); \$6.30/bu. (dry)
Wheat	\$3.10/bu.
Silage	\$15.00 per ton
Grain yields (depend on planting and harvesting dates):	
Corn	71-130 bushel per acre
Single-crop soybeans	28-47 bushel per acre
Double-crop soybeans	27 bushel per acre
Double-crop wheat	50-60 bushel per acre
Silage	20 tons per acre
Other costs for soybeans (single-cropped):	
Seed	\$10.00 per acre
Fertilizer	\$20.45 per acre

Table 1. Continued.

Herbicide	$12.75 per acre
Miscellaneous	$5.00 per acre
Other costs for corn:	
Seed	$10.00-$12.50 per acre
Fertilizer	$65.25 per acre
Herbicide	$11.00 per acre
Insecticide	$7.00 per acre
Miscellaneous	$8.00 per acre
Other costs for wheat (double cropped with soybeans):	
Seed	$12.00 per acre
Fertilizer	$34.00 per acre
Miscellaneous	$5.00 per acre
Other costs for soybeans (double cropped with wheat):	
Seed	$14.00 per acre
Fertilizer	$6.50 per acre
Herbicides	$22.00 per acre
Miscellaneous	$3.00 per acre
VI. General restraints	
Acres class I land	500 acres
Acres class II land	100 acres
Owner-operator	1 man-year
Hired labor	1 person hourly as needed
Grain tractors	1-120 horsepower
Silage-alfalfa tractors	2-70 horsepower
Combines	1 with grain head
On-farm grain storage	65,000 bushel
Grain drying capacity	300 bushel per hour for 10 pts.

TABLE 2. ALTERNATIVE MANAGEMENT STRATEGIES FOR ALFALFA PRODUCTION ON A 600-ACRE REPRESENTATIVE FARM, WEST CENTRAL KENTUCKY, 1983

Item	Strategy I	Strategy II	Strategy III
Yield in tons per acre:			
Horse quality (@ $125/ton)	1.75	1.1	0.5
Dairy quality (@ $85/ton)	3.50	2.2	1.1
Beef quality (@ $50/ton)	1.75	1.7	1.9
Frequency of cutting:	4 + 1 "freeze down"	4	3
Alfalfa weevil control:			
Cost/acre	$5.00	$5.00	$5.00
Frequency/year	1.0	0.6	0.3
Potato leafhopper control:			
Cost/acre	$3.00	0	0
Frequency/year	1.0	0	0
Broadleaf weed control:			
Cost/acre	$3.00	0	0
Frequency/year	1.0	0	0
Grass control:			
Cost/acre	$7.00	$7.00	0
Frequency/year	0.4	1.0	0
Boron:			
Cost/acre	$1.50	$1.50	0
lbs/acre[a]	1	1	0
Lime:			
Cost/acre[a]	$4.00	$4.00	$4.00
Nitrogen:			
Cost/acre	1.25	1.75	2.19
lbs/acre[a]	3.57	5.00	6.25
Phosphate:			
Cost/acre	24.86	24.00	25.80
lbs/acre[a]	82.86	80.00	64.50
Potash:			
Cost/acre	30.86	21.60	13.50
lbs/acre[a]	171.43	120.00	75.00
Establishment costs for seed			
Cost/acre	8.57	12.00	20.00
Life expectancy (years)	7.0	5.0	4.0

[a]The cost in lbs/acre of fertilizer is compounded and averaged over the life expectancy of the stand of alfalfa.

producer. Management strategy I was designed to represent a producer who had as his goal the production of the highest quality alfalfa for the horse industry and intended to sell as large a proportion of alfalfa as possible to that industry at the highest possible price. As a result, emphasis was placed on high cutting frequencies and great care was taken in pest control to ensure the highest quality product. This strategy was designed to represent the kind of management system a forage agronomist might cite as a "first rate" operation.

Management strategy II was designed to represent a farmer who viewed alfalfa production as an important enterprise in terms of its contribution to revenue but lacked the good field time or labor required to produce the top quality product. This strategy would be more closely aligned with the kind of management a farmer might utilize for sale to the dairy or beef industry. While such a farmer might still grow alfalfa as an important part of the farming activities, he produces a different product for a different market (primarily cattle feed).

Management strategy III required only minimal labor and equipment other than for cutting. With the exception of minimal alfalfa weevil control, little labor or field time was required for any activities other than cutting three times per year. This strategy describes a farmer who grows alfalfa as only a minor source of income. As a result, both the yield and quality suffer. Alfalfa production under this strategy is neither labor nor field time intensive.

Three grades of alfalfa could be produced by the model. The highest quality alfalfa (in demand by the thoroughbred horse industry in Central Kentucky and designated horse quality) was priced at $125 per ton. While some alfalfa is supplied to the horse industry at much higher prices, $125 per ton is an average expected price. The second quality alfalfa (used primarily by the dairy industry and designated dairy quality) was priced at $85 dollars per ton, while the lowest quality (used primarily for beef cattle and designated beef quality) was priced at $50 dollars per ton. Both absolute and relative prices for the various grades of alfalfa were somewhat arbitrary, but they were established by studying local markets and through conversations with forage specialists in the University of Kentucky Agronomy Department.

RESULTS

Two approaches were used in generating the results. The first approach entailed allowing alfalfa to be grown only under one management strategy. Three separate linear programming models were solved. The model which allowed alfalfa grown under strategy I generated a net income over variable costs to the farm of $163,192, Table 3. The net return figure may appear high, but it does not include a charge for labor supplied by the farmer, a charge for the opportunity cost of the farmer's investment, or a depreciation charge for machinery and equipment. Returns above variable costs on each acre of alfalfa were high at $454. Under the set of assumed prices, no alfalfa was grown on land that was suitable for grain production, and only 74.25 of the 100 acres of land suitable for alfalfa was actually used to grow alfalfa, Table 3. An analysis of shadow prices revealed that this was because sufficient labor and field time were not available for planting the remaining acreage. This is clear evidence that alfalfa competes with the grain crops for scarce resources other than land. The remaining acres were assumed to be rented out at $40 dollars per acre.

Strategy II produced slightly greater returns to the grain crop enterprises, but substantially less return to the alfalfa enterprise on a per acre basis. Returns over variable costs to the farm decreased to $151,950. Returns over variable costs per acre of alfalfa decreased to $266. Corn production increased and soybean-wheat double crop acreage decreased. As was the case for the other strategies, the model also had the option of growing soybeans as a single crop at substantially increased soybean yields. However, the double crop combination proved to be more profitable in all instances, given the farm resources. This adds support to the contention that the appropriate management strategy must be considered in the whole farm context. The increased soybean yields in the single crop option were clearly not sufficient to offest the loss in wheat income. Some 82 of the 100 acres of class II land were planted to alfalfa, with the remaining acreage being rented out.

Only in strategy III was all 100 acres of available class II cropland planted to alfalfa. However, the net return to the farm,

TABLE 3. IMPACTS OF ALTERNATIVE ALFALFA MANAGEMENT STRATEGIES ON A 600-ACRE REPRESENTATIVE FARM, WEST CENTRAL KENTUCKY, 1983

Item	Strategy I	Strategy II	Strategy III
Alfalfa production:			
Acres planted:			
Class I land	0	0	0
Class II land	74.25	82.00	100.00
Hay sold in tons:			
Horse quality	130	90	50
Dairy quality	260	180	110
Beef quality	130	140	190
Gross returns for acres grown:			
Horse quality @ $125/ton	16,243	11,275	6,250
Dairy quality @ $85/ton	22,089	15,334	9,350
Beef quality @ $50/ton	6,497	6,970	9,500
Total	44,828	33,579	25,100
Total variable costs	11,110	11,806	12,894
Variable costs/acre	150	144	129
Net returns for alfalfa	33,718	21,773	12,206
Net returns/acre	454	266	122
Acres class II land rented out	26	18	0
Grain crop production:			
Corn:			
Acres planted	222	289	362
Gross returns @$3.00/bushel	85,537	109,653	139,095
Soybeans-double crop:			
Acres planted	278	210	137
Gross returns @$6.30/bushel	47,207	35,753	23,382
Wheat-double crop:			
Acres planted	278	210	137
Gross returns @$3.10/bushel	47,318	35,837	23,436
Gross returns:			
Grain crops	180,063	181,242	185,813
Alfalfa	44,828	33,579	25,100
Alfalfa land rented out	1,030	720	0
Total gross returns for farm	225,921	215,541	210,913
Total variable costs for farm	62,729	63,591	63,988
Total return over variable costs	163,192	151,950	146,925

$146,925, was substantially less than for the other two strategies. Returns over variable costs per acre of alfalfa grown decreased to $122. Gross returns for the alfalfa enterprise were only $25,100. Corn production again increased and double-crop wheat-soybean production declined.

The second approach used was to allow the linear programming model to choose one or more management strategies for growing alfalfa, Table 4. Acreage grown under each management strategy was chosen based on its contribution to the overall profitability of the farm. This approach generated a larger net return to the farm ($164,457) than any of the strategies taken separately. The model, in maximizing returns over variable costs, grew 63 acres of alfalfa on class II land under management strategy I and 37 acres under management strategy III. All alfalfa was grown on the 100 available acres of class II land. Gross returns to the grain crops ($182,295) using this approach exceeded the returns generated when the model was run separately with either strategy I or II.

TABLE 4. ALFALFA MANAGEMENT STRATEGIES IN COMPETITION WITH EACH OTHER FOR 600-ACRE REPRESENTATIVE FARM, WEST CENTRAL KENTUCKY, 1983

Alfalfa production (all of class II land):	
Acres grown strategy I	63
Acres grown strategy III	37
Hay sold in tons:	
Horse quality	129
Dairy quality	262
Beef quality	181
Gross returns:	
Horse quality @ $125/ton	16,128
Dairy quality @ $85/ton	22,245
Beef quality @ $50/ton	9,026
Total returns	47,399
Total variables costs:	14,202
Net returns for alfalfa	33,197
Net returns for alfalfa per acre	332
Acres class II land rented out	0
Grain crop production:	
Corn:	
Acres planted	280
Gross returns @ $3.00/bushel	107,322
Soybeans-double crop:	
Acres planted	220
Gross returns @ 6.30/bushel	37,437
Wheat-double crop:	
Acres planted	220
Gross returns @ 3.10/bushel	37,525
Gross returns:	
Grain crops	182,295
Alfalfa	47,399
Total gross returns on farm	229,693
Total variable costs on farm	65,236
Total return over variable costs	164,457

The difference in the value for the objective function for the two approaches ($163,192 when alfalfa is grown only under management strategy I versus 164,457 when the model selects the combination of management strategies) was not large. However, if a farmer pursued only alfalfa management strategy I, part of the alfalfa land would be rented out. More likely, a farmer would let the management of some of the alfalfa acreage deteriorate if the required labor or machinery were not available to operate the entire alfalfa acreage under strategy I. The model indicates that this is the profit maximizing solution.

RANGE AND SENSITIVITY ANALYSIS

Range analysis provided additional information with respect to the values over which each shadow price in the optimal solution is relevant,Table 5. Alfalfa was never grown on class I land but utilized all of the available acreage on class II land.

The first approximation of the stability of the solution is determined by noting the range of values for the right-hand-side over which the shadow prices were valid. With the exception of the shadow prices on labor, shadow prices remained stable even when net prices on activities changed greatly. Very large changes in the price of alfalfa are required before additional alfalfa would be grown and sold using class I land in direct competition with corn and soybeans. For example, alfalfa of the highest quality (horse) would have to reach $811 per ton before production and sales would increase to 29 tons.

The mix of the three alfalfa management strategies on class I and II land that entered the optimal solution would not change unless substantial reductions in costs occurred for the alfalfa activities that did not enter the solution. Management strategies I, II, and III for alfalfa grown on class I land had production costs of $150, $144, and $129 per acre, respectively, but did not enter the optimal plan. These costs would have to decrease to $33, $35, and $33 per acre before entry would occur.

The highest shadow price for factors of production was attributed to labor availability during the time period April 16-25. The base run farmer labor availability was 54 hours with the possibility of hiring labor at $4.00 per hour to a maximum of 27 hours. The shadow price of farmer labor was $322 with a range of 38 to 54 hours while the shadow price for hired labor was $238 with a range of 6 to 27 hours.

Because of the narrow upper range of these two shadow prices, the sensitivity of the model to changes in upper bounds of the range was tested through parametric changes in farmer and hired labor availability for the time period April 16-25. The narrow upper range for farmer labor resulted because of the availability of hired labor. The narrow upper range for hired labor resulted probably because some other resource was binding at that level. The resource that is most binding may not necessarily have the highest shadow price because resources may be measured in different units. In all instances, upper ranges in shadow prices occur because some other resource is binding at that level. All resources with positive shadow prices represent fully employed resources. However, interest in shadow prices is with respect to the overall stability of the solution. Table 5 reports selected parametric changes. When the farmer labor restraint is not binding at 88 hours of labor, no labor is hired and the mix between management strategies I and III shifts to 82 and 18 acres of alfalfa, respectively.

If the hired labor constraint is no longer binding, the initial 54 hours of farmer labor is utilized and an additional 44 hours of labor

TABLE 5. SENSITIVITY ANALYSIS OF LABOR AVAILABILITY APRIL 16-25, A 600-ACRE REPRESENTATIVE FARM, WEST CENTRAL KENTUCKY, 1983

Run	Farmer labor constraint (hours)	Hired labor constraint (hours)	Value of the objective function	Shadow price of farmer labor ($)	Shadow price of hired labor ($)	Acres of land in alfalfa for management strategy I	III
1[a]	54	27	164,457	322	238	63.2	36.8
2	64	27	166,816	211	156	77.5	22.5
3	85	27	167,597	4	0	82.0	18.0
4	88	27	167,597	0	0	82.0	18.0
5	54	38	166,413	211	156	75.0	25.0
6	54	44	167,413	4	0	82.0	18.0

[a] The base run.

are hired. Some other resource becomes restrictive. Again, the alfalfa mix between management strategies I and III is 82 and 18 acres of alfalfa, respectively. The model remains stable through all perturbations in the right-hand-side values.

CONCLUDING COMMENTS

The general conclusion of this analysis is that management strategies for alfalfa need to be considered in relationship to a total farm plan. A management strategy that appears optimal in an agronomic sense may not always be optimal from the standpoint of maximizing returns over variable costs to the farm. In the first approach, management strategy I (considered desirable from an agronomic point of view) did generate the greatest returns over variable costs to the farm. However, renting out part of the land was the most profitable alternative given the resources of the farm. The solution that produced the greatest net return included the production of part of the alfalfa under a management strategy not considered optimal from an agronomic point of view. In addition to producing a slightly greater return over variable costs ($164,457 versus $163,192), the approach made it possible to plant the entire available acreage to alfalfa or field crops. The less intensive management lessened the impacts of bottlenecks in labor and field time availability present in a solution that allowed for only the first management strategy.

The smallest profits to the entire farm occurred when the least intensive management strategy for alfalfa (III) was the only option allowed. Management strategies should be chosen on the basis of their impacts on the profitability to the total farm plan. It is not sufficient to consider only the impacts of the management strategy for an enterprise such as alfalfa on the profitability of that enterprise. The profitability of the other enterprises that are competitive with alfalfa for available labor, machinery, and field time is also of concern.

REFERENCES

Brink, Lars, Bruce A. McCarl, and D. Howard Doster. *Methods and Procedures in the Purdue Crop Budget (Model B-9):An Administrator's Guide.* Dept Agr. Econ. Stat. Bull. 121, Purdue University; March, 1976.

Chiang, Alpha C. *Fundamental Methods of Mathematical Economics*, McGraw-Hill, 2nd Edition, 1974.

Chva'tal, Vasek. *Linear Programming,* W.H. Freeman and Company, New York, 1980.

Debertin, David L., C. L. Moore, Sr., Garnett L. Bradford, and Larry D. Jones. *Kash Profits Input Form;* Dept. of Agr. Econ., University of Kentucky; December, 1976.

Debertin, D. L., C. L. Moore, Sr., and L. D. Jones. *Organizing, Conducting and Evaluating an Extension Workshop Using Computerized Decision Aids: The KASH PROFITS Experience.* Dept. Agr. Econ. Extension Bull. 29, University of Kentucky, 1980.

Debertin, D. L., C. L. Moore Sr., L. D. Jones, and A. Pagoulatos. "Impacts on Farmers of a Computerized Management Decision-Making Model." *Amer. J. Agr. Econ.* 63(1981): 270-4.

McCarl, Bruce, Wilford Chandler, D. Howard Doster, and Paul Robbins."Experience with Farmer Oriented Linear Programming for Crop Planning." *Can.J. Agr. Econ.,* 25,1(1977): 17-30.

Phouts, Rolf W. "The Theory of Cost and Production in the Multi-Product Firm", *Econometrica,* 29(1961): 650-8.

Regev, Uri, Andrew P. Gutierrez, and Gershan Feder. "Pests as a Common Property Resource: A Case Study of Alfalfa Weevil Control", *Amer. J. Agr. Econ.,* 58(1976): 186-97.

Reichelderfer, Katherine H. and Filmore E. Bender. "Application of a Simulative Approach to Evaluating Alternative Methods for the Control of Agricultural Pests", *Amer. J. Agr. Econ.*, 61(1979): 258-67.

Shoemaker, Christine. "Optimization of Agricultural Pest Management, Part 3: Results and Extensions of a Model." *Math Biosciences,* 18(1973): 1-22.