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DAFOSYM: A SYSTEM SIMULATION MODEL
FOR ANALYZING THE ECONOMICS OF FORAGES
ON COMMERCIAL DAIRY FARMS

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DAFOSYM: A SYSTEM SIMULATION MODEL FOR ANALYZING THE ECONOMICS OF FORAGES ON COMMERCIAL DAIRY FARMS

By

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ABSTRACT

DAFOSYM: A SYSTEM SIMULATION MODEL
FOR ANALYZING THE ECONOMICS OF FORAGES
ON COMMERCIAL DAIRY FARMS

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A systems approach was taken in developing DAFOSYM (DAiry FOrage SYstems Model), a computer simulation research model which aids in analyzing technical and economic issues of Great Lakes dairy forage production in the context of the whole farm. The model simulates four on-farm production activities which trace the conversion of farmgrown feedcrops (alfalfa, corn silage, high-moisture corn) into a marketable livestock product (milk): crop growth and yield; crop planting and harvesting; feedcrop storage and handling; and feedcrop disappearance.

The objective of DAFOSYM was to enable model users to conduct experiments which compare alternative dairy forage system design, technology, and management. Three issues served as guidelines in designing the model: the model is generic in that a complete spectrum of forage production systems (ranging from all alfalfa to all corn silage) in the Great Lakes setting can be analyzed; the model accounts for dynamic system interactions (timeliness of field operations, weather risk) which affect quantity and quality tradeoffs of feedcrops produced for the dairy herd; the model provides a measure of both the level of profitability and riskiness associated with any system over a multiple-year period by generating a sample cumulative distribution function of the system performance measure, net feed costs.

Model output is suitable for ranking system alternatives for their risk-return tradeoffs using stochastic efficiency criteria.

Major subcomponents underlying DAFOSYM include: a phenological crop growth model which simulates alfalfa yield and quality (protein, digestibility) on a daily basis as a function of historical weather data; a multivariate stochastic process model which generates corn yields and number of available field working days; and process-engineering algorithms which account for sequences of field operations, feedcrop losses, and on-farm feedcrop processing from field to cow.

This bio-engineering economic model should serve as a catalyst for continued interdisciplinary research and communication. The study emphasizes model development, implementation, and validation. Model use is demonstrated with a series of sample simulation runs which compare and rank alternative corn silage:alfalfa systems for hypothetical 120-cow and 80-cow herds using Michigan weather and yield data. User-oriented model documentation is provided.

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I am grateful to Philippe Savoie whose cooperation enabled us to undertake and complete our joint model-building venture with relative ease. I am also appreciative of Paul Wolberg's many hours of programming assistance which have resulted in a manageable software package.

Funding for this study was provided by the Michigan Agricultural Experiment Station and the U.S. Dairy Forage Research Project (USDA-ARS). I gratefully acknowledge this support.

Finally, I cannot ignore the tangible contribution of my wife Janet, who typed the entire thesis from first draft to final copy. In addition, pursuit of her own career during my graduate schooling has enabled us to have more than just bread on the table, and has made the lengthy process of getting an advanced degree much more bearable.

Never ask of money spent
Where the spender thinks it went.
Nobody was ever meant
To remember or invent
What he did with every cent.

--Robert Frost
"The Hardship of Accounting"

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CHAPTER I

INTRODUCTION

1.1 Importance of the Dairy Forage Production Component in Michigan Agriculture

Although Michigan ranks sixth among states leading in milk production and produces only 3.9% of U.S. raw milk (Michigan Agricultural Statistics, 1981), dairying is the most important segment of Michigan agriculture when measured on a cash-receipts basis. Since World War II, dairy product sales have consistently equaled 25-30% of total farm marketings in Michigan (Speicher and Wright, 1978). Table 1.1 demonstrates that over the period 1975-1979, cash receipts from dairy products and dairy livestock (26%) far surpassed all other individual commodities as well as several important groups of commodities, including: cattle/calves-hogs-eggs (18%); corn-soybeans-wheat-sugar beets (25.2%); and fruit-vegetables (12.3%).

Forage crops play an important role in Michigan's dairy industry. Based on 1980 Telfarm data (Brown and Nott, 1981), hay equivalent and corn silage acreage accounts for 47% of all tillable acreage, and 57% of all feedcrop acreage, on Michigan dairy farms. Hay equivalent acreage alone accounts for 35% and 43% of tillable and feedcrop acreage, respectively, on these farms. Assuming Telfarmers are representative of all Michigan dairy farmers, it can be inferred that approximately 12%, 78%, and 50%

Table 1.1 Composition of Total Cash Receipts from Farm Marketings of Selected Commodities, Michigan 1975-1979, (%).

Commodity	1975	1976	1977	1978	1979	Avg.
Dairy*	24.8	28.4	25.7	25.9	25.0	26.0
Cattle/calves**	8.4	7.3	8.0	12.4	12.1	9.6
Hogs	6.1	5.9	4.9	4.6	4.8	5.3
Eggs	3.3	3.9	3.2	2.7	2.5	3.1
Corn	13.2	15.0	14.1	11.3	12.9	13.3
Soybeans	3.8	4.5	6.6	4.2	7.1	5.3
Wheat	6.8	4.7	4.3	2.5	4.4	4.6
Dry Beans	7.8	4.6	5.8	3.9	4.9	5.4
Sugar Beets	2.6	1.9	2.1	1.7	1.6	2.0
Vegetables	5.0	5.5	5.7	5.9	5.0	5.4
Fruit	5.8	5.8	5.9	9.4	7.3	6.9
Other	12.4	12.5	13.7	15.5	12.4	13.1
Total	100.0	100.0	100.0	100.0	100.0	100.0
Total Cash Receipts, ($ Billions)	1.661	1.728	1.925	2.099	2.501	1.983

* Includes dairy products and net sales of dairy livestock based on Telfarm data, 1980.

** Excludes sales of dairy livestock, based on Telfarm data, 1980.

Source: Michigan Agricultural Statistics, 1981.

of all Michigan acreage in corn grain, corn silage, and hay, respectively, is ultimately marketed through dairy. If this inference is correct, over the period 1975-1979 just under 19% of all Michigan field crop acreage[1] was marketed through dairy, and over 14% of all field crop acreage consisted of forages marketed through dairy.

1.2 Problem Statement

Because of the importance of the dairy forage component of Michigan agriculture, both basic and applied dairy forage research has been conducted at Michigan State University. Previous and ongoing investigations in this area have been conducted primarily in the departments of Agricultural Engineering, Crop and Soil Sciences, Animal Sciences, and Agricultural Economics. A broad spectrum of research topics has been investigated which encompass technical and economic aspects of growth, harvest, storage, and feeding of forages, and of their utilization by the dairy herd. Specific examples have included: the effect of all corn silage versus all hay on lactating cows (Brown et al., 1966); intake of dry versus wet alfalfa (Thomas et al., 1968); nutritional characteristics of forage (Pulli, 1973; Allinson et al., 1969); the impact of alternative cutting sequences, number of cuts, and stage of maturity on alfalfa yield and quality (Lee, 1973); new packaging systems (Schwab, 1974); economic evaluation of whole-farm dairy systems and management (Hoglund, 1976); alternative alfalfa establishment strategies (Tesar, 1976); modeling forage nutrient utilization in livestock (Black, 1978);

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[1]Field crop acreages as defined by Michigan Agricultural Reporting Service in Michigan Agricultural Statistics.

preservatives for forage crops (Thomas, 1978); treatment of silages with non-protein nitrogen (Huber et al., 1980); evaluations of dairy forage machine complements (Sisco et al., 1980); and methods to shorten field-curing time of alfalfa (Wieghart et al., 1980).

The above research has been conducted at both the departmental and inter-departmental levels. To a greater degree, however, researchers have recognized that the technological and economic impacts of dairy forage investigations must be evaluated in a broader farming systems context. This is due to the nature of dairy forage agriculture in Michigan. Telfarm data (Brown and Nott, 1981) shows that for all size classes of dairy farms, forages[1] fed to the dairy herd are primarily homegrown and that only a relatively small portion is marketed for cash sales. The same data show that specialized dairy farms grow corn grain for feeding and sales, and are, on average, net producers of grain. This demonstrates that feed production and utilization on commercial dairy farms in Michigan is largely an enclosed system of interdependent processes which convert feedcrops into economic animal products. In order to fully assess the impact of alternative technology, management, or system design, the whole broader set of interactions between these interdependent production subsystems must be evaluated.

From a research perspective, this implies that the experimental design of dairy forage investigations must address the entire crop production/livestock interface, i.e., that whole-farm production

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[1]Forages used in Michigan include grass and legume hays and haylages, as well as various grain crop silages. For the remainder of this study, the term "forage" will refer to alfalfa and corn silage.

systems must be "placed into the test tube" in order to determine the relevance or impact of disciplinary experiments on system level output.

Such research would be difficult if not also prohibitively expensive. For this reason, one of the proposed responsibilities of the Michigan State research cluster group of the U.S. Dairy Forage Research Center[2] is to develop and refine computer models which serve as vehicles for conducting research of both technical and economic issues of whole-farm dairy forage production and utilization in the Great Lakes States setting. The present study was undertaken with the goal of designing and implementing a first generation version of this model, the DAiry FOrage SYstems Model (DAFOSYM).

1.3 Objectives of the Study

The objectives of the study are to:

1. Identify the key components and relationships which describe the production and utilization of feedcrops grown on a commercial Great Lakes State dairy farm for use in milk production. Homegrown feedcrops include forages (alfalfa, corn silage) and high-moisture shelled corn. Key components include on-farm subsystems and production processes which influence, or are influenced by the growth, harvest, storage, feeding and utilization of the feedcrops.

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[2]The U.S. Dairy Forage Research Center (USDFRC) was established in 1980 in Madison, Wisconsin, as a joint venture of USDA-ARS and seven land-grant universities in the North Central region. The USDFRC is staffed by researchers at the Center, as well as in satellite "cluster groups" at each of the supporting institutions.

2. Design, develop, and operationalize a computerized simulation model of the system identified in (1) above. The model should be appropriate for use as a research tool which addresses both technical and economic issues related to dairy forage farm-firms in the Great Lakes area. The model should be capable of evaluating questions relevant to system design, management, and technology, and should provide a measure of both the returns and risk associated with system alternatives analyzed.

3. Demonstrate the use of the model developed in (2). Using Michigan weather and crop yield data, six experiments are conducted in which the model is used to simulate representative 80-cow and 120-cow dairy forage systems. Systems simulated include alternative farm plans which reflect production systems designed to provide alternative forage rations[1] for the lactating herd. Evaluation includes a ranking of the alternative systems using stochastic efficiency criteria.

The results and contributions of the study should prove useful to dairy forage research in the following ways:

1. It specifies the important relationships between the production subsystems of a commercial dairy farm.

2. It provides a format for evaluating the sensitivity of farm system level economic output to subsystem level technical and economic parameters.

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[1]Forage rations are defined by the proportion of total forage dry weight fed to the lactating dairy cows consisting of either corn silage or alfalfa.

3. It indicates which portions of the dairy forage production system are poorly understood, and hence, provides direction for future research.
4. It provides--in the computerized model--a research tool which can be used in future studies, and which encourages interdisciplinary communication.

1.4 Research Procedure

The DAiry FOrage SYstems Model (DAFOSYM) is the product of an interdisciplinary study undertaken by two primary investigators: the author and Philippe Savoie, Department of Agricultural Engineering, Michigan State University. Both primary investigators undertook this study as a research topic for their respective Ph.D. dissertations. The task which these investigators set out for themselves was to coordinate efforts to design, develop, and implement an operational model which addressed itself to issues of technical and economic production efficiency of dairy forage systems at the farm-firm level. Although the investigators' goal was to merge their efforts into a single model, the research was largely independent in nature with each being responsible for individual subcomponent design and modeling. Coordination between the investigators consisted primarily of specifying overall model design, and assuring that individual subcomponents were compatible with overall model and research objectives.

The allocation of research responsibility between the two investigators can briefly be summarized as follows: The author was responsible for modeling crop environment and crop yields of alfalfa and corn,[1] as well as for the harvest, storage, and feeding of corn; Savoie was responsible for modeling machinery input-output relationships, as well as for drydown, harvest, storage, and feeding of alfalfa. Each was responsible for accounting for material flows, resource use, and costs in their individual areas. The contribution of each of these investigators is described in detail in each of the respective "companion" dissertations.

The model reported in this study represents a first version of a dairy forage systems model in that all components are not developed at the same level of sophistication, due to either expertise, personnel, or time constraints. At present, the subcomponent which accounts for crop utilization by the dairy herd is being developed under the direction of a third investigator, Dr. J. Roy Black, Department of Agricultural Economics, Michigan State University. Black's contribution to the study will consist primarily of adapting on-going dairy protein research models for use compatible with DAFOSYM objectives. Hence, the present model subcomponent used to account for dairy feed disappearance is a simplified version, and is viewed as being a temporary component of the final DAFOSYM model.

1.5 Summary of Model Characteristics

Two primary characteristics describe the research method of the DAFOSYM model:

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[1] For the remainder of the study "corn" will be used as a generic term which includes corn silage (CS), high moisture shell corn (HMC), and dried corn grain (CG).

1. Bio-engineering economic model. Bio-engineering economic variables describing production relationships of a dairy forage farm-firm system are modeled. Production processes in the model describe the transformation of user-inputted farm resources (inputs) into homegrown feedcrops (intermediate outputs) and their conversion into economic outputs (milk). For each of these processes, categories of variables which are monitored include: material flows of production through the system; resource use associated with those flows; costs and returns associated with resources expended and products produced.
2. Dynamic state variable simulation model. The processes involved in producing homegrown feedcrops (crop growth, harvest, storage/feeding, utilization) are simulated on a minimum time increment of one day over a multiple-year period. Daily time increments allow for simulation of detailed process interactions affecting crop yield and quality. Multiple-year simulations provide a measurement of both the expected returns and variance associated with any system by generating the cumulative probability distribution of that system's performance measure.

1.6 Outline of the Dissertation

The purpose of this dissertation is to explain the development of the author's contribution to the DAFOSYM model.[1] Chapter 2 uses

[1]Detailed explanation of Savoie's contribution to the model is described in the companion dissertation (Savoie, 1982).

a review of dairy forage economics literature to identify the primary issues to be addressed by the model. Chapter 3 provides an overview of model organization and experimental design. Chapters 4 and 5 deal with model development: Chapter 4 describes how a phenological crop growth model is adapted to account for alfalfa yield and quality prior to harvest; Chapter 5 describes the stochastic process corn production model. These two chapters are the core of the dissertation in that they represent the author's primary contribution to overall model development. Chapter 6 demonstrates use of the model in conducting various experiments which address questions of dairy forage system design. Alternative dairy forage production systems (consisting of alternative crop mix, machinery complements, feed storage structures), each designed to provide alternative forage rations for a representative commercial dairy herd, are simulated and evaluated. Research summary and recommendations are provided in Chapter 7.

CHAPTER II

CRITICAL ISSUES FOR DAIRY FORAGE MODEL DESIGN

2.1 Introduction

The problem statement of Chapter 1 calls for a computerized research model which can be used as a research tool for analyzing technical aspects of dairy forage production in an economic framework. The goal of Chapter 2 is to identify which technical issues need to be addressed and incorporated into model structure. Previous research studies are reviewed to provide insight into important issues.

Three important issues are specified: (1) Dairy forage budgeting studies are used to identify the importance of taking the broad generic approach designated by analyses which allow alternative farm systems tested to be defined by the entire spectrum of potential rations fed to the herd. (2) Dynamic simulation studies indicate the relevance of accounting for feedcrop quantity/quality tradeoffs due to the dynamic interactions of weather risk, machinery complement capacity, and timeliness of operations. (3) Finally, a third issue addressed by neither group of studies is the importance of accounting for across-year crop yield variability and its impact on risk and returns.

2.2 Dairy Forage Economics: Review of Budgeting Studies

A number of dairy forage economics studies utilize budgeting techniques in order to estimate either cost-of-production or net returns. The merit of these studies is that most take a systems approach in their analysis, recognizing the importance of the interface of crops and livestock. All of the studies reviewed are conducted at the farm-firm level. The general procedure in these budgeting studies is to establish the desired herd size and milk production level per cow. A ration is balanced for the herd using a least-cost (simplex algorithm) ration balancer. Next, a synthetic farm-firm is designed which is capable of generating feedstuffs for this herd on an annual basis. Finally, the resources expended as well as the costs/returns associated with each farm plan are then budgeted and accounted for. The primary purpose in reviewing these studies is to note the design of the research, and to identify the factors being analyzed.

Budgeting studies by Schwab (1969) and Hoglund et al. (1972) test the effect of varying three factors on dairy forage profitability. Schwab and Hoglund et al. analyze two management levels across three soil management groups in combination with three alternative rations fed to the dairy herd. Rations are defined by the composition of the forage source for the lactating cows, ranging from those high in corn silage to those high in alfalfa. Similar studies by Black et al. (1974) and Parsch (1980) each analyze three soil management groups in combination with three rations. Rations are defined by both the ratio of corn silage:alfalfa in the feed, and whether or not non-protein nitrogen (NPN) is used as a protein additive in corn silage. All four studies demonstrate that rations high in corn silage are most profitable on highly productive soils, but that high levels of alfalfa minimize costs on the less productive sandy loams. Additionally, Black et al. and Parsch show that use of NPN is a critical factor of profitability on all soil type/ration combinations.

Results of a study by Knoblauch et al. (1979a) differ from those above. Knoblauch et al. analyze marginal and productive soil in combination with alternative rations and find that least cost plans for high-producing herds contain equal proportions of corn silage and alfalfa as opposed to all haylage or 70% corn silage forages on productive land. For less productive land, least cost farm plans include alfalfa as the only roughage source.

A study by Nott (1974) analyzes a marginal and productive land base in combination with alternative forage rations, use or non-use of NPN, and two quality levels of alfalfa. Over all combinations analyzed, Nott finds that NPN always results in greater net returns than non-NPN rations. However, on highly productive land, returns from a 50% alfalfa haylage ration are found to be nearly equal to returns from a 100% corn silage ration using NPN, provided that high quality haylage (21% crude protein) is made available to the herd. On less productive soils, the reverse is true: A ration containing 70% alfalfa (18.5% crude protein) is found to net higher returns than a 75% NPN corn silage ration.

On productive soils Hoglund (1963) demonstrates results similar to Nott (1974) and Knoblauch et al. (1979a), provided a high level of management is exercised, i.e., least cost farm plans include equal proportions of corn silage and alfalfa as the forage source.

When only low management levels are available on productive soils, however, 35% alfalfa is optimal. Hoglund hypothesizes that higher management levels are required to harvest alfalfa in a timely fashion so as to reduce losses. On less productive soil, Hoglund shows 65% alfalfa is preferable due to relative yield differences with corn silage.

In a later study, Hoglund (1968) compares the effects of use and non-use of NPN with alternative corn silage:alfalfa combinations, while also testing the sensitivity of the outcome to 20% variations in corn silage and alfalfa yields. A 50% CS ration results in higher returns than either a 30% or 100% CS ration provided NPN is used. As expected, when corn yields increase, net income from farm plans is greater the larger the proportion of corn silage in the ration. The same is true for increased alfalfa yields, but Hoglund notes that the same relative increase in alfalfa yields has less impact than similar corn yield changes.

Two budgeting studies look at the impact of alfalfa quality and milk production level on costs (Milligan and Knoblauch, 1980; Benson, 1979). Milligan and Knoblauch (1980) provide cows producing 10,000, 14,000 and 18,000 pounds of milk per year with rations containing 0%, 50%, and 75% CS. Alfalfa contains either 12.6% crude protein (.48 Mcal/lb NEL) or 17.0% crude protein (.56 Mcal/lb NEL). Given any milk level and ration, lowest production costs are obtained with the high quality alfalfa due to reduced purchases of protein. But across all levels of milk production, costs are minimized with the 50% corn silage rations. When low quality alfalfa is forced into the solution, however, high corn silage rations (75%) are least-cost.

The Benson study (1979) analyzes a total of 14 ration combinations for cows producing at levels of 60 lb./day and 80 lb./day. Rations contain either 100%, 50%, or 0% CS, both with and without NPN. Alfalfa is available at four levels of quality with crude protein at 21%, 18%, 14%, and 10%. Least-cost rations for 60-lb. cows contain 100% NPN corn silage, whereas least-cost 80-lb. cow rations contain 100% high quality (21% crude protein) alfalfa. 50% CS rations containing high quality alfalfa (crude protein greater than 18%) render only slightly less net returns, however. Benson notes that the cost-reducing effect of NPN is less with higher producing cows where nutrient requirements are greater, i.e., that forage quality is always of greater importance at high production levels.

Other important dairy forage budgeting studies analyze material energy flows and costs under alternative rations (Holtman et al., 1977); baled hay versus haylage in combination with alternative levels of corn silage for 40, 80, and 160-cow herds (Knoblauch, 1979b); alternative corn silage-alfalfa rations for five different farm sizes (Nott, 1973); and field-cured versus conditioned baled hay and haylage (Shandys, 1963).

2.3 Comment on Budgeting Studies

A strength of the budgeting studies reviewed above is a systems-oriented approach in which forages are evaluated in light of their contribution to the larger dairy forage system. System performance measures--total cost or net returns--are calculated by tracing changes in resource use throughout the production system. As factor levels are varied in these studies, broad shifts in the farm resource base--including crop acreage mix, machinery complement, feed storage structures, etc.--are accounted for.

It should be noted that the common variable which is analyzed across all studies reviewed is the ration fed to the dairy herd. In each case, rations are defined by the composition of the forage (corn silage:alfalfa ratio). Because dairy cows can substitute forages over a broad range, the use of ration as a control variable in these studies allows a broad spectrum of production systems to be analyzed for any given herd or land base.

The weakness common to all of the budgeting studies reviewed above is that since each is a static analysis, it is unable to capture the dynamic aspects of dairy forage production which may have impact on system performance over time. A Michigan study (Knoblauch, 1976) using 1960-74 Telfarm data demonstrated that dairy farms using 50% corn silage-50% alfalfa rations had both higher levels and lower variability of net returns than did farms using either 0% or 70% corn silage systems. However, the same study showed that during the period 1960-69, this identical ration resulted in the highest variability of net returns.

Nott (1973) has hypothesized that if forage research were to account for the interdependencies of weather risk, machinery complement capacity, and crop quality losses due to timeliness, then corn silage systems would be shown to be less risky. He suggests that the inclusion of "risk management" is one of the most important problems to be dealt with in future forage research.

2.4 Dairy Forage Economics: Review of Dynamic Simulation Studies

Von Bargen (1966) suggests that haymaking generally does not result in optimum returns to the farming enterprise due to: (1) the sequential field operations which characterize the harvest process, and (2) the exposure to hazards of weather during field drying. Using dynamic simulation models, researchers have attempted to account for technological aspects of forage growth and production which affect quantity and quality of crops during the multi-stage process which transforms them from growing plants into milk to be marketed.

Cloud et al. (1968) develop a daily simulation model of hay harvesting and utilization. Equations which express yield and quality of alfalfa as a function of calendar date are developed. Sequences of daily historical weather data in combination with machinery complements of various capacities are then simulated to account for crop quality and quantity harvested and available to the dairy herd. A second set of equations expressing milk production as a function of forage quality, dry matter intake, and grain consumption are used to place a dollar value on harvested crops. Crop dry matter and quality losses are accounted for, and hay produced is allocated to three quality storage locations: no rain damage, slight rain damage, and heavy rain damage with hay to be salvaged for cash sale only.

Millier and Rehkugler (1970) describe a daily simulation model similar to Cloud et al. except that a random number generator is used to simulate the probability of days suitable for harvest. Yield and quality equations are estimated for first-cut alfalfa as a function of calendar days. Regrowth yield and quality for subsequent cuttings is based on a fixed cutting interval. Alternative harvest rate capacities and cutting sequences are then evaluated for their impact on dry matter and quality available for the dairy herd. In a more recent study, Bebernes and Danas (1978) expand and modify the Millier model to include historical weather data, machinery complements representing alternative hay-packaging systems, and alternate crop acreage levels to be harvested. Dry matter and quality losses reflecting crop maturity, leaching, and machinery handling losses are also included. Output from the model includes both cost and time analysis.

A model developed by Parke et al. (1978) differs from those cited above in that harvest is restricted to a one-cut system. However, the modeling of rainfall (based on historical data) affects both moisture and losses of the cut crop. Likewise, weather expectations on the part of the decision maker are accounted for by simulating the decision to harvest on a specific day, given a weather forecast. Parke uses the simplex algorithm (LP) to determine a minimum cost feed ration in order to evaluate nutrients produced in the simulated growth and harvest of the crop.

McGuckin and Schoney (1980) describe a dairy forage model to evaluate the riskiness of alfalfa haylage versus hay. A phenological crop growth model is used to generate alfalfa yields on a daily basis as a function of historical weather data. Crop drydown, yield and quality losses, weather expectations and alternative management strategies are incorporated into the simulation. Feedcrops are allocated using a linear programming ration balancer. Cumulative distribution functions of net returns generated over a multiple-year simulation serve as the model performance measure.

A model developed by Lovering and McIsaac (1981) simulates growth and harvest of forage crops, and accounts for effect of storage method on quality losses. State variables in the model update yield and quality of each harvested plot. A component feed storage submodel (McIsaac and Lovering, 1980) monitors feed quality throughout the storage process. Feeds are converted to milk on an annual basis, and costs/returns calculations are based on a set of equations which account for non-linear increments in milk production per unit increment of feed produced.

2.5 Comment on Dynamic Simulation Studies

The primary advantage of the simulation studies over the static budgeting models reviewed earlier is their ability to account for the dynamics of the growth and harvesting processes which affect both the quality and quantity of feed available to the dairy herd. These dynamic interactions are characterized in the models by variables which monitor or account for crop maturity, harvest timeliness, weather risk, and number and sequence of harvest days.

The simulation models exhibit two weaknesses, however:

1. The range of alternative systems which are designed or analyzed is severely restricted. Unlike the budgeting studies reviewed earlier, the sole source of roughage analyzed in the simulation models is the hay or haylage crop with no potential for growing and feeding corn silage or high moisture corn in combination with legumes or grass. Given the impact of forage composition on total costs demonstrated in the budgeting studies, this is a serious shortcoming.

2. Variations in crop yield and quality not only are limited to the hay or haylage crop, but also, with the exception of McGuckin and Schoney, ignore the possibility of analyzing risk resulting from year-to-year yield variability. Models cited which predict crop yield and quality as a function of calendar date--while capable of reflecting the impact of cropping dynamics (crop maturity, harvest timeliness) on profitability--are by design inappropriate for multiple-year simulations.

2.6 Implications for the Design of DAFOSYM: Issues to Address

Insights gained from the review of previous dairy forage studies resulted in the three basic criteria which were established for the design of the DAFOSYM model. Each criterion is discussed in turn:

1. Generic model. The dairy forage model must be capable of analyzing systems in which the forage source of the dairy ration can be ranged from all alfalfa to all corn silage. Animal nutrition research has demonstrated that lactating cows can substitute forages over a broad range and still maintain levels of production consistent with their genetic potential (Rumsey et al., 1963; Brown et al., 1965; Brown et al., 1966; Hemkin and Vandersall, 1967; Thomas et al., 1970; Holter et al., 1973). Regardless of whether all, some, or none of the forage and high moisture corn crops are to be homegrown for the dairy herd, the limit on the number of farm plans or crop enterprise combinations which can be designed is restricted only by the ability of the herd to substitute feeds. A generic model must be capable of analyzing this entire spectrum of alternative systems if

it is to avoid finding merely local solutions, instead of the desired global solutions, to the dairy forage resource allocation problem. This criterion is especially important in the Great Lakes setting because large quantities of roughages (corn silage and alfalfa) and high moisture corn are grown on commercial dairy farms for internal use.

2. Dynamic system interactions. The model must be able to account for the dynamics of feed crop quantity and quality affected by environmental and technical factors. With respect to the alfalfa crop, the model must accommodate the following technological aspects of crop growth and production:

a. Dry matter yield increases with crop maturity.

b. Crop quality (protein, digestibility) decreases with maturity.

c. Daily weather pattern affects the length of harvest period and quantity of rain-damaged hay.

-- If rainy days are numerous, the harvest period is prolonged, providing time for the yield of the standing, uncut crop to increase and the quality to decrease.

-- While the number of clear days determines the number of days of harvest operations, the sequence of clear and rainy days affects drydown and is equally important: the quantity of rain-damaged alfalfa is greater for systems requiring longer field-curing.

d. Length of the harvest period affects initiation of regrowth of subsequent cuttings.

e. Each machine complement has a different input/output relationship. A change in the harvesting package results in changes in the resources used and products produced on a given area.

With respect to the corn silage and high moisture corn crops, the following technological aspects of crop production must be accounted for:

a. Crop yield is affected by both the date of planting and date of harvest of the corn crop.

b. Date of planting and date of harvest are a function of available field work days and machinery capacity.

Finally, with respect to interactions between the alfalfa and corn crops, the model must accommodate the following:

a. Harvesting capacities of alfalfa, corn silage, and high moisture corn are interdependent if implements or tractors are used for more than one crop.

b. Delays in the planting of the corn crop may delay the initiation of the first cutting alfalfa.

c. Delays in the summer (third) cutting of alfalfa may delay the initiation of the corn silage harvest (southern Michigan).

3. <u>Risk assessment: Across-year yield variation</u>. The model must be able to account for the variability of feedcrop yields about their expected values. Variation in crop yields over time can be partitioned into two components: a systematic component

reflecting long-run biological, technological and managerial trends; and a second random portion which may be regarded as unpredictable and due to the vagaries of environmental conditions. It is the second random portion which must be addressed here for each the alfalfa, corn silage and high moisture corn crop in order to provide capability of assessing risk-return tradeoffs of alternative dairy forage systems.

By addressing the first two issues cited above, a generic model of dairy forage systems evolves which combines the breadth of the systems orientation encountered in the budgeting studies, and the depth of the technical process orientation encountered in the dynamic simulation studies. By addressing the third issue, that of risk assessment, the design of DAFOSYM expands analysis into a third dimension which permits evaluation of alternative dairy forage systems over a multiple-year period.

CHAPTER III

MODEL OVERVIEW

3.1 Introduction

The discussion in Section 2.6 pointed out the need for a research model capable of addressing three relevant issues of dairy forage systems. Such a model would: (1) be generic in the sense that it is capable of analyzing a broad spectrum of systems characterized by the composition of the dairy ration roughage source; (2) address the dynamics of technological factors which affect crop quantity/ quality produced; and (3) describe the riskiness inherent in alternative systems due to across-year yield variations of crops grown. The major contribution of this study is the development of a computerized system simulation model, DAFOSYM, which addresses these needs. The purpose of this chapter is to present an overview description of the model, and its methodology. It should provide insight into the intended use of the model, as well as the type of experiments that can be conducted using it. A detailed discussion of the author's contribution to model development is contained in Chapters 4 and 5. A complete understanding of model working and structure cannot be gained without reference to the model co-developer's companion dissertation (Savoie, 1982).

3.2 Model Research Objective

The model research objective underlying DAFOSYM is to evaluate dairy forage system alternatives. In discussing this research objective, it will be useful for the reader to maintain distinction between systems, models, and experiments, as well as the relationship between them.

3.2.1 Systems, Models, Experiments[1]

A system is a set of interconnected elements organized towards a goal or set of goals. A system is completely defined by three primary components: (1) system inputs are factors which stimulate change in the system; (2) system structure is the set of interactions or relationships between system elements; and (3) system output is the product resulting when system structure is stimulated by system inputs.

A model is an abstract representation of a real-world system whose goal is to mimic system behavior. Hence, a complex, stochastic, dynamic model predicts system output by mimicking complex situations characterized by uncertainty and change over time. Models can be judged by how well they mimic real system behavior.

An experiment is a procedure for testing hypotheses about systems. The goal of conducting an experiment is to discover something about system behavior and relationships. Hypotheses concerning systems can be tested either by experimenting directly with the real-world system, or by experimenting with a model of that system.

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[1]Discussion in this section draws heavily on Dent and Blackie (1979) and Manetsch and Park (1977).

The fundamental link between systems, models, and experiments is that model design must reflect the use to be made of the model. If important facets of real-world systems are excluded from the model, experiments concerning these facets cannot be undertaken using the model. Hence, the characteristics that distinguish a well-designed model are that it (a) addresses itself to important system facets, and (b) permits a broad spectrum of hypotheses to be tested using it.

3.2.2 Evaluating System Alternatives

DAFOSYM is a model of a dairy forage farm-firm system in the Great Lakes setting. Its purpose is to serve as a research tool for conducting experiments which address questions concerning dairy forage resource allocation.

Experiments using the model have as their objective the evaluation of system alternatives. A system alternative is defined as either (a) an alternative way of structuring the desired system if the problem is to design a non-existing system, or (b) an alternative management strategy if the problem is to manage an existing system (Manetsch and Park, 1977, p. 22). In Chapter 6, the results of six simulation experiments are reported which emphasize the former category of system alternatives. Six farm plans designed to provide alternative levels of corn silage and alfalfa for each an 80-cow and a 120-cow herd on a fixed land base are evaluated. Each alternative requires a re-structuring of the crop mix, machinery complement, and crop storage facilities for the hypothetical farm-firms.

3.3 Model Design: Addressing the Issues

The discussion in Section 2.6 called for a dairy forage systems model which is generic in design, which incorporates dynamic system interactions, and which assesses the riskiness of systems. The manner in which DAFOSYM addresses each of these criteria can be discussed in terms of model design.

3.3.1 Generic Model

The range of system alternatives which can be addressed by the model is limited only by the ability of the dairy herd to substitute feedstuffs in the ration. Systems can be evaluated which are designed to provide forage rations ranging from all alfalfa to all corn silage. Additionally, these systems may include high-moisture shelled corn grown on the farm. Although model structure contains the essential production relationships to enable experimentation of dairy forage systems in the context of Great Lakes agriculture, two caveats should be noted:

1. Simulation runs require a site-specific vector of system-exogenous inputs for model execution. System-exogenous (uncontrollable) inputs[1] to the model include both weather data and climatological-agronomic relationships for the location being simulated. For the present study, the vector of exogenous model inputs was developed using south central Michigan (Ingham County) data. Hence, although model structure and relationships are generic with respect to system design, management, and technology, simulation run results must be interpreted in light of the specific set of exogenous

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[1]For definitions of basic system analysis concepts, see Manetsch and Park (1977, Chapter 1).

variables used to drive the model.

2. Responsibility for appropriate design layout rests with the researcher using the model. System alternatives to be evaluated are introduced into the model by changing levels of control variables representing system-controllable inputs. Controllable inputs reflect the resource base (machinery complement, storage structures, acreage levels) and management options available to the farm operator. Testing a broad range of system alternatives requires that the model user design as many configurations of controllable inputs.

3.3.2 Dynamic System Interactions

Although the ultimate objective of the research is to make an economic assessment of alternative systems, the costs/returns associated with any system alternative are dependent on biological-engineering relationships, as well as on economic factors. These bio-engineering relationships primarily describe the process of managing feedcrops--physical materials--whose quantity and quality are determined by dynamic system interactions in the physical sphere. For example: machine capacity relative to area harvested affects timeliness of harvest; timeliness of harvest means plants are harvested at a lower maturity which increases alfalfa quality but decreases quantity; large harvest capacity reduces the probability of weather-damaged hay after it is cut, but large cutting capacity increases probability of weather exposure because more hay is cut per unit of time.

In order to capture dynamic facets of the dairy forage systems such as these, the simulation is modeled at the bio-engineering economic level. Three categories of variables can be identified in the model: (1) the state and rate of material flows of production through the system; (2) resource use associated with the material flows; and (3) costs/returns incurred with the use of those resources. Primary material flow variables monitor the quantity and quality of feeds available to the herd as they are processed through the system. Resource use variables estimate expenditure of resources in physical terms.

3.3.3 System Risk

Under the assumption that variation in system outcome is a measure of risk, DAFOSYM methodology permits assessment of risk by allowing multiple-year simulations of each system alternative. Over the multiple-year period, system-controllable inputs are held constant, so that the only source of input variation to the model derives from a vector of system-exogenous inputs, representing weather- and yield-related risk variables. To use computer experimental design terminology,[1] each system alternative becomes a treatment, and each simulation year, a replicate. Hence, the multiple-year simulation results in an estimate of the frequency or probability that system performance will attain a certain level.

With respect to using the model to evaluate the risk inherent in system alternatives, the following caveat should be noted:

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[1] An excellent discussion of computer experimental design is found in Dent and Blackie (1979, Chapter 6).

If evaluation of risk is to imply that system alternatives are to be ranked according to those which are "better," or preferred, then DAFOSYM output does not provide sufficient information. Risk evaluation aimed at making prescriptions for decision makers requires two important pieces of information: (1) an assessment of the probability distribution of the system performance measure; and (2) knowledge of the prospective decision maker's attitude, or preference, for risk.[1] DAFOSYM provides only the former.[2]

In order to conduct the experiments described in Chapter 6, a general assumption was made regarding the preferences of farm-firm managers in order to facilitate analysis. It was assumed that decision makers--as maximizers of expected utility--prefer more income to less, but are risk averse as well. This assumption--which permits use of first and second degree stochastic dominance criteria for designating efficiency sets--is explained in greater detail in Appendix F.

3.4 Model Identification

The essence of the DAFOSYM model is to capture the characteristics of the important relationships which describe dairy forage production in the Great Lakes setting. While the important production characteristics are emphasized, certain other aspects of the farming system are either simplified or ignored in order to make the model manageable. Model identification consists of defining how the model is to abstract from the real-world system such that analysis of the

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[1]Decision making under uncertainty is discussed in Anderson, Dillon, and Hardaker (1977).

[2]See Section 3.5 below.

central issues is facilitated.

3.4.1 Description of the Farming System Modeled

The production system which is used as the model in this study is a hypothetical commercial dairy farm in south central Michigan. The primary product which this farm produces for cash sales is raw milk. Secondary enterprises consist of feedcrops which are grown primarily in support of milk production. Crops grown consist of corn, harvested as either corn silage or high-moisture shelled corn; and alfalfa, harvested as either haylage or dry hay (baled). Area of each of the crops grown and harvested is the primary factor which defines the farm plan. A complete machinery complement, feed storage/handling system, and labor supply suitable for processing the mix of crop enterprises is assumed available as part of the farm resource base.

The modeled crop yield relationships are characteristic of some of the more productive soils in Michigan. Tillable farm acreage is assumed to be of Soil Management Group II (Brookston-Conover clay loam) with excellent drainage. Annual cumulative heat units between April 1 and October 31 average 2500 growing degree days (temperature base 5C); cumulative precipitation over the same period averages 52.6 cm. (20.7 inches). Experimental research plots in this environment have yielded 6.35 tons dry matter/hectare (DMT/HA)[1] (119.9 bu/acre) of corn and 14.11 DMT/HA (6.3 DMT/acre)[1] corn silage over the period 1971-1980, averaged over all hybrids (Rossman, various dates). Comparable plots have yielded 14.45 DMT/HA

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[1]Tons/hectare and tons/acre designate metric and English tons, respectively.

(6.45 DMT/acre) alfalfa averaged over three varieties[1] for the period 1970-1979 (Tesar, 1979).

The annual sequence of cropping activities is representative of well-managed Michigan dairy farms for the area. Corn planting begins after April 20, depending on soil and weather conditions. First-cut alfalfa is harvested as early as late May, but not prior to finishing corn planting. Subsequent harvests of alfalfa are taken approximately in early to mid-July, mid- to late August, and (under a four-cut system) mid-October or later. Harvest of corn silage begins after September 1, following completion of third cutting alfalfa harvest. Harvest of high moisture corn follows corn silage.

All alfalfa, corn silage and high moisture corn are stored on the farm and are available as feed for the dairy herd and replacements. In high-yield years, filled storage structures necessitate cash crop sales; in low-yield years, feedcrop purchases may be necessary. All rations for the milking herd are balanced at a milk production level reflecting the herd's genetic potential. Feed supplements in the form of soybean meal and non-protein nitrogen (NPN) (added to corn silage) are purchased as necessary to provide sufficient energy and protein levels.

3.4.2 Boundary for Modeled System

Model emphasis is before-the-farm-gate utilization of resources in the production of feedcrops to be marketed through the livestock enterprise. The environment in which this bounded system operates

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[1]Based on 4-cut system for Vernal, Pioneer 520, Saranac. Comparable 3-cut systems averaged 12.27 DMT/HA (5.48 DMT/acre).

is characterized by two sources of exogenous inputs to the system: (1) meteorological-agronomic conditions which determine crop yields and sequences of available field work days, and (2) economic market conditions which supply a vector of prices for inputs purchased and commodities sold.

No interactions are assumed to exist between the farm-firm and the input or output markets. This implies that acquisition of inputs by the farm-firm does not affect input prices nor that crop yields or milk produced affects commodity prices. Likewise, all input and output prices are deterministic. Thus, the farm is modeled as a microcosm where all dynamic interaction is restricted to technical production aspects of crop growth, harvesting, storage/feeding, and feed utilization activities. This simplification, while ignoring market considerations and price-risk, facilitates analysis of technical and economic production efficiency for a given regime of relative prices.

The environmental characteristic which receives attention in the study is the meteorological-agronomic relationship. This vector of exogenous inputs to the farming system is assumed to be non-deterministic and its impact on system performance is one of the central issues which the study addresses.

3.4.3 Activities of the Modeled System

Four before-the-farm-gate dairy forage production activities are modeled in DAFOSYM. These include: (1) crop growth/yields; (2) crop planting/harvesting; (3) crop storage/feeding; and (4) feedcrop utilization. These four activities completely describe the cropping/livestock interface of a dairy forage system. (See Figure

3.1.) Agronomic and engineering relationships in the model for the first three activities determine the actual quantity and quality of homegrown feeds which are available for consumption by the dairy herd given the cropping system. The fourth activity then places a value on the feedstuffs produced by determining their conversion rate into a marketable product--milk--and into cash crop sales and/or purchases.

No attempt is made in this study to model a complete dairy farm-firm. Elements modeled are restricted solely to those production activities or processes which directly affect, or are affected by, the ration fed to the dairy herd. These elements define the modeled farming system.

Production components which are essential to dairy farming but which are not modeled in this study include livestock housing, milking systems, livestock waste handling, livestock services (milking labor, veterinary, etc.), and tillage systems. Additionally, although the crop growth and feedcrop utilization activities reflect utilization of a specified acreage of cropland and cow units, no attempt is made to account either for the value of land or cow-unit flows depleted during the production period.

3.4.4 Production and Accounting Period

The assumed production period of the modeled farming system is one year. Over this period the productive resource base of the farm is assumed to be at steady-state level with neither acquisition nor disposal of durable assets. Although the research methodology entails multiple-year simulations, this procedure reflects the process of replicating system performance in the time dimension. A more detailed explanation is provided in Section 3.5.

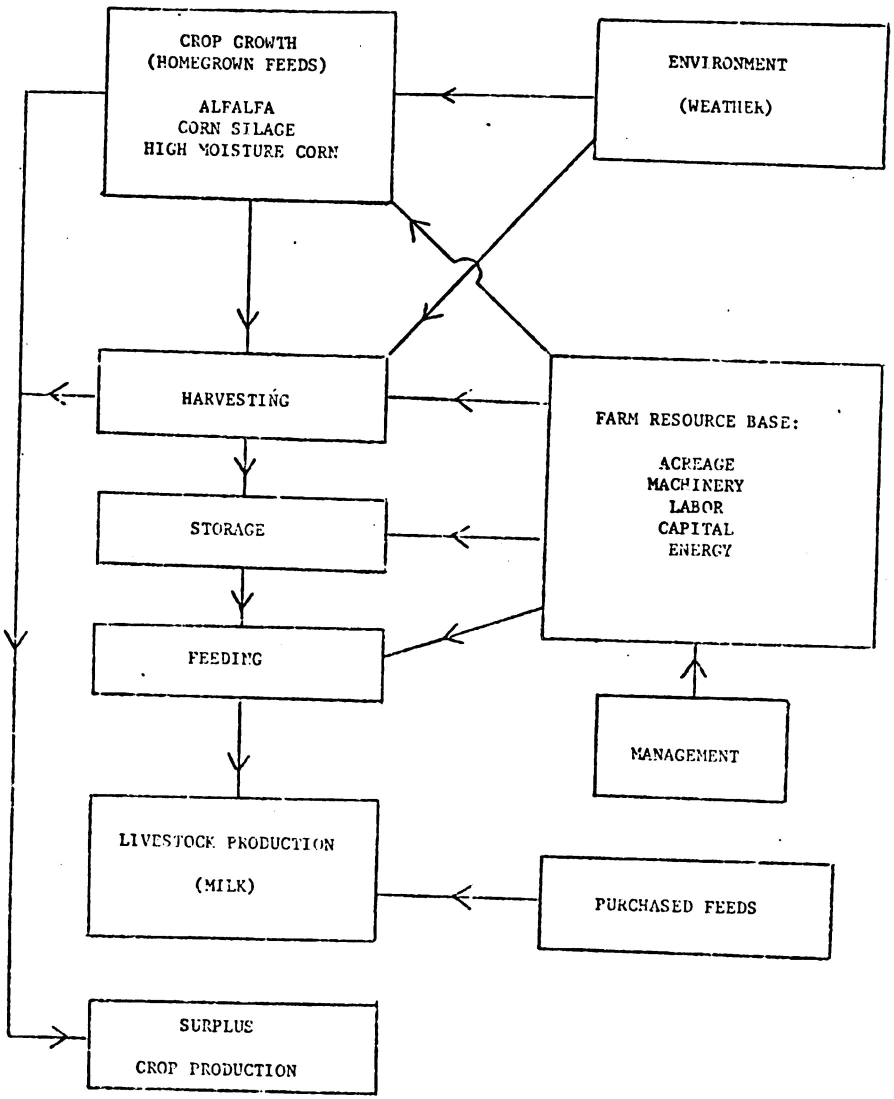

Figure 3.1 Modeled System of DAFOSYM

The accounting period of the model corresponds to the production period. This implies that all dollar returns from milk are realized in the same accounting year as those crop-related costs which are incurred in the production of feedstuffs used in the production of milk. This assumption facilitates the measurement of system performance as reflecting one year's use of resources to produce one year's milk production. End-of-year inventories of excess crops are forced to zero via cash sales, and shortages of feeds are purchased in order to maintain steady-state accounting.

3.4.5 Categories of Variables Modeled

The primary characteristic of the DAFOSYM simulation is that for any given production period, it monitors the transformation of farm resources into feedstuffs produced for the dairy herd, and then accounts for costs and returns associated with those resources used and products produced. Three categories of variables are monitored as the sequence of production events is simulated. Each is discussed in turn.

(1) Resource use. Resource use is measured in appropriate physical units for all inputs expended in the feed production process across the four farm activities simulated.[1] Resources used include land, labor, fuel, repairs, fertilizer, seeds, chemicals, as well as service flows from durable assets including the machinery complement and the feed storage/handling system. Additional purchased resources in the form of feed supplements are also accounted.

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[1]Activities simulated are crop growth/yields, crop planting/harvesting, crop storage/feeding, feedcrop utilization. See Section 3.4.3.

The resource base of the farm for any simulation run is a model user-specified option. This resource base designates to the model all system-controllable inputs, i.e., overt inputs assumed to be under the control and discretion of the farm operator. Let X be the vector of controllable inputs to the system. The vector X is to be distinguished from the vector of system-exogenous inputs (meteorological-agronomic and prices) described earlier.[1] Designate the vector of system-exogenous inputs Z. Whereas Z describes the agronomic and economic environment in which the farm-firm operates, X describes the specific system alternative being simulated and includes such input categories as crop acreage committed to each crop, specific configuration of machines in the machinery complement, size and number of feed storage structures, etc. Once the vector X has been designated, engineering relationships in the model establish the level of resource use of all variable and fixed resources by simulating the four system activities comprising a single production period.

(2) Material product flows. Material flow variables in DAFOSYM estimate dry matter production of each of the three feedcrops (alfalfa, corn silage, high moisture corn) produced on the farm. Biological-engineering relationships in the model monitor daily growth of alfalfa and feed losses incurred in the harvesting, storing and feeding phases of production. Similar estimates are made for the corn crop on a 15-day basis. Losses estimated are specific to the crop and harvesting/storage configuration specified. Ultimately, the model accounts for the accumulated quantities of each feed

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[1] See Section 3.4.2.

available for consumption by the herd at the end of the production period.

An additional material flow vector maintains a measure of the nutrient status of the alfalfa crop on a daily basis from the crop growth stage through feeding. Nutrient measures of alfalfa include both _in vitro_ dry matter digestibility (IVDMD) and crude protein. Concentration of quality levels of corn silage and high-moisture corn are assumed constant for the harvested materials.

Using a crude protein criterion, alfalfa haylage and dry hay can be separated and stored into two separate groupings representing higher and lower quality haylage and hay, respectively. Storage policy to separate crops on a quality basis accommodates more efficient feeding of high and low-producing milk cows.

Designating the vector of dry matter quantity and nutrient density of each of k (k = 1,2,3) feedcrops produced as DM_k, the modeled material flow relationship in DAFOSYM can be represented by the crop production function given in equation 3.1.

$$DM_k = g(X,Z) \qquad (k = 1,2,3) \tag{3.1}$$

This production function states that the quantity and quality of homegrown feedcrops available to the dairy herd each production period is related both to resources used and exogenous environmental factors.

(3) _Production costs_. Costs associated with all resources used on the farm in the production of DM_k are accounted for on an annual basis in the model. Since the vector of resources X includes durable and variable resources, both fixed and variable costs can be identified. Annual fixed costs convert the initial dollar

investment of the machinery complement and feed storage structures into an annualized flow. Total annual fixed costs of the farming system are given in equation 3.2 as the vector of fixed costs (FC) associated with the service flows of durable assets in X.

$$(3.2) \qquad FC = f(X)$$

$$(3.3) \qquad VC = v(X, DM_k) \qquad (k = 1,2,3)$$

In DAFOSYM, a capital recovery factor[1] with user-specified asset life and discount rate is used to determine FC. There are two exceptions to equation 3.2. Although X includes the crop area and herd size of the farm, annual fixed costs of these resources are not accounted for in the model.

The vector of variable costs (VC) is simulated in equation 3.3 as a function both of resources used and material flows DM_k through the system. Equation 3.3 is, in effect, the variable cost function[2] of the model. For certain inputs in the model, average variable costs of production[2] are positively related to DM_k. For example, as yields of crops increase, throughput and harvest rate of the machinery complement is reduced, thereby increasing labor, fuel, and repair costs per unit of feedcrop produced.

3.4.6 System Performance Measure

For each production period, an accounting is made of the performance of the dairy forage system alternative being simulated. The

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[1] Capital recovery factors are described in most discussions on capital budgeting in the literature, e.g., Weston and Brigham, Chapter 9 (1978).

[2] For a discussion of cost functions, see Henderson and Quandt, Chapter 3 (1971).

accounting performance measure in DAFOSYM is the net feed cost (NFC) of feeding the dairy herd and replacements for a one-year period. This measure is a common denominator which reflects the economic value of all resources expended in the four simulated activities to produce a given quantity of milk. Equation 3.4 defines NFC as the sum of total on-farm crop production costs (TCPC) and net cost of purchased feeds (NCPF).

$$NFC = TCPC + NCPF \tag{3.4}$$

Total on-farm crop production costs (TCPC) are defined in equation 3.5 as the sum of the annual fixed cost and variable cost vectors developed in equations 3.2 and 3.3.

$$TCPC = FC + VC \tag{3.5}$$

It should be recalled that, although the vector X designates the crop area and herd size in the farm resource base, FC does not measure the annual use cost of these resources. Hence, TCPC measures all on-farm non-land non-herd production costs associated with the crop growth, crop planting/harvesting, and feed storage/handling activities.

The derivation of net cost of purchased feeds (NCPF) in equation 3.4 is given in equation 3.6 as the sum of expenditures on purchased feed supplements (EPFS) and expenditures on deficit feeds (EDF) minus sales of homegrown surplus feeds produced (SSF).

$$NCPF = EPFS + EDF - SSF \tag{3.6}$$

Purchased feed supplements (soybean meal, NPN) represent a cash expenditure required to balance the dairy ration in order to obtain a specified ration nutrient density. Expenditures on deficit feeds reflect cash costs of purchases of alfalfa hay, corn grain, etc., in years of low yields of these crops when homegrown. Again, designating the quantity-quality vector of the k feedcrops produced on the farm DM_k as in equation 3.1, expenditures for purchased supplements (EPFS) and cash-purchased feedcrops (EDF) are seen to be functions both of feedcrop quantity and quality grown on the farm (equations 3.7, 3.8) and of the availability of other feedcrops.[1]

(3.7) $EPFS = p(DM_k, EDF)$

(3.8) $EDF = d(DM_k, EPFS)$

(3.9) $SSF = s(DM_k, EPFS, EDF)$

Sales of surplus feeds grown on the farm (SSF) in equation 3.9 represent negative costs to the system due to revenues generated from the excess crop sales. Normally, surplus feed sales occur only in high yield years.

Substituting equations 3.5 and 3.6 into equation 3.4, it can be seen that the performance measure of the dairy forage system reflects the interface of both the cropping and livestock systems. It should be noted that equation 3.4 is the "mirror image" of net returns to the residual resources of the dairy farm. "Residual resources" here refers to all components of the production system neither modeled nor cost-accounted in DAFOSYM. These were enumerated in Section 3.4.3. The least-cost ration balancer used to generate feed budgets for the dairy herd (see Appendix G) assumes a constant

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[1]Technically, equations 3.7 - 3.9 describe a linear programming (simplex algorithm) optimization approach to balancing a dairy ration. The simplified feed utilization cow component of the present DAFOSYM version uses a linear programming ration balancer solution to account for feed disappearance. This temporary model component is briefly described in Appendix G.

level of milk production M_o as a function of quantity and quality of homegrown feeds, and the availability of purchased feed supplements (equation 3.10). Gross revenues (GR) for this system are given in equation 3.11 as the product of milk produced and milk price (P). Net returns (NR) in equation 3.12 are then simply the profit maximizing version of the cost minimizing system performance measure given in equation 3.4 above.

(3.10) $M_o = m(DM_k, EPFS) \qquad (k = 1,2,3)$

(3.11) $GR = M_o * P$

(3.12) $NR = GR - NFC$

3.5 Model Methodology

The objective underlying the development of DAFOSYM is to provide a research tool for evaluating dairy forage system alternatives. The methodology employed to achieve this objective is a dynamic state variable model which lends itself to simulating the performance of a dairy forage farm-firm in a risky environment. The simulation model output culminates in a sample cumulative distribution function of the system performance measure generated over a multiple-year simulation period. The goal is to permit assessment of the risk-return tradeoffs when comparing dairy forage system alternatives.

A risky environment is defined in this study as one exhibiting variability in the events which occur. Whenever a system is subjected to non-deterministic or stochastic events (states of nature), system output can no longer be determined with certainty, and must be described in probabilistic terms. The objective in developing a non-deterministic model, then, is to provide full disclosure as to the riskiness which may be inherent in any system alternative by providing a measure of the variability of system performance over time.

The need to incorporate risk assessment in simulation models is addressed by various authors. Robison and King (1978) propose risk modeling because researchers are no longer willing to assume that single-valued response functions are a realistic description of agricultural production.[1] Dent and Blackie, p. 78 (1979) caution that although risk modeling may be ineffective or even detrimental for some purposes, a model to be used in a management decision support role needs to include uncertainty because "good decisions require more information than simply a knowledge of the average or most likely response" which deterministic models yield. Anderson (1976) makes the strongest appeal for risk modeling:

> ...few, if any, careful decision makers can afford to be guided only by single-valued responses like the mean.... Ideally, but especially when utility or attitudes to risk are in doubt, models should generate probability distributions of the pertinent variables on which decisions depend. Full disclosure of information and its quality is an uncertainty principle of major importance in modelling. (p. 221, Anderson's underlining.)

3.5.1 Source of Risk

The source of risk in DAFOSYM derives solely from the vector of climatological-agronomic input variables to the model. This vector Z results in random variability of across-year yields of

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[1] See Heady and Dillon (1961) for a classic empirical treatment of single-valued response functions.

alfalfa, corn silage, and high moisture corn crops, as well as in the availability of work days for harvesting the alfalfa crop, and for planting and harvesting the corn crop. Methods used to model the impact of weather variability differ greatly for the alfalfa and corn crops. For alfalfa, historical time series weather data are used to drive a phenological crop growth model, as well as to simulate sequences of harvest days as a function of rainfall-management interactions. Alternatively, a stochastic process model is used to generate representative time series data of corn yields, and days available for planting and harvesting.[1]

The impact of this weather-related risk vector Z on the system performance measure (NFC) is determined by relationships defined in the modeled system structure. Although these relationships are complex and dynamic, these impacts can be qualitatively summarized as follows:

1. For corn, the relationship between available field days and corn yield is positive; but for corn yield and net feed costs (NFC), the relationship is negative.
2. For alfalfa, the relationship between yield, crop quality, and net feed cost is negative; but between yield and quality, the relationship is also negative. Because alfalfa quality is also affected by the interaction of the sequence of harvesting days, the impact on system outcome of weather variability is largely indeterminate without simulating the process.

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[1]Detailed discussion of these methods is deferred to Chapters 4 and 5.

3.5.2 Generating the Cumulative Probability Distribution of System Outcome

A simulation run for DAFOSYM is characterized as subjecting the modeled dairy forage system to n (t = 1,2,...n) states of nature. For each state of nature, an alternative vector of climatological-agronomic-related variables is generated using both historical time series data (alfalfa) and a stochastic process generator (corn). Once levels for each of these variables have been set, the vector Z_t serves as a system-exogenous input to the dairy forage model for state of nature t being simulated. When the time period for a state of nature exactly corresponds to a production accounting period of the modeled farm-firm (one year), then simulation of a single state of nature is equivalent to generating one sample observation on the system outcome measure. In this manner, a single simulation run results in a sample distribution of n observations on the system performance measure, net feed costs (NFC).

Designating NFC, X, and Z as defined previously, the system performance measure NFC presented in equation 3.4 can be rewritten simply as a function of system-controllable and system-exogenous inputs as in equation 3.13.

$$\text{(3.13)} \qquad NFC = y(X,Z)$$

X is a deterministic vector of system-controllable inputs defining the system alternative resource base. In equation 3.14, for each of t (t = 1,2,...n) states of nature, vectors X and Z_t serve as driver variables for simulating the t-th observation of the system performance measure NFC_t.

$$\text{(3.14)} \qquad NFC_t = y(X,Z_t) \qquad (t = 1,2,\ldots n)$$

Over the n states of nature, the system sample output distribution, NFC(X,Z) is thus generated. Three comments can be made regarding this system output distribution.

1. The need for subjective encoding of the system outcome distribution is obviated. In assessing risk and returns incurred under system alternatives, the ultimate concern is with the probability density function of the system performance measure. Because the probabilistic nature of NFC(X,Z) is totally dependent on the non-deterministic exogenous input vector Z, there is no need to subjectively encode it.[1] Instead, NFC(X,Z) can itself be used as an indicator of the level and variability of system performance.

2. Simulated sample distributions can be described by their moments or by their cumulative distribution function. Once the n observations have been generated, either the sample moments or the cumulative probability distribution of NFC(X,Z) can be estimated. The latter is defined according to a rule given by Schlaiffer (1959, p. 104). The n observations are arranged in order of size, and the kth observation is used as a reasonable estimate of the $k/(n + 1)$ fractile of the distribution. This rule is appropriate regardless of the form of the underlying input distributions which generate the sample output distribution (Anderson, 1974b). This is an important consideration because NFC(X,Z) is an empirical distribution whose shape cannot be analytically determined due to the non-homogeneous probability distributions of the underlying exogenous input variables from which it is simulated (King, 1979).

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[1]Anderson, Dillon, and Hardaker (1977) discuss subjective probability encoding and its relationship to risk analysis.

The importance of deriving cumulative distribution functions of system performance measures is that they are necessary in determining preferred action choices using stochastic efficiency criteria for decision makers whose risk preferences are unknown. This is discussed in greater detail in Appendix F.

3. One serious criticism levelled against the validity of simulation models is that stochastic process modelling often ignores statistical dependence which may exist between underlying exogenous input variables (King, 1979; Anderson, 1974a). Anderson notes two types of dependency: serial (e.g., corn yields of plots planted over successive dates; rainfall in successive periods), and contemporaneous (e.g., same-year corn yields and alfalfa yields; rainfall and temperature on a given day). If serial and contemporaneous dependencies are believed to exist but are ignored in model specification, the validity of the system output distribution can be questioned. In the present study, both serial and contemporaneous dependencies were deemed to be relevant, but both were accounted for in model specification. This is discussed in greater detail in Chapter 5.

3.6 Research Experimental Design

Based on the previous discussion regarding research objectives, model description, and methodology, the research experimental design of DAFOSYM can now be summarized using Figure 3.2 as a reference.

An experiment using DAFOSYM consists of evaluating the risk-return tradeoffs of m (i = 1,2,...m) dairy forage system alternatives. Each system alternative i is a treatment defined by setting factors of the system-controllable input vector X at specified pre-designed levels. For each of the m (i = 1,2,...m) system alternatives, the

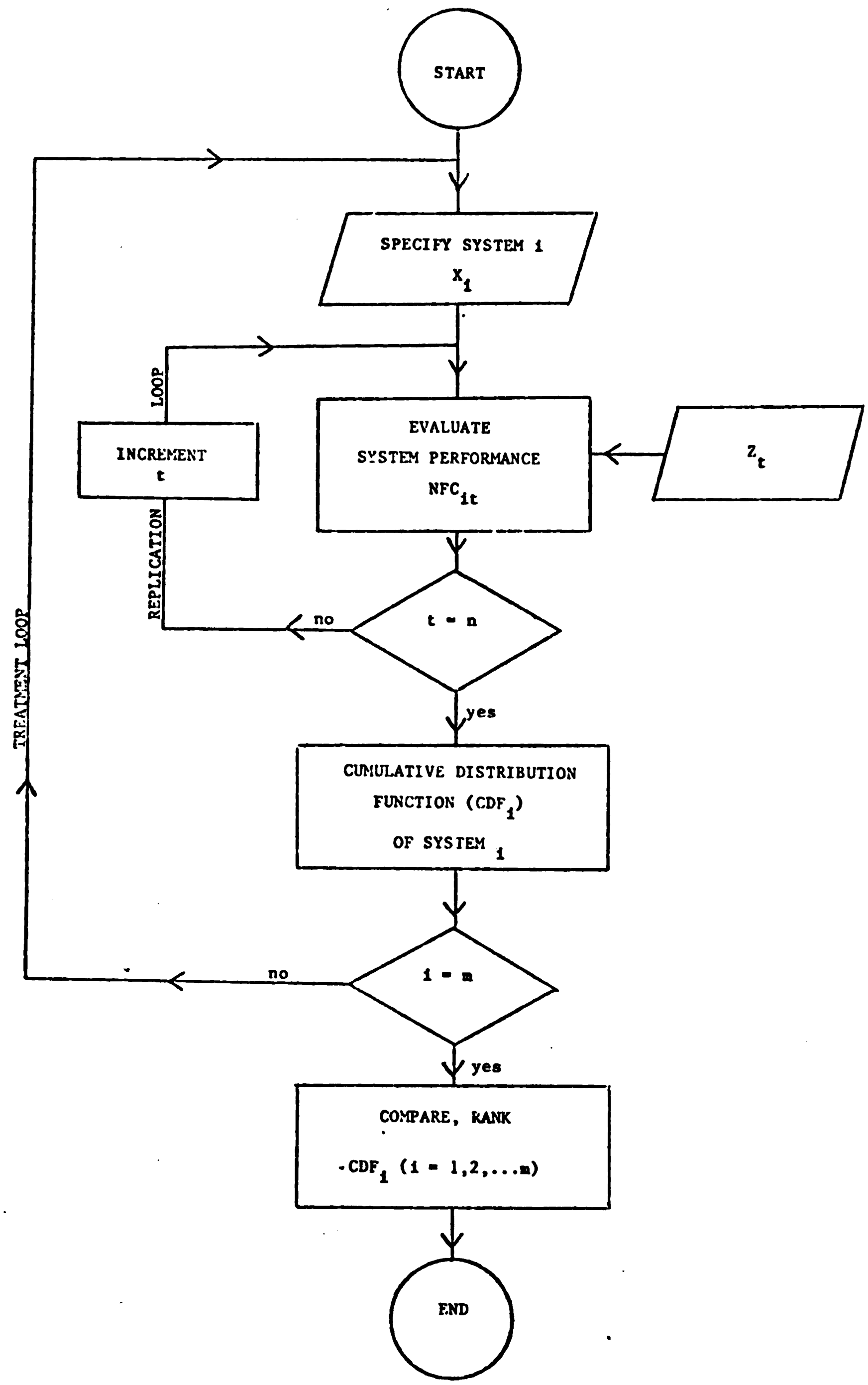

Figure 3.2. Research Experimental Design of DAFOSYM Model

vector X_i specifies the resource base or management strategy to be evaluated.

Performance of system i, NFC_i, is measured by simulating four system activities (crop growth, crop harvesting, crop storage/ feeding, feedcrop utilization) over the production accounting period of the model, which is one year. By submitting each system alternative i to n (t = 1,2,...n) states of nature defined by n alternative vectors of system-exogenous inputs Z_t (t = 1,2,...n), a total of (m * n) system performance measures, labelled NFC_{it} (i = 1,2,...m; t = 1,2,...n), are generated. The n states of nature simulated for each alternative system i characterize the replication of system performance over n years of alternative yield-climate regimes. Each set of n replications represents an n-observation sample distribution of the system performance measure, $NFC_i(X_i,Z)$ (i = 1,2,...m). Cumulative distribution functions (CDF_i) can be defined for each of the m sample distributions, and can be used to determine which of the i systems tested is preferred using stochastic dominance efficiency criteria.

3.7 Model Software Structure

The core of the computer simulation model DAFOSYM consists of four separate software modules, each compatible with a FORTRAN V compiler. Each of the two primary investigators into this study developed two of the modules: FORage HaRVest (FORHRV) and ALfalfa HARVest (ALHARV) were developed by Savoie; ALFalfa MODule (ALFMOD) and CoRN MODule (CRNMOD) were developed by the author. Each module is comprised of approximately 15 software subroutines and performs a well-defined domain of functions related to the simulation. A fifth module, BIGMOD, organizes the sequence of calls to the other four modules, and is responsible for outputting run results. Likewise, BIGMOD contains the feed utilization component which accounts for feed use at the end of each simulation year. Functions performed by each of the four core modules are summarized in turn:

FORHRV -- is a static initialization model called at the beginning of the simulation. The module is responsible for initiating engineering relationships and input-output coefficients for the specified machinery complement, as well as for establishing resource-use rate variables for harvesting and feed storage activities of the alfalfa crop.

ALHARV -- is a dynamic state variable model which simulates the status of harvested alfalfa yield and quality on a daily basis beginning with the cutting of the crop. The model accounts for sequences of alfalfa harvest days and crop drydown, and stores alfalfa produced into separate storage locations based on crop quality.

ALFMOD -- simulates yield and quality of the growing alfalfa crop on a daily basis up to the time of harvest. Yield is generated by an adapted version of a phenological crop growth model, ALSIM (Fick, 1981), which is driven by historical weather data and a soil moisture budget. Estimates of standing crop quality are in turn driven by state variables generated in the growth model.

CRNMOD -- simulates planting, harvesting, and storage of corn. Planting and harvesting are simulated on 10- and 15-day time increments, respectively, using a multivariate stochastic process model BTAGEN to generate available field work days. The process model also generates stochastic yields of corn silage and high moisture corn as a function of date of planting and date of harvest.

The four modules together with the organizing module BIGMOD comprise the DAFOSYM computer model. Development, underlying assumptions, algorithmic procedures, and user software information for FORHRV and ALHARV are described in detail by Savoie (1982). Development of ALFMOD and CRNMOD are described in Chapters 4 and 5 of the present study; user software information for these modules is provided in the Appendices A through E.

CHAPTER IV

MODEL DEVELOPMENT: PRE-HARVEST ALFALFA YIELD-QUALITY

4.1 Introduction

Due to the interdisciplinary nature of the present study, a modular research procedure was followed. Each of the primary investigators was responsible for design, modeling, and software implementation of well-defined subcomponents which ultimately could be merged into the final DAFOSYM model. As described in Sections 1.4 and 3.7 above, responsibility for modeling the dynamics of alfalfa crop production in a dairy forage setting was divided between the author and Savoie: the former developed ALFMOD which describes yield and quality of the standing alfalfa crop up until the time of harvest; the latter's ALHARV, using output from the ALFMOD module, then describes the alfalfa harvest and storage processes. Discussion in the present chapter restricts itself solely to model development of the pre-harvest alfalfa yield-quality component, ALFMOD.[1]

Key elements of the discussion group themselves around three topics: (1) adaptation of a phenological alfalfa crop growth model for predicting yields in the dairy forage farm-firm context (Section 4.3); (2) validation of the crop growth model under Michigan

[1]For a description of the alfalfa harvesting component, ALHARV, see Savoie (1982).

conditions (Section 4.4); and (3) the addition of a quality component to the alfalfa crop growth model (Section 4.5).

4.2 Rationale for Using a Phenological Alfalfa Crop Growth Model

The nucleus of the ALFMOD subcomponent is an adapted version of ALSIM1-Level 2,[1] a phenological crop growth model originally developed by Fick (1975, 1981). Level 2 is a dynamic computer simulation model which traces the growth of alfalfa plant components on a one-day time increment as a function of its soil-climatic environment. Ecosystem variables which drive the growth processes in Level 2 are daily weather data and a soil moisture budget.

Incorporation of a sophisticated physiological submodel into a larger farming systems management model such as DAFOSYM can be justified on the basis of two issues which complicate not only the "real-world" management, but also the system modeling, of the alfalfa production process:

1. Alfalfa growth is characterized by a rapid dynamic tradeoff of yield and quality as the growing plant matures. This relationship is itself highly variable across years and across cuttings, and is a product of the soil-climatic environment of the plant.
2. Daily weather pattern dynamics affect not only the growth rate of the standing plant, but also the length of the harvest period, and the beginning date of crop regrowth. Rainy days delay the average date of cutting and thus influence the quantity and quality of forages to be harvested.

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[1]Hereafter, ALSIM1-Level 2 is referred to as Level 2.

A phenological crop growth simulator, such as Level 2, provides a suitable method for addressing the subtleties underlying these issues. With respect to the dynamic yield-quality tradeoff, it generates the daily time path of alfalfa growth which can be used as the basis for tracking yield and quality of the alfalfa crop over the entire cropping season as a function of any soil-climate regime and cutting sequence. Likewise, with respect to weather pattern influences, the phenological model can initiate the regrowth time path at any starting date within the cropping season. As well, the accompanying historical weather data and soil moisture budget provide an indicator of the number and sequence of days available for harvest. Each of these issues is discussed in turn.

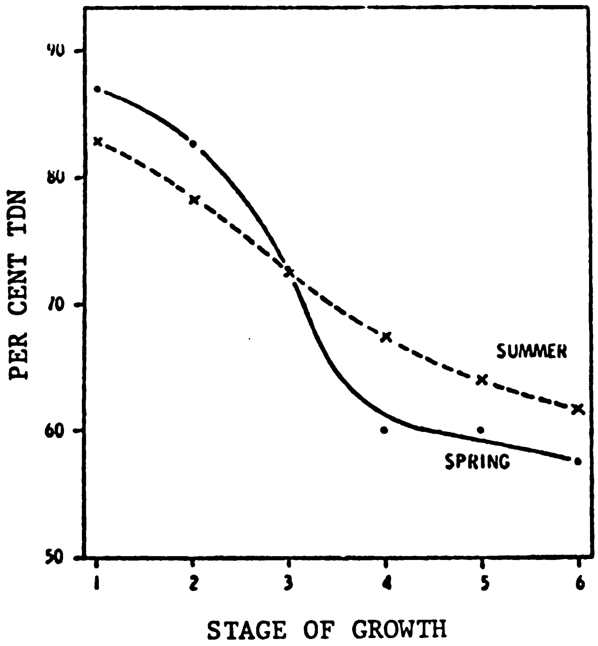
4.2.1 Dynamics of Yield and Quality of the Standing Alfalfa Crop

The literature is well-documented with studies exhibiting the time path of alfalfa yield and quality as the plant matures (Weir et al., 1960; Spahr et al., 1961; Welch et al., 1969; Thorn, 1978). All of these studies demonstrate that nutrient concentration of alfalfa deteriorates rapidly as plant dry matter accumulates. With maturity, a decreasing leaf-to-stem ratio reduces the fraction of nutrients in the total plant because stems contain less digestible energy and protein than leaves. In addition, the concentration of digestible energy and protein in leaves and stems declines with maturity (Mowat et al., 1966). The combined effect results in a management tradeoff of less feed of greater quality versus more feed of lesser quality as the date of cutting is delayed and the crop approaches physiological maturity.

Perhaps the most comprehensive research on alfalfa stage of maturity is reported in a series of studies conducted in conjunction with Smith at Wisconsin. Van Riper and Smith (1962) and Baumgardt and Smith (1962) document the yield-quality time path tradeoffs of alfalfa for both the first cutting and a summer regrowth cutting (second cut) over a two-year time period. The studies show that although the first cutting renders the largest dry matter yield, the highest concentration of crude protein and digestible energy resides in the regrowth cutting. At 1/10 bloom, the first cut contained 17.9% crude protein and 56.0% TDN, compared with 21.1% crude protein and 57.4% TDN for the second cut. Rate of decline of protein and TDN was more rapid for the spring cutting.

A follow-up study of similar design conducted over a three-year period (Smith, 1964) reports similar results: first cuttings averaged 18.2% crude protein and 60.1% TDN whereas the regrowth contained 19.5% crude protein and 67.3% TDN at 1/10th bloom. Averaged over the three studies, rate of decline of crude protein and TDN was .30%/day and .41%/day, respectively, for the first cutting, and .26%/day and .32%/day, respectively, for the regrowth period. Nevertheless, summer regrowth yielded only 60% as much plant dry matter on average as the first cutting.

A cursory analysis of the Smith studies suggests well-behaved yield-quality relationships when data are averaged over the period of each experiment. Figure 4.1, reproduced from Smith (1964) exhibits the alfalfa quality relationship underlying the Smith data. More importantly, however, the Smith-related studies caution that the significance of across-year variations in the data complicates the



Stages of growth are:

1 = vegetative
2 = pre-bud
3 = early bud
4 = 1/10 bloom
5 = full bloom
6 = green seed pod

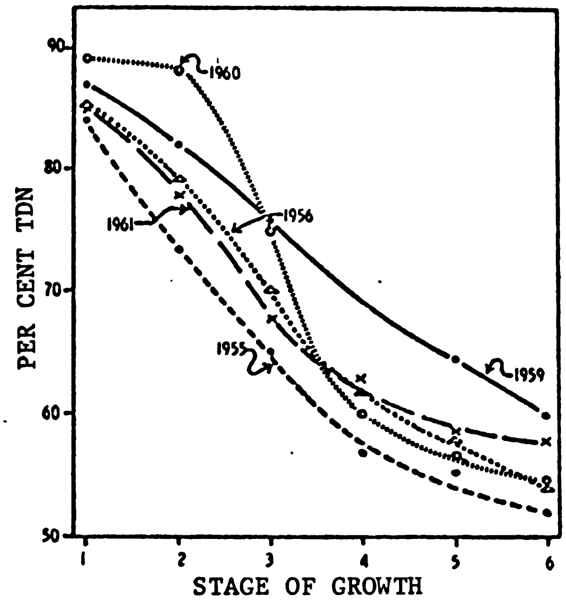
Source: Smith, 1964.

Figure 4.1 Changes in Percent TDN in the Spring and Summer Growth of Alfalfa Averaged over 3 Years the prediction of alfalfa yield and quality. Figures 4.2 - 4.4, also reproduced from the Smith studies, demonstrate: (1) broad across-year quality ranges at given stages of alfalfa maturity (Figure 4.2); (2) wide variation in both quality and stage of maturity as functions of calendar date (Figure 4.3); and (3) differences in both intercept and slope of alfalfa quality for both spring and summer cuttings across years (Figure 4.4). The Smith studies conclude (Baumgardt and Smith, 1962, pp. 8,9):

> These data raise some important questions concerning the practice of using date of harvest to estimate nutritive value of forages without regard to species or year of harvest.... Differing growth characteristics and maturity dates due to temperature and precipitation patterns probably accounted for the nutritive value variation.

A closely-related study (Matches et al., 1970) which investigates location effect in addition to stage of maturity reaches similar conclusions. Greater quality and stage of maturity variability was demonstrated across years for the same locations than for a specified year across locations. The authors conclude (Matches et al., 1970, pp. 6,7,8):

> The fact that such large differences [in quality and stage of maturity] occurred within a location between years and between the first and second growth indicates that prevailing environmental conditions have a marked influence on the rate of crude protein decline with maturity. Similar erratic trends occurred in the case of _in vitro digestible dry matter_.... It is quite apparent that quality changes in alfalfa with maturity can be expected to differ from year to year.... Consequently, it is important that alfalfa management trials be conducted over a period of several years, and that quality determination be made on more than just the first harvest growth within a year.

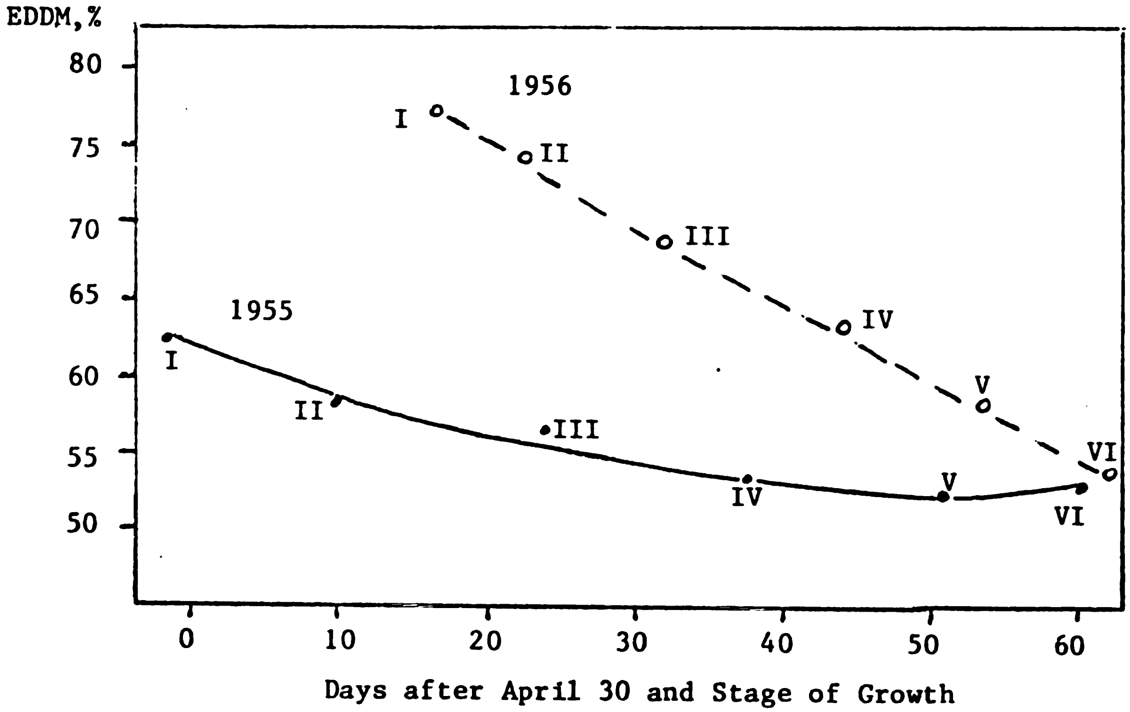


Stages of growth are:

1 = vegetative
2 = pre-bud
3 = early bud
4 = 1/10 bloom
5 = full bloom
6 = green seed pod

Source: Smith, 1964.

Figure 4.2 Differences Across Years in Total Digestible Nutrients in the Spring Growth of Alfalfa

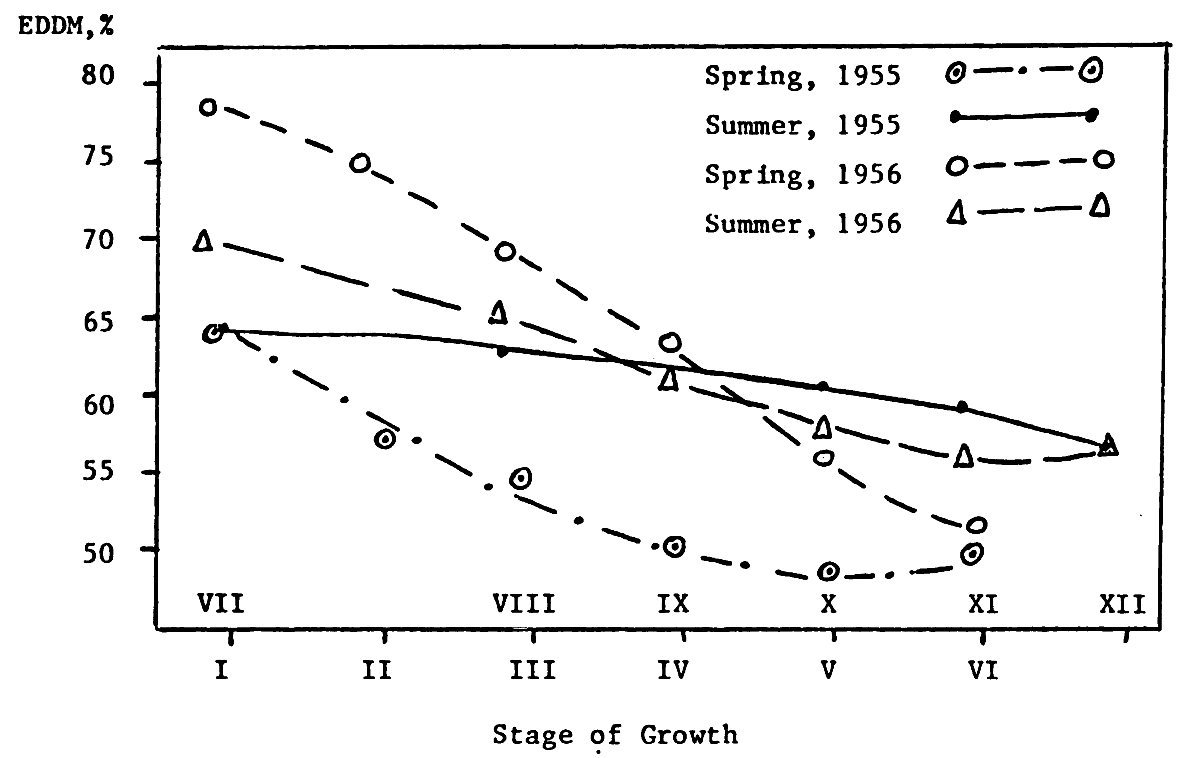


Stages of Growth (Spring Growth):

I	=	succulent	IV	=	1/10 bloom
II	=	pre-bud	V	=	full bloom
III	=	mid-bud	VI	=	green seed pod

Source: Baumgardt and Smith, 1962.

Figure 4.3 Changes in the Estimated Digestible Dry Matter (EDDM) Averaged over Spring Growth Alfalfa and Alfalfa-bromegrass Forages, 1955 and 1956



Stages of Growth (Spring Growth):

I = succulent
II = pre-bud
III = mid-bud
IV = 1/10 bloom
V = full bloom
VI = green seed pod

Stages of Growth (Summer Growth):

VII = succulent
VIII = bud
IX = 1/10 bloom
X = full bloom
XI = green seed pod
XII = seed

Source: Baumgardt and Smith, 1962.

Figure 4.4 Changes in the Estimated Digestible Dry Matter (EDDM) Averaged over Alfalfa and Alfalfa-bromegrass Forages, Spring and Summer Growth, 1955 and 1956

Other studies have tested what these "prevailing environmental conditions" might be which affect alfalfa yield-quality dynamics. Jensen et al. (1967) show that poorer quality forage is produced in a high temperature regime than in cooler temperatures, but that soil temperature has less impact on quality and growth than air temperature. Similarly, Greenfield and Smith (1973) show that plant dry matter and in vitro digestible dry matter (IVDDM) concentrations are mostly influenced by air temperature between bud stage and first flower, and that cooler temperatures increase quality. Finally, Vough and Marten (1970) show that soil moisture stress has an effect similar to low temperature. Under moisture stress, yields are reduced while leaf-to-stem ratios increase, thereby improving overall plant quality.

Implications for modeling. In a management perspective, the implication of the alfalfa yield-quality dynamics is that earlier harvest starting date and/or increased harvest capacity results in lesser quantities of standing forages containing higher concentrations of nutrients being harvested. Modeling the impact of this tradeoff on system performance measure necessitates modeling the time path of alfalfa yield and quality on a small time step basis, cutting-by-cutting, throughout the cropping season. Although the original Level 2 model contains no quality-prediction component, it does generate the daily time path of alfalfa yield as a function of plant environment. Because the Level 2 yield is segmented into a stem and leaf state variable, it is suitable for adaptation to include a quality component. This adaptation was undertaken by the author and is described in Section 4.5 below.

4.2.2 Daily Weather Pattern Dynamics

Whereas the soil-climatic environment affects alfalfa growth, the daily weather pattern--defined by the number and sequence of clear and rainy days during the harvest period--influences the length of the harvest period and the beginning date of crop regrowth.[1] If rainy days are numerous during the harvest period, the cutting process is prolonged and results in an increase in the stage of maturity at which the alfalfa plant is harvested when averaged over the entire harvest area. Hence, an increase in the absolute number of rainy days during harvest increases standing yield, but decreases crop quality.

While the frequency of weather pattern characteristics is described by the absolute number of rainy/clear days per harvest period, the sequence of rainy/clear days is also an essential descriptor of weather pattern dynamics. The number of sequential clear days, together with the specific machinery complement and its related set of input-output coefficients, determines the length of time required to field-cure the cut alfalfa before harvest can begin. Assuming that alfalfa cutting policy is a function of cut-cured alfalfa actually harvested (i.e., a maximum lead-area of cut alfalfa to harvested alfalfa is specified), then the sequence of clear days as well as their frequency affects average maturity stage of cut alfalfa. If the number of sequential clear days is small, harvest

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[1] Daily weather pattern also affects the quantity and quality of rained-on hay. The impact of weather on field-curing hay is modeled in ALHARV and is discussed in Savoie (1982).

and, consequently, cutting is delayed. Conceivably, the effect of a reduced absolute number of clear days on average harvest maturity could be countered by longer sequences of clear days.

The frequency and sequence of the daily weather pattern influences stage of maturity of alfalfa harvest, and consequently, the initialization of crop regrowth for all subsequent cuttings during the cropping season. If the first harvest of the cropping season is delayed due to poor weather, it is probable that average plant maturity is reduced for any given calendar date on subsequent cuttings. For any particular weather sequence, the date on which crop growth and/or cutting begins influences yield and quality of the harvested crop. As these starting dates change, different sequences and frequencies of daily weather patterns are encountered during the harvest period, and continue to have impact on all subsequent cuttings during the remainder of the cropping year.

Implications for modeling. From a modelling perspective, the phenological crop growth simulator, Level 2, addresses the weather pattern issue. First of all, because the model is driven by daily weather input data, both the sequence and frequency of rainy/clear days is readily available to the harvest management component,[1] and thus obviates the need to simulate daily weather patterns. Secondly, model structure of Level 2 permits the generation of the time path of alfalfa yield, regardless of the starting date of either the initial spring cutting or of subsequent summer regrowth. Adaptations

[1]Criteria for a go-no go day are specified in ALHARV (Savoie, 1982).

by the author included extension of the original Level 2 version to permit (a) multiple-day harvest periods along the daily yield-quality time path, and (b) a regrowth reset date which is a function of the length of the prior harvest cutting period. These adaptations are described in Section 4.3 below.

4.2.3 Other Considerations

In spite of the fact that a phenological crop growth model can be adapted to address itself to subtle technological issues related to the dynamics of alfalfa production, rationale for its use in the larger farming systems model is subject to its performance in relation to the stated objectives of the present study. In terms of the DAFOSYM model, the phenological crop growth simulator must generate alfalfa yield estimates which are representative of, and supported by, empirical data from the area to be simulated. This topic of empirical validation of Level 2 yield predictions is deferred until Section 4.4.

Beyond its ability to generate immediate output which is empirically substantiated, a phenological submodel serves a broader objective. As a mechanistic model,[1] it disaggregates the alfalfa production function into component parts describing the physiological processes underlying crop yield. As such, the subcomponent serves as a medium of interdisciplinary research which enhances communication between research disciplines. In addition, it encourages a modular approach to research not only by enabling state-of-the-art investigations to be undertaken by specialists in the respective disciplines,

[1]For a distinction between "black-box" and mechanistic (white box) models, see Brockington (1979).

but also by its potential integration into broader system models. In this manner, a larger systems model consisting of disciplinary submodels provides a format for evaluating the sensitivity of farm system level economic output to subsystem level technical and economic parameters.

4.3 ALFMOD: Adapting ALSIM for Use in DAFOSYM

The name ALSIM is used for a series of dynamic state variable computer simulation models of alfalfa growth which have been developed by Dr. Gary Fick, Department of Agronomy, Cornell University. Like other independently developed alfalfa growth models--SIMED (Holt et al., 1975), SIMFOY (Selirio and Brown, 1979), GROWIT (Smith and Loewer, 1981)--the ALSIM versions are deterministic phenological models which simulate the physiological processes of alfalfa growth, incorporating both biological and environmental elements. Both the earlier version, ALSIM1-Level 1 (Fick, 1975), and the updated expanded version, ALSIM1-Level 2 (Fick, 1981), were developed for use in integrated pest management studies. The Level 1 version has been utilized as a subcomponent in alfalfa weevil control studies (Ruesink et al., 1980; Klonsky, 1982) and in a study assessing alfalfa-dewatering technology (McGuckin, 1980). Level 2--the version adapted for use in the present study--represents an improvement over the Level 1 version in that it contains a soil water component and hence predicts "actual" rather than "potential" yields.

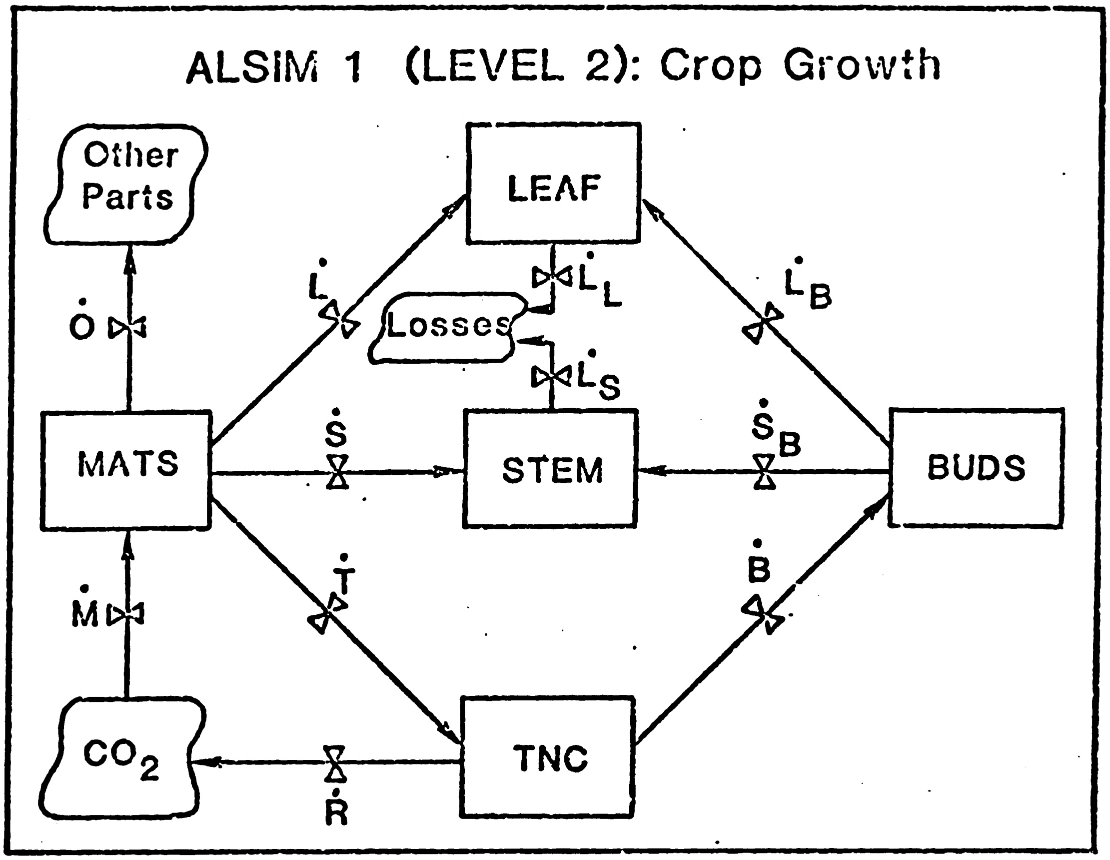
The crop growth-environmental relationships contained in Level 2 serve as the core of the yield prediction component in ALFMOD. Nevertheless, extensive software and algorithmic modifications, as well as expansions on the content of the original Level 2 model itself were required in order to adapt it for use in the farming systems context of the present study. Description of the original Level 2 model and modifications for use in DAFOSYM follow.

4.3.1 ALSIM Summary Description

The purpose of ALSIM1-Level 2 is to predict material flows between parts of the alfalfa plant, and to predict dry matter yield of the components of the plant as a function of the soil-climatic environment. The model operates on a 5^{o}C. base at a one-day time increment. The material of Level 2 is fixed carbon expressed as plant dry matter (grams/meter^2). The primary state variables of the model are:

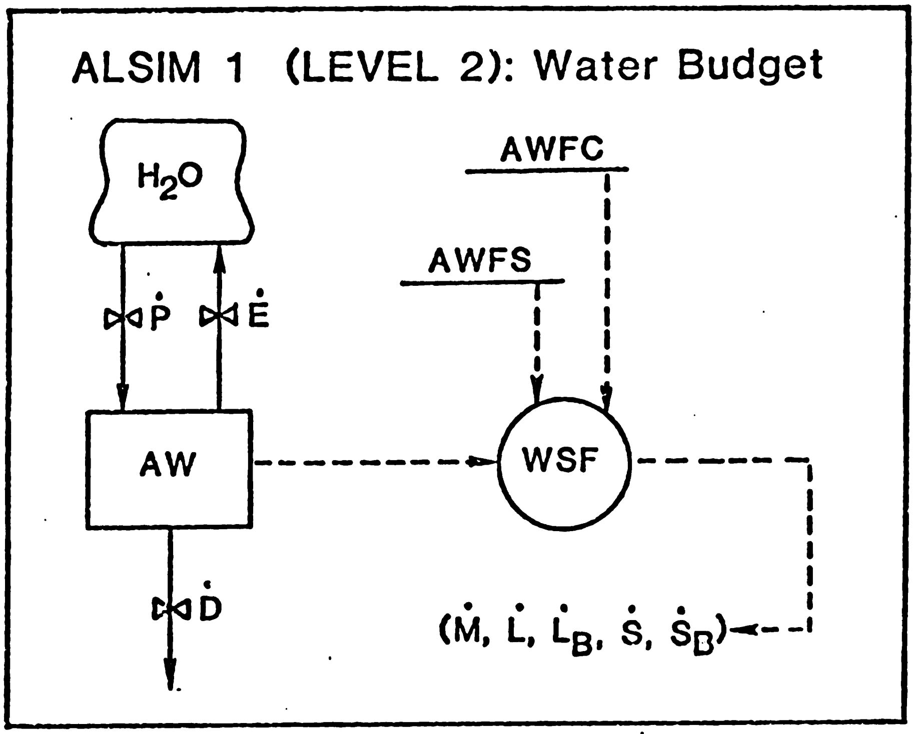
MATS	=	supply of photosynthetic DM that can be used for the growth of the parts of the plant defined in the model
TNC	=	total non-structural carbohydrates accumulated in the taproots
BUDS	=	basal buds of the plant
STEM	=	stems
LEAF	=	leaves
AW	=	available soil water in the root zone
GDDB5	=	cumulative growing degree days, base 5^{o}C.

Figures 4.5 and 4.6, reproduced from Fick, depict the overall structure of the plant growth component and the soil water budget of the model, respectively. Required daily climatological input data to the model consist of maximum temperature, minimum temperature, solar radiation (langleys), and precipitation for the specific location being simulated. Similarly, available soil water at field



The relational diagram of the crop growth components of Level 2 shows five main state variables and eleven processes to be simulated. The state variables represent parts of the simulated alfalfa crop: MATS (materials available for top growth and storage), LEAF (leaves), STEM (stems), TNC (total nonstructural carbohydrates in the taproots), and BUDS (basal buds for regrowth). The processes are described by rate equations that simulate the transfer of material between the parts of the crop: $\dot{M}$ (crop growth rate), $\dot{L}$ (leaf growth rate), $\dot{S}$ (stem growth rate), $\dot{T}$ (TNC storage rate), $\dot{R}$ (TNC respiration rate), $\dot{B}$ (bud growth rate), $\dot{S}_B$ (growth rate of stems coming from buds), $\dot{L}_B$ (growth rate of leaves coming from buds), $\dot{L}_L$ (rate of leaf loss), $\dot{L}_S$ (rate of stem loss), and $\dot{O}$ (rate of other uses of MATS). (Reproduced from Fick, 1981).

Figure 4.5 Flow Diagram: ALSIM1-Level 2 Crop Growth



The relational diagram of the soil water budget component of Level 2 shows the plant available water in the soil (AW) being increased by precipitation ($\dot{P}$) and decreased by evapotranspiration ($\dot{E}$) and runoff and deep percolation ($\dot{D}$). A water stress factor (WSF) is computed from AW and parameters for available water at field capacity (AWFC) and the available water fraction at which stress begins (AWFS). The growth rates $\dot{M}$, $\dot{L}$, $\dot{L}_B$, $\dot{S}$, and $\dot{S}_B$ (see Figure 4.5) are influenced by WSF. (Reproduced from Fick, 1981).

Figure 4.6 Flow Diagram: ALSIM1-Level 2 Water Budget capacity and available soil water at the beginning of the simulation must be specified in accordance with the soil type being modeled. Soil moisture in the model is depleted by evapotranspiration and percolation (based on a model by Ritchie, 1972; 1973) and is replenished either by rainfall or irrigation. Deficiencies of soil moisture in the root profile put the plant under stress and retard the growth rate.

The dynamics of the growth simulation consist of sequentially updating the values of the primary state variables by solving a series of rate (first order difference) equations driven by the daily climatological input data. Alfalfa yield is defined as the sum of STEM and LEAF. Losses in the model result from either harvest, senescence, or freezing. Harvest results in removal of topgrowth and the resetting of the state variables LEAF and STEM to zero. Regrowth then recommences and continues as long as environmental conditions are appropriate, or until a subsequent harvest is initiated.

A detailed description of Level 2, including model testing and documentation of model development, is found in Fick (1981). Development and testing of the regrowth mechanisms used in ALSIM are further described in Fick (1977).

4.3.2 Modifying and Expanding ALSIM for Use in DAFOSYM

The core relationships of the original Fick model describing the physiological processes of alfalfa growth are essentially employed in unadulterated form in ALFMOD. Nevertheless, certain expansions to the alfalfa growth model, as well as extensive operational modifications, were required in order to facilitate using the alfalfa simulator in the dairy forage farm-firm systems context of the present study. These primary modifications which describe the conversion of Level 2 to ALFMOD are summarized below.

<u>Conversion to FORTRAN</u>. The original versions of ALSIM were coded into Continuous System Modeling Program (CSMP), a FORTRAN-based IBM-specific computer simulation language. In order to operationalize the Fick model on other than IBM hardware systems, the author recoded Level 2 into FORTRAN V using Speckhart and Green (1976) and the IBM CSMP user's manual (1972) as references. Two nearly identical FORTRAN versions of Level 2 were developed: ALFMOD--the module which serves as the alfalfa growth component of DAFOSYM; and ALF2LP--an intermediate version of ALFMOD which can be used to simulate alfalfa growth independently of any broader farming system or management context.[1] The general structure of the FORTRAN software versions and a brief guide to their use is presented in Appendices E and B. Additional comments are contained in the software.

<u>Alfalfa quality subcomponent</u>. The original Level 2 version of ALSIM predicts dry matter production of various parts of the alfalfa plant over time. ALFMOD was expanded to include estimation of the concentration of crude protein and <u>in vitro</u> dry matter digestibility of both stems and leaves as the plant matures over time in the field.

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[1]Both the model content as well as the majority of the software contained in the 15 subprograms of both ALFMOD and ALF2LP are identical. Although "ALFMOD" and "ALF2LP" are used interchangeably in Chapter 4, they serve the two different purposes noted in the text. Technically, because it is an independent software model, ALF2LP was used for the validation and testing described in Section 4.4.

Ordinary least squares estimation procedures and the resulting prediction equations for each of the quality measures is reported in Section 4.5 below.

Regrowth starting date control. The original Fick algorithm, which was limited to one-day harvest periods, was modified to permit multiple-day harvesting periods of the alfalfa crop. During the harvest period of the crop, the modified algorithm of ALFMOD continues to update daily values of the state variables for dry-matter accumulation in the plant until the last day of cutting occurs. During this period, the updated values of the supply of photosynthate (MATS), the accumulated nonstructural carbohydrates in the root reserves (TNC), as well as the water available to the plant in the moisture profile (AW), are temporarily stored in the model. Once the total area of the alfalfa crop has been cut, the starting date for the regrowth of the subsequent cutting is then arbitrarily set to a date half-way between the first and last days of cutting. State variables for TNC, MATS, and AW are then reinitialized at stored values corresponding to the appropriate regrowth starting date. This procedure has two advantages: (1) Throughout an extended multiple-day harvest period, daily segments of the alfalfa crop continue to grow and be harvested on the "old" growth-quality curve; (2) regrowth of the subsequent cutting is retarded, hence, reflecting the impact of slow or delayed harvests earlier in the season on harvested yields and quality of subsequent cuttings.

Multiple-year simulation capability-weather data input file. Executive program control of both ALFMOD and ALF2LP was expanded to include capability multiple-year simulation runs. A historical weather data file--ELANSWTHR5378--containing 26 years of daily weather data (maximum temperature, minimum temperature, solar radiation, precipitation) was developed to accommodate the multiple-year simulations under East Lansing, Michigan climatological conditions. Development of the weather data file is described in Appendix D.

4.4 Validation of ALFMOD under Michigan Conditions

Validation procedures were undertaken in order to assess the phenological alfalfa growth simulator, ALFMOD, in relation to its prescribed use in the dairy forage systems model. Validation here refers to comparing the performance of the alfalfa model against recorded empirical data for the system being simulated (Dent and Blackie, Chapter 5, 1979). Given the system modeled in DAFOSYM, the purpose of the validation procedure was to determine whether ALFMOD was suitable for simulating growth of the alfalfa crop under East Lansing, Michigan climatological conditions on a clay loam soil.

Recalling the technical aspects of alfalfa production, there are numerous empirical yield measurements against which simulated performance could be tested. These include:

1. expected or average end-of-year yield of alfalfa;
2. expected or average yield on a cutting-by-cutting basis, reflecting the proportion of total yield harvested at each cutting;
3. variance of end-of-year yield;
4. variance of yield, cutting-by-cutting basis;
5. yield along the growth curve, i.e., the time path of alfalfa yield for the first, second, and third cutting

under different cutting systems (i.e., 1,2 or 3-cut systems) with different cutting dates.

Similarly, testing could be undertaken to validate alfalfa quality predictions generated by the model. Such tests could be compared with empirical data identical to those cited, except that measurements would be taken of protein concentration and digestibility instead of yield in points 1-5 above.

Although each of the above measures reflects an aspect worthy of validation, the validation process is itself limited by (a) the availability of empirical data, and (b) a suitable method for testing model performance against that empirical data. In the present section, a formal validation of two of the five measures listed above is reported. First, model yield performance along the growth curve (point 5, above) is tested against two years' historical yield data under three cutting systems. Next, end-of-year total yield (point 1, above) is tested against nine years' historical data. Due to empirical data limitations, the other measures of model performance are then evaluated in a less objective, less formal manner.

4.4.1 Growth Curve Yield Validation

The validation procedure used for testing ALFMOD yield predictions along the alfalfa growth curve is described by Dent and Blackie (1979) and Cohen and Cyert (1961). First, the simulation model is set up to conform to conditions for which historical output data is available. The model is then run and, subsequently, a linear regression is fitted on the resulting set of paired observations of model output versus historical measurements. An unbiased model would provide a regression line which passes through the origin (intercept = 0) with a slope of

1. The test is then to determine whether the intercept and slope of the fitted regression line are significantly different from 0 and 1, respectively.

Data and model input parameters for validation. Three considerations were taken into account when selecting historical data which would be suitable for yield validation purposes:

a. Yield measurements taken throughout the crop growing season should be obtained in addition to yields measured at harvest time only. Likewise, historical data reflecting yields measured from one- and two-cut systems in addition to the more typical three-cut system was preferable. Such multiple-yield measurements from several alternative cutting systems are desirable because they allow comparison of the simulation model to predict yield along the growth curve as well as at harvest time. Validation based on growth curve measurements is more comprehensive in that it tests performance of the alfalfa growth model throughout the cropping season, as opposed to merely at two or three points representing harvest.

b. It was desirable to obtain measurements described in (a) for more than one year in order to be able to test model predictions under more than one weather regime.

c. Relevant daily climatological data at the test plot locations, as well as information on plot soil texture and structure, must be available.

Historical yield data for Vernal alfalfa conforming to the above specifications was obtained through private correspondence from Dr. F.W. Fuess, Illinois State University. Two years of weekly yield data were taken by Fuess between May 3 and August 30 for 1,2, and 3-cut alfalfa systems on a Conover loam soil at East Lansing, Michigan in 1961 and 1962. Both experiments were conducted on established Vernal plots. Experimental procedures and results, as well as the weekly yield data (in graphical form) are presented in Fuess (1963) and Fuess and Tesar (1968).

The soil moisture holding capacity coefficient--an input to the simulation model--was estimated for a Conover loam soil by consulting the Michigan Irrigation Guide (Vitosh and Fisher, 1981). Available water at field capacity (AWFC) was set at 200 mm which corresponds to .1875 inches of water/inch in a 3½ foot soil profile. Although this figure reflects AWFC of both the Conover and Brookston soils at East Lansing, the figure is somewhat arbitrary since the actual root depth of the test plot alfalfa plants was not known. However, the assumed 3½ foot soil profile represents the source of 85% of the soil moisture of the mature alfalfa plant (Schwab et al., 1971).

Validation results and discussion. The ALFMOD model was used to simulate alfalfa growth for the two-year validation period using daily maximum and minimum temperature, precipitation, and solar radiation collected at the East Lansing weather station for 1961 and 1962. Three runs, corresponding to three cutting systems, were made: one-cut harvested August 30; two-cuts harvested June 21, August 30; and three-cuts harvested May 31, July 12, and August 30. Model output from the three simulation runs were paired with the historical Fuess data and an ordinary least squares regression line of the form $Y_{MODEL} = a + b_1 Y_{FUESS}$ was fitted for each cutting over the two-year period under each of the three cutting systems (where Y represents simulated or actual yield measured on a weekly basis). The regression results for the six fitted lines are presented in Table 4.1. Graphical presentation of model output versus the historical data for the three-cut system is presented in Figures 4.7 and 4.8. The water stress factor (WSF), which is also plotted, takes a value between 0 and 1 and indicates whether the simulated plant is under moisture stress.

Table 4.1 demonstrates that ALFMOD output corresponds well with measured data for the two- and three-cut systems. Only for the one-cut system are both the slope and intercepts found to be significantly different from 1 and 0, respectively, at the .01 and .05 levels of significance. Correlation coefficients between the simulated and historical data were also calculated for the 1, 2, and 3-cut systems and were found to be .95, .95, and .97, respectively.

These results demonstrate that the model can be used with confidence on two- and three-cut systems. Nevertheless, a word of caution is in order. First of all, in spite of the overall ability of ALFMOD to track the growth path of the Fuess data, one must recall that this validation process covers only a two-year period. Nothing can be said of how well the model might have followed the historical growth curve for other climate-soil combinations. It should be noted, however, that Fuess reports the 1962 cropping season to have included long dry spells due to poor and irregular distribution of precipitation.

Secondly, a close inspection of the growth curves for the data analyzed above demonstrates a wider divergence between model output and historical yields for the late regrowth periods immediately following harvest. Both Fuess and the simulated water stress factor indicate that plants were under stress during this period; yet, it appears

Table 4.1 Results of Regression Analysis Testing ALFMOD Yield Values Against Fuess Data

System: Cuts/yr.	Cut no.	Estimated Coefficient[1] a	b	R^2	n	Rejection Significance Level[2]	
1	1	.444 (.132)	.831 (.049)	.90	35	††	¶¶
2	1	.248 (.126)	.911 (.059)	.95	15		
2	2	-.007 (.122)	.751 (.110)	.72	20		¶
3	1	.155 (.091)	.963 (.056)	.97	9		
3	2	-.086 (.097)	1.128 (.087)	.94	12		
3	3	-.307 (.142)	1.194 (.224)	.703	14		

Numbers in () are standard errors of regression coefficients.

[1] a = intercept; b = slope

[2] Null hypothesis $H_o(a)$ is that a is not significantly different from zero; null hypothesis $H_o(b)$ is that b is not significantly different from one.

† = rejection of $H_o(a)$ at the .05 level
†† = rejection of $H_o(a)$ at the .01 level
¶ = rejection of $H_o(b)$ at the .05 level
¶¶ = rejection of $H_o(b)$ at the .01 level

All tests use the Student t-statistic with n-2 degrees of freedom.

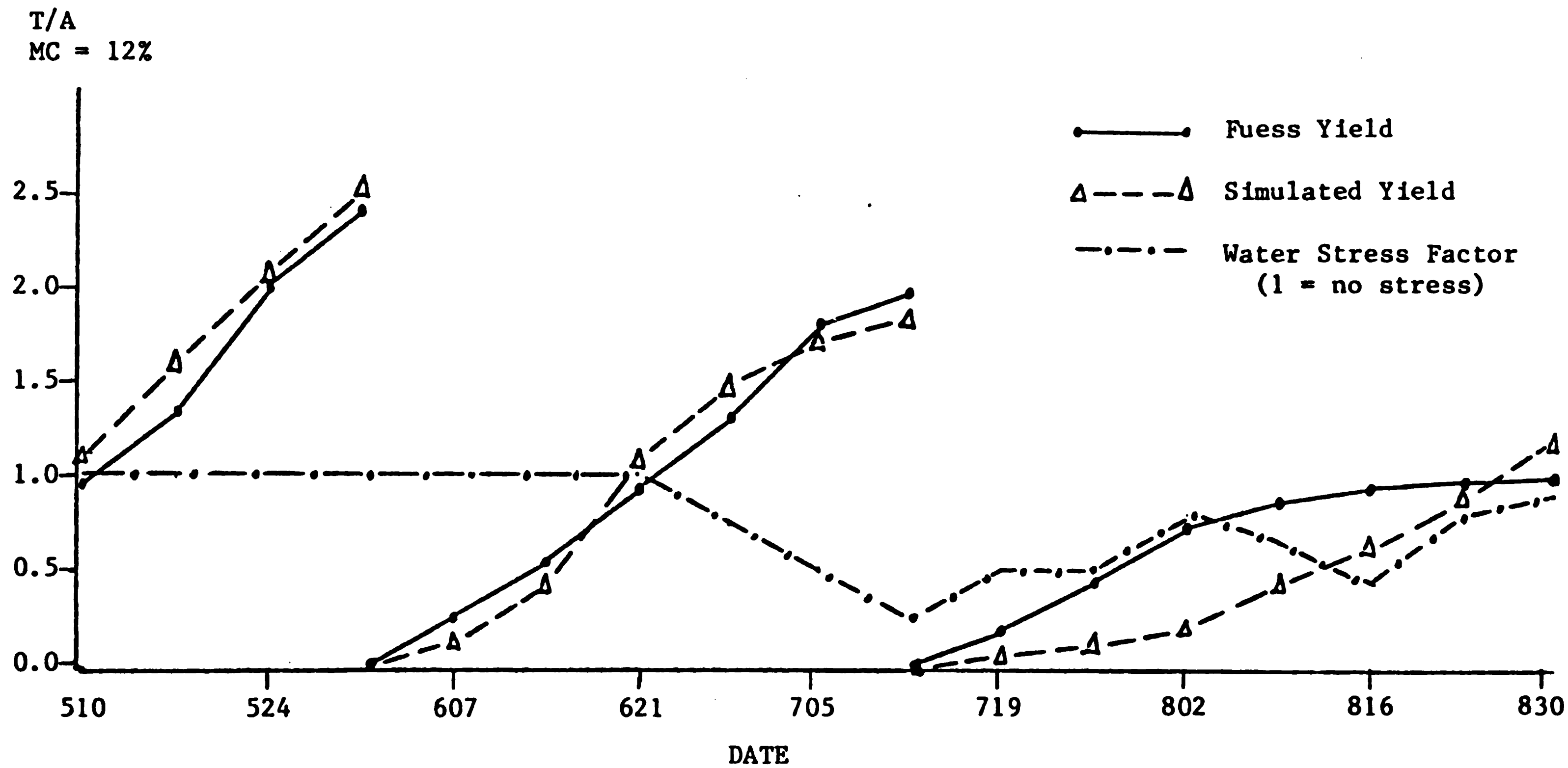

Figure 4.7 Simulated (ALFMOD) Versus Historical (Fuess, 1963) Alfalfa Yield, 3-cut System, East Lansing, Michigan, 1961

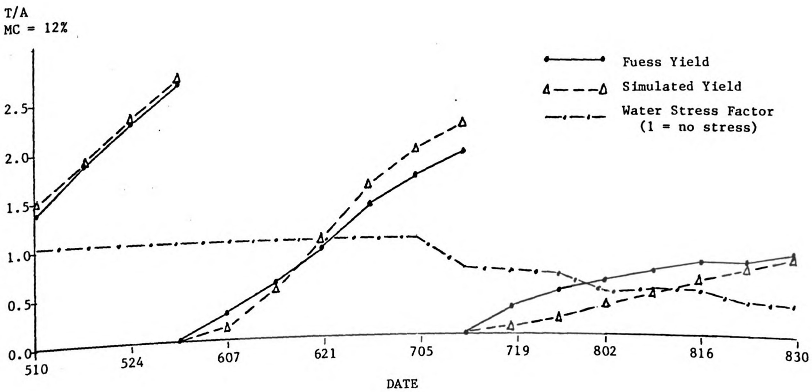

Figure 4.8 Simulated (ALFMOD) Versus Historical (Fuess, 1963) Alfalfa Yield, 3-cut System, East Lansing, Michigan, 1962

ALFMOD over-stressed plants relative to historical data. Although model input parameters can be adjusted to correct this, the author has found that these corrections could not be made without causing overproduction at other periods earlier in the cropping season. Hence, model testing and/or calibration are recommended prior to extensive use of the model under broad ranges of simulated environments.

4.4.2 End-of-year Yield Validation

The results reported in Section 4.4.1 are a comprehensive test of the alfalfa model's ability to predict yield throughout the growing season. Over the two-year test period, the growth curve yield validation represents a comparison between simulated and historical measurements at 82 data points. Nevertheless, it is desirable to determine model performance over a longer time horizon than solely the two-year period evaluated above. However, the tradeoff in testing over a greater number of years was that the detailed weekly yield measurements were not available. Hence, the tests reported in the present section are directed at total end-of-year yield comparisons between empirical data and simulation output measured over a nine-year period. The student-t distribution is used to determine whether mean values of the two samples (historical and simulated) are significantly different.

End-of-year yield data. Alfalfa test plot data was obtained from Dr. M.B. Tesar (Tesar, 1979) for stands of alfalfa established in 1970 on Brookston loam soil and harvested an average of four times annually over the period 1970-1979 at Michigan State University. Simple linear regression techniques were utilized to detrend the

the yield data for Vernal, P520, and Saranac varieties, but the results were highly insignificant, i.e., yields of each variety did not significantly decrease over the life of the stand. Yield data obtained was annual end-of-year yield summed over the individual cuttings.

Results and discussion. The alfalfa simulation model was set up to simulate the period 1970-1978 (weather data for 1979 was not available) under similar conditions and harvesting dates. T-tests were then used to test the hypothesis that the mean simulated output was equal to the mean of each of the three sampled varieties from the plot data. Results of these tests are presented in Table 4.2. Rejection of the null hypothesis leads one to infer that the samples (simulated and empirical) were not likely drawn from the same underlying parent population. As can be seen, the only significant difference over the nine-year period is between the simulated output and Saranac. Saranac is a high-yield variety suitable for short stand-life (3 years). Alternatively, P520 is a successful high-yielding variety in mid-Michigan with a long stand-life (5 years). Because the original ALSIM model was not designed to be a variety-specific model, two pooled data sets (one pooled over Vernal, P520, and Saranac; the other pooled over Vernal and P520) were constructed and submitted to t-testing. Pooled data sets might represent combinations of "typical" or rational varieties of alfalfa to grow in mid-Michigan. Results of the pooled t-tests are also found in Table 4.2.

The results of the t-tests demonstrate that the alfalfa model performs well when comparing mean yields of pooled-variety tests as well as for certain "standard" (Vernal) or long-stand varieties

Table 4.2 Sample Statistics and t-tests for ALFMOD Performance Versus Various Alfalfa Test Plot Yields, Michigan State University, 1970-1978, DMT/A

Sample Statistics	ALFMOD	Alfalfa Varieties[1], 1970-1978, MSU				
		Vernal	P520	Saranac	Pool VPS[2]	Pool VP[3]
$\overline{X}$	6.613	6.170	6.813	5.940	6.307	6.493
s	.530	.598	.666	.892	.675	.6039
CV	.080	.097	.097	.150	.107	.093
t[4]	---	-1.653	.705	-2.650	-1.069	-.448

[1]Data source: Tesar, 1979.

[2]Sample statistics pooled over Vernal, P520, and Saranac.

[3]Sample statistics pooled over Vernal, P520.

[4]The t statistic is calculated:

$$t = (\overline{X}_1-\overline{X}_2)/s_p\sqrt{(1/n_1) + (1/n_2)}$$

$$\text{where: } s_p = \sqrt{\frac{(n_1-1)s_1^2 + (n_2-1)s_2^2}{n_1 + n_2 - 2}}$$

For the two-sided test the hypotheses are:

H_o: $\overline{X}_1 = \overline{X}_2$ $\quad H_a$: $\overline{X}_1 \neq \overline{X}_2$

Critical $t_{.05/2,16} = 2.120$; critical $t_{.01/2,16} = 2.921$

For the one-sided test the hypotheses are:

H_o: $\overline{X}_1 = \overline{X}_2$ $\quad H_a$: $\overline{X}_1 < \overline{X}_2$ or H_a: $\overline{X}_1 > \overline{X}_2$

Critical $t_{.05/16} = 1.746$; critical $t_{.01,16} = 2.583$

In all cases, simulation sample output is compared with plot sample data.

(P520). However, if the goal is to model a specific variety (e.g., Saranac), then model validation and/or calibration needs to be undertaken to determine how well the model performs prior to simulation.

4.4.3 Other Indications of Model Performance

The three remaining important measures cited earlier of how well an alfalfa model performs are: (a) how well it predicts distribution of yield over individual cuttings (point 2, Section 4.4); (b) how well it predicts variability of yield across cuttings (point 4, Section 4.4); and (c) how well it predicts variability of total end-of-year yields across years (point 3, Section 4.4).

With respect to (a), data representing four individual cuttings taken approximately on June 1, July 10, August 25, and October 20 over a 5-year period were obtained from Tesar (1980). The data were pooled across two varieties (Vernal and Saranac) grown on Brookston loam at East Lansing, Michigan. Over the 5-year period the average proportion of total yield harvested at each of the four cuttings was 36.0, 28.6, 20.7, and 16.5 percent, respectively. This compares favorably with a 26-year simulation run of ALFMOD with simulated harvests taken on the above dates. Proportion of total yield obtained at each cutting averaged over 26 simulation years was 34.9, 26.4, 21.5, and 17.2 percent, respectively.

With respect to (b) and (c) above, sample statistics from the Tesar data (1980) indicate that the coefficient of variation (CV) for each of the four cuttings was 12.3, 12.5, 25.9, and 12.9 percent, respectively. This compares with simulated CV's for each of the four cuttings of 9.0, 8.4, 27.5, and 18.1 percent, respectively. Evidently, due to moisture stress and weather irregularity late in the season, variability of yield increases for the later cuttings. CV's for total end-of-year yield for the 5-year empirical and simulated samples were 4.8 and 8.3 percent, respectively. However, the simulated 9-year sample presented in Table 4.2 resulted in a CV which was less than respective end-of-year CV's for the historical data against which it was compared.

In summary, the validation tests reported in this section demonstrate that the phenological growth model provides favorable simulation of the alfalfa growth curve, expected end-of-year total yields, and distribution of yield across cuttings under Michigan environmental conditions. An area which appears to be in need of improvement, however, is late season growth curve response under moisture stress. Additionally, although the model correctly predicts higher yield variance for later season cuttings than for early harvests, the author conjectures that the absolute level of variance for individual cuttings and total yield somewhat underestimates variance of yields encountered in test plots.

4.5 Accounting for Alfalfa Quality in ALFMOD

The discussion in Section 4.2.1 above demonstrated that there is a rapid tradeoff of yield and quality[1] as the growing alfalfa plant matures. Because the original Level 2 alfalfa growth simulator contains no quality component, a series of equations was estimated in order to incorporate the alfalfa yield-quality relationship into the DAFOSYM model.

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[1]Measures of alfalfa quality include crude protein and IVDMD.

4.5.1 Specification Problems

One of the initial difficulties encountered in this process was related to the specification of the quality model. The Smith studies (see Section 4.2.1) demonstrated that alfalfa quality at any given stage of maturity varies both across cuttings and across years (Figures 4.3, 4.4). This leads to the hypothesis that alfalfa quality is the result of a complex set of environmental relationships, described perhaps, by a function containing several meteorological-soil variables serving as arguments. Given the numerous alfalfa quality studies which have been published, such hypothesized models could be specified, estimated and tested, providing that data sets for the independent argument variables (e.g., temperature, sunlight, precipitation, soil moisture, etc.) had been collected and were readily available. Because such data sets are generally unavailable, or at best, difficult to obtain, some researchers (Cloud et al., 1968; Millier et al., 1970; see Section 2.4) have reverted to specifying alfalfa quality models using either calendar date or number of days since last cutting as the sole argument. In light of the Smith studies, such models are of limited usefulness since they take no account of the underlying physiological relationships which influence alfalfa quality. Across years, such models will predict identical quality of the standing crop for any given date, a relationship which Smith's results clearly refute.

A more recent model developed by Klonsky (Ruppel et al., 1982) specifies cumulative heat units (measured as growing degree days base 5^{o}C.) as the argument of alfalfa crude protein, digestibility, and crude fiber. This model is clearly an improvement over Cloud et al. and Millier et al. in that growing degree days as a measure of environmental events serve as an index of plant maturity and reflect across-year quality variability resulting from different annual weather patterns. Nevertheless, the Klonsky model is unable to distinguish quality differences as a function of environment across cuttings. The data set on which the Klonsky model is based is first-cut alfalfa measured between mid-May and early July over a two-year period. Across cuttings, any given growing degree day reading will result in identical quality estimates by the model, even though growing degree days historically accumulate at a much higher rate for second and third cuttings, than for first.[1] Implicitly, a quality model specifying cumulative heat units as an index of plant maturity will underestimate crude protein and digestibility and overestimate crude fiber for summer regrowth cuttings, if that model is estimated using spring growth data only. This problem can be averted only if separate quality equations are estimated for each individual cutting, or, if a single quality equation contains a dummy shifter variable for each cutting. In either case, the cumulative-heat-units approach requires that empirical measurements of alfalfa quality be taken over first cutting as well as for subsequent regrowth periods. With the exception of the Smith-related studies, such empirical measurements would represent a useful and welcome departure from the trend apparent in the literature of evaluating only spring growth alfalfa.

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[1]Problems using growing degree days as a measure of plant maturity for initiating the harvest algorithm are discussed in Section 4.6.

4.5.2 Alfalfa Quality as a Function of Herbage Composition

Due to the difficulties noted above, the alfalfa quality model estimated for use in the present study specifies the protein and *in vitro* dry matter digestibility (IVDMD) of alfalfa to be a function of the proportion of alfalfa herbage consisting of leaves and stems. This model specification is convenient for two reasons. First, it avoids the problems noted in Section 4.5.1 which result from using phenological events or calendar dates as indices of plant maturity. In effect, the dry weight proportion of the plant consisting of leaves and stems is itself an assessment of the maturity of the plant, rather than an index or surrogate measurement of maturity. Secondly, although the original Level 2 model contains no variables which identify developmental stages of the plant over time, it does contain two state variables which monitor the dry weight accumulation of leaves and stems separately.

Data source. The data used for estimating alfalfa quality is reported by Mowat et al. (1966). Pure stands of Vernal and Dupuits were harvested at approximately weekly intervals over three growing seasons. Harvest dates of the plots began 2½ weeks after plant growth commenced and continued until mid-summer (July 23) each year. Data reported in Mowat are the three-year means for each separate variety averaged over six replications. For each of the twelve weekly harvests, data reported for both Vernal and Dupuits include: (a) protein concentration of leaves; (b) protein concentration of stems; (c) IVDMD of leaves; (d) IVDMD of stems; and (e) proportion of leaves constituting total plant dry weight.

Estimation procedure and results. Ordinary least squares regression techniques were used to estimate alfalfa quality based on the Mowat et al. data. Independent variables for all specifications consisted of the proportion of the alfalfa herbage consisting of either leaves or stems. Alternative functional forms which were specified and estimated included simple linear models as well as quadratic and cubic polynomials and log and semi-log transformations. Selection of estimated equations to be used as predictors in the simulation model was based on both R^2 and poolability across the two alfalfa varieties. Vernal and Dupuits are representative of a broad range of maturity genotypes grown in northern temperate climates. In order to avoid a quality model which was variety-specific, each selected functional form was estimated both with and without dummy (binary) variables for the intercept and slope coefficients distinguishing the two alfalfa variety data sets. F-tests were then conducted in order to determine whether the dummy parameter estimates were significantly different from zero. The null hypotheses for all tests were not rejected at the .05 level of confidence, implying that there were no structural differences underlying the Vernal and Dupuits quality data. Hence, all estimated quality equations represent a pooling of data over the two varieties.

The four estimated quality equations selected for use in the model are:

$$\text{CPL} = \underset{(.0188)}{.0852} + \underset{(.0475)}{.4672} * \text{PCL} \tag{4.1}$$

$$R^2 = .874 \quad \text{SER} = .0111 \quad n = 16$$

(4.2) $$CPS = \underset{(.1075)}{1.0140} - \underset{(.3532)}{2.8069} * PCS + \underset{(.2880)}{2.1283} * PCS^2$$

$R^2 = .932$ SER = .0042 n = 16

(4.3) $$DIGL = \underset{(.0319)}{.6031} + \underset{(.1378)}{.6250} * PCL - \underset{(.1426)}{.5279} * PCL^2$$

$R^2 = .776$ SER = .0084 n = 20

(4.4) $$DIGS = \underset{(.0292)}{1.0596} - \underset{(.0509)}{.8666} * PCS$$

$R^2 = .942$ SER = .024 n = 20

where PCL and PCS are the dry weight percentage of leaves and stems, respectively, in the alfalfa herbage (decimal); CPL and CPS are the crude protein concentration of leaves and stems, respectively (decimal); and DIGL and DIGS are the IVDMD of leaves and stems, respectively (decimal). Values in parentheses are standard errors of estimated coefficients; SER is the standard error of each regression.

Range of Quality Prediction. The software algorithm of ALFMOD truncates the values of the independent variables by limiting PCL to values between .50 and .29, and PCS to a range between .50 and .71. These values correspond to the ranges of herbage composition reported in the original Mowat data set and prohibits alfalfa quality estimates from being extrapolated beyond the empirical measurements of the original plots. Given these truncations, maximum and minimum estimates of alfalfa quality which can be generated by the model are: CPL, .318 - .221; CPS, .143 - .094; DIGL, .784 - .739; DIGS, .626 - .444. When weighted by the proportion of total herbage consisting of leaves and stems, the range in crude protein concentration for the whole alfalfa plant will vary between .231 and .131. Similarly, the range of estimated whole plant digestibility will be .705 and .529. Using the Smith data (Smith, 1964) as a reference, this implies that alfalfa quality simulated by the model reflects alfalfa plant maturity ranging between early bud and green seed pod.

4.6 Linkage of ALFMOD and ALHARV Algorithms: Harvest Starting Date

Individually, the ALFMOD and ALHARV modules account for the daily yield-quality of the standing and harvested alfalfa crop, respectively, in DAFOSYM. The linkage between these two major components in DAFOSYM is diagrammed in Figure 4.9. Using daily historical weather data, ALFMOD updates the yield-quality of the standing alfalfa crop for each day d to be simulated during the calendar year. Once the appropriate starting date of cutting c is reached, ALHARV is called and harvest begins, providing that weather for that day is favorable. Harvested yield-quality of alfalfa to be placed into storage and feed available for the dairy herd from that day's production is calculated. At the end of that harvest day, control is again returned to ALFMOD, and crop growth resumes. This process continues throughout the multiple-day harvest period until the total area of alfalfa for cut c has been harvested.

At the end of each cutting, alfalfa yield state variables are reset to zero and a new time path of yield-quality is established for the subsequent regrowth. When the starting date for the subsequent harvest is reached, ALFMOD again calls ALHARV daily, and the process repeats itself. This procedure continues until all cuttings have been harvested and the last julian day of the calendar year has been simulated.

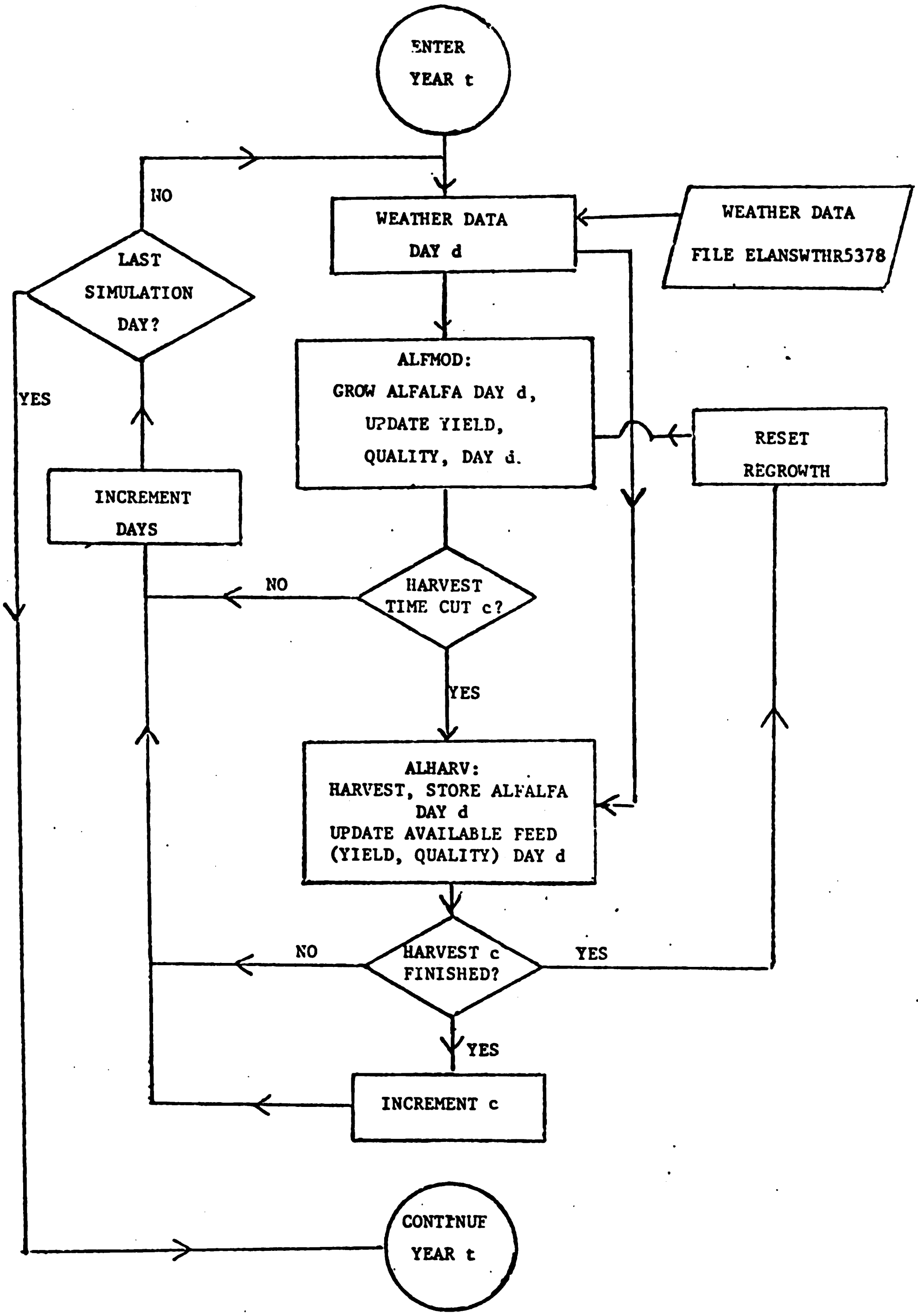

Figure 4.9 Linkage of ALFMOD and ALHARV Modules in DAFOSYM

Harvest starting date mechanism. It should be noted that it was the author's original intention that the initiation of alfalfa harvest in the simulation model should be keyed to a phenological event which could be used as a surrogate for plant maturity in the model. This would have permitted model users to specify management policy dictating that harvest begin at, e.g., first flower, 1/10 bloom, etc. Since the original Level 2 model predicts only plant dry matter accumulation and does not contain a plant maturity scale, the relevant question was to determine which variable could be used as an index of plant maturity. Researchers have generally suggested that the appropriate variable is cumulative degree days. Holt et al. (1975) suggests that buds appear at 450 and first flowers at about 600 cumulative degree days (base temperature = 5^{o}C.); Selirio and Brown (1979) contend that flowers appear at 550 (base 5^{o}C.). Finally, McGuckin's (1980) analysis of Wisconsin data demonstrates that mid-bud, first flower and full bloom occur at 650, 730, and 850 growing degree days (base 5^{o}C.), respectively.

In order to verify these assertions and ascertain an appropriate maturity measure for Michigan, cumulative growing degree days (base 5^{o}C.) were calculated over a 26-year period (1953-1978) for East Lansing. The degree days were cumulated starting on April 1 of each year, and assumed harvests were taken on June 1, July 10, and August 25. These dates correspond to Tesar's average dates of harvest for alfalfa yield trials at Michigan State University, which are taken at a stage of maturity between first flower and 1/10 bloom (Tesar, 1981). Mean values of growing degree days for the 26-year period are 418, 582, and 739 (coefficients of variation are .18, .08, and

.06, respectively). These data suggest that across cuttings, a specified stage of alfalfa plant maturity cannot be measured by a single value of cumulative degree days. It appears that degree days accumulate more rapidly per unit stage of maturity in late summer growth periods. Likewise, when comparing the Michigan data to that of Holt et al., Selirio and Brown, and McGuckin, it appears that location may also have impact on the appropriate index of alfalfa maturity.

The above conclusions are conjectures since stage-of-maturity measurements at each harvest were not available with the Tesar data. However, a different study at Michigan State University conducted under Tesar (Fuess, 1963) does provide calendar dates of 1/10 bloom in alfalfa test plots over a two-year period (1961, 1962) for 1, 2, and 3-cut systems. The cumulative growing degree days for this study are presented in Table 4.3. To be noted are the wide variation in calendar dates at 1/10 bloom across years, and the wide dispersion of growing degree days for 1/10 bloom alfalfa across cutting systems. Similarly, although the 1962 results for the 3-cut system in Table 4.3 seem to suggest a consistent 1/10 bloom at approximately 500 degree days, this value is well below values of other researchers cited above. Since alfalfa normally reaches 1/10 bloom 4-6 days after first flower, it can be inferred that locational differences affect the maturity index. Again, although the Fuess study represents a small sample, it is the author's conclusion that there is insufficient evidence that growing degree days can be used with confidence as an index of alfalfa maturity in models which simulate numerous cutting systems across years.

Table 4.3 Cumulative Growing Degree Days (Base 5C) at 1/10 Bloom Alfalfa, East Lansing, Michigan, for 1, 2, and 3-cut Systems[1]

Cutting Number		System[2]					
		1-cut		2-cut		3-cut	
		1961	1962	1961	1962	1961	1962
1	Date 1/10 bloom	610[3]	531	614	531	*[4]	601
	Degree days	454	524	526	524	(310)[4]	524
2	Date 1/10 bloom	---	---	*[4]	802	712	703
	Degree days	---	---	(1070)[4]	666	591	478
3	Date 1/10 bloom	---	---	---	---	*[4]	816
	Degree days	---	---	---	---	(791)[4]	516

[1]Based on Fuess, 1963.

[2]Harvest dates are: 1-cut: August 30; 2-cut: June 21, August 30; 3-cut: May 31, July 12, August 30.

[3]First digit is months, last two digits are days, e.g., 610 = June 10.

[4]* indicates 1/10 bloom not reached at harvest date. () indicate cumulative degree days at time of harvest.

Given the lack of a suitable phenological event to be used as an index of alfalfa maturity, harvest starting date in DAFOSYM is initiated by a user-specified calendar date for each cutting. This date represents the earliest date at which harvest can begin for any cutting. ALHARV does contain a secondary flag which does permit harvest to be initiated as a function of plant protein level, provided the user-specified calendar date has been attained. This secondary mechanism is described in Savoie (1982).

CHAPTER V

MODEL DEVELOPMENT: CORN PRODUCTION

5.1 Introduction

DAFOSYM model design called for a generic research approach (Sections 2.6, 3.3.1) characterized by a model capable of evaluating farm plans which include alfalfa and/or corn grown as feedcrops for the dairy herd. CRNMOD (CoRN MODule) is the dynamic subcomponent of DAFOSYM which simulates the yield and on-farm production processing of corn as either corn silage or high-moisture shelled corn for use by the livestock enterprises. The notable difference which distinguishes the modules developed for simulating corn and alfalfa production is that CRNMOD is a stochastic process model which represents a black box approach to simulation, unlike the mechanistic white box approach which describes ALFMOD.

Discussion in Chapter 5 parallels the model development perspective of the previous chapter. Key topics of the discussion include: technical issues of corn production influencing the modeling approach taken (Section 5.2); examination of an alternative modeling method (Section 5.3); a description of the stochastic process approach to simulating the dynamics of corn production, including use of the process generator BTAGEN (Section 5.4); data development for the stochastic corn model (Section 5.5); and a description of the corn production algorithm (Sections 5.6, 5.7).

5.2 Technical Issues of Corn Production

Section 2.6 cited two corn-related issues which characterize the dynamics of corn production: (1) corn yield is affected by both the date of planting and date of harvest; (2) date of planting and date of harvest are affected by the number of days available for field work. The former issue is primarily agronomic in that it describes corn growth in the context of the plant's physical environment. By contrast, the latter issue defines a set of constraints which that same physical environment imposes on management such that plant growth and yields are influenced. Each is discussed in turn.

5.2.1 Corn Yield Relationships

Date of planting. The relationship of corn yield to date of planting is well-documented in the literature. Zuber (1966) tested corn grain yields over a five-year period for corn planted between April 20 and June 20 in Missouri. Highest grain yields for all hybrids are obtained in late April plantings. Yields of late-planted corn average 75% of early planting yields. Two studies (Griffith, 1965; Pendleton and Egli, 1969) conducted over multiple-year periods in Indiana and Illinois show similar results with the exception that highest yields result from early May plantings. Michigan studies reported by Hildebrand et al. (1964) and Rossman and Cook (1966) show highest grain yields result from May 1-10 plantings based on ten years' data averaged over short, medium and long-season hybrids. In the Michigan studies, early June plantings yield only 73% as much as early May plantings.

Corn silage date of planting studies show similar results with the exception that yield reductions are less drastic with delayed plantings. Based on two years' data, Barber (1965) shows that both grain and silage yields are highest for corn planted in early May. However, grain yields of corn planted in early June total only 72% of early May plantings, compared with 86% for the corresponding corn silage yields. A Michigan study (Erdmann and Hildebrand, 1976) shows similar results: corn planted June 2 yields 72% as much grain as corn planted on May 9, but 91% as much silage as corn planted on the same date.

Date of harvest. Studies showing the impact of date of harvest on corn yields over a wide range of plant maturities are not as well-documented as for date of planting studies. Nevertheless, the reviewed studies demonstrate similar trends. Perry et al. (1968) and Caldwell and Perry (1971) show that corn silage harvested at successive dates between late summer and early winter in Indiana attains the highest yield in early October when whole plant dry matter is 33%. By late November when plant dry matter has increased to 61%, silage yield has dropped to 88% of the early October maximum. Throughout this entire period, grain yields fluctuate only slightly but do not decrease significantly until December. Over a seven-week harvest period Cummins (1970) shows corn silage and grain yields are at a maximum in the dent stage when plant dry matter is at 32%. More than three weeks later, silage and grain yields are shown to drop to 81% and 84% of maximum, respectively. Johnson and McClure (1968) and Weaver et al. (1978) show silage yields are highest at the dough-dent stage of maturity (35% plant dry matter). Additionally, Weaver et al. show that by the time the corn plant has reached 60% dry matter (six weeks later), corn silage yield has dropped to 82% of maximum.

The results of the date of planting and date of harvest studies cited above can be summarized as follows: delayed plantings reduce corn silage and corn grain yields, but silage yield reductions are less drastic than corresponding grain yield reductions; delayed harvest (after the dent stage of maturity) reduces both silage and grain yields, but the decrease may not be significant over a period of several weeks. Although these results are affected by management practices (choice of hybrid, plant spacing and density, fertility program), the underlying explanation is largely determined by the interaction of soil, climate, and plant physiology.

5.2.2 Suitable Work Days--Corn Yield Relationships

Corn yield relationships reported in the previous section reflect the direct impact of soil and climate on crop yields. These same exogenous environmental factors exert a secondary influence on corn yields which is indirect in that it affects the dates on which the corn crop is planted and harvested. This secondary effect is embodied in the concept of available field working days.[1] As the number of available field work days increases in any given period, field operations are completed in a more timely manner. In turn, timely field operations are translated into earlier average date of planting and harvesting, and ultimately, higher yields.

In general, available field working days and corn yield exhibit a positive relationship. However, the interaction between available

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[1] Available field working days are defined as the number of days in any given calendar period suitable for a specified field operation. The same concept is also referred to as "suitable work days" and "go-no go" days.

working days and corn yield is compounded whenever across-year weather variability is accounted for. Year-to-year variation in weather patterns brings about corresponding variation in both the corn yield relationships as well as in the number of available days per critical calendar period. Additionally, available field working days for corn may have a positive impact on alfalfa harvest, and vice versa. Favorable weather in spring expedites corn planting and yield, but also enables first-cut alfalfa harvest to begin early when crop quality is high. Conversely, a timely third-cutting alfalfa harvest (late August in south central Michigan) enables corn silage harvest to begin (late dough-early dent stage) before silage yields diminish.

Implications for modeling. If the impact of timeliness on corn yield dynamics is to be incorporated into DAFOSYM, then the number of suitable work days in any given calendar period must be known. For some locations, data depicting either the probability of available days (Feyerherm et al., 1966), or the observed number of available days (Fulton et al., 1975) has been published. Recently, a more common approach has been to simulate available days using soil moisture models (Elliot et al., 1975; Rosenberg et al., 1982). Criteria in these models vary across soil type, field operation and crop, but generally reflect soil condition and field tractability in the upper soil profile as a function of weather data input.[1] Studies employing suitable day models to assess timeliness costs

[1]An excellent review of simulation models and their respective criteria for suitable days is contained in Singh (1978).

include Tulu (1973; 1974), Singh (1978), Edwards and Boehlje (1980), and Danok et al. (1980).

5.3 Examination of a Phenological Corn Growth Model

The original research plan of the present study included parallel use of phenological crop growth models to generate yields for both the alfalfa and corn crops. Analogous to the family of physiologically-based models which describe alfalfa growth (see Section 4.3), dynamic computerized models which simulate corn growth as a function of the environment have been developed: SIMAIZ (Duncan et al., 1967; Loomis et al., 1968); Nebraska Corn Model (Splinter, 1974); CORNMOD (Baker and Horrocks, 1976); and CORNF (Stapper and Arkin, 1980).

CORNF, the most recently developed of these models, was tentatively selected for use as a potential subcomponent of DAFOSYM. However, after submitting the model to a series of tests under Michigan environmental conditions, it was decided that the model would not be used in the present study due primarily to its inability to predict reduced corn yields as simulated date of planting was delayed.[1]

Although the model was rejected for use in the present version of DAFOSYM, it is worthwhile to note that CORNF was initially selected on the basis of several model characteristics which indicated that it would be well-suited to addressing the issues of corn-related (a) dynamic system interactions and (b) system risk cited in Sections 2.6 and 5.2. Each is discussed in turn.

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[1]Model testing of CORNF is described in greater detail in Appendix H.

Dynamic interactions. CORNF distinguishes both total plant and ear dry matter accumulation on a one-day time increment for specified maturity genotypes (short season through full season), planted over a range of user-inputted planting dates. Likewise, the model outputs estimates of grain moisture content and an index of phenological events which can be used to identify plant maturity. These model characteristics are important in that they would have allowed CORNF to be used not only as a yield predictor for both the high-moisture corn and corn silage crops, but as well, would have permitted the model to assess the impact of dynamic interactions between daily weather pattern, corn yield, and timeliness cost in a manner similar to those described for alfalfa (Section 4.2).

System risk. Like ALFMOD, CORNF contains the same underlying soil moisture-evapotranspiration model (Ritchie, 1972) and is driven by the same set of daily weather inputs. This has the following implications: First, the most important factor of year-to-year corn yield variability--soil moisture deficit--is accounted for; second, if CORNF could have been validated under Michigan conditions, the need for statistical analysis to determine correlation coefficients reflecting contemporaneous and/or serial dependence in yields would have been obviated.

Because the phenological corn crop growth model did not perform satisfactorily under initial investigation,[1] the alternative stochastic process approach was taken in modeling the corn production subsystem in DAFOSYM.

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[1] See Appendix H.

5.4 Simulating Corn Production Using a Stochastic Process Model

The key concept in CRNMOD which describes the modeling approach used to simulate corn production is a stochastic process model. This approach, while satisfying the model research objective of DAFOSYM, represents a sharp divergence from the research method used to simulate alfalfa yield in ALFMOD. The crop production function of equation 3.1 (Section 3.4.5) shows that the vector of feedcrops produced and available as feed for the dairy herd (DM) is influenced by the vector of system-exogenous inputs (Z).

(3.1) $$DM_k = g(X,Z) \qquad (k = 1,2,3)$$

The primary distinction between the phenological crop growth model approach of ALFMOD and the stochastic process approach of CRNMOD can be described in terms of this vector Z.

5.4.1 Black Box Versus White Box (Mechanistic) Approach

The vector Z can be described in equation 5.1 as being partitioned into two subsets, Z^a and Z^c, representing system-exogenous inputs which are fed into the alfalfa and corn model components, respectively.

(5.1) $$Z = [Z^a, Z^c]$$

Z^a consists of a vector of historically recorded time series weather data used to drive the phenological alfalfa crop growth model, which in turn, generates a simulated estimate of alfalfa yield. Alternatively, Z^c for CRNMOD reflects a "direct" vector estimate of simulated corn yield and available field working days using a stochastic process generator.[1] In both cases, the simulated results reflect estimates

[1] Process generators are discussed in Section 5.4.2.

of a representative time series of alfalfa and corn yields in their respective environments characterized by uncertainty.

The distinguishing characteristic between these yield estimates is that ALFMOD describes in a mechanistic fashion how yield is determined by the environment. By contrast, CRNMOD bypasses this mechanistic biological, physiological description of how yield and environment are related, and directly estimates what the result of that relationship is. The CRNMOD approach views each element of Z^c (e.g., corn yield) as being a random variable completely described by its probability density function without reference as to why the density function takes its specific shape. For this reason, stochastic process models are referred to as black box models, as opposed to the white box, mechanistic approach which characterizes ALFMOD (Brockington, Chapter 1, 1979).

5.4.2 Selection of a Process Generator, BTAGEN

The essence of a stochastic process model is embodied in the process generator. A process generator is a model subcomponent which generates pseudorandom sample observations from a specified probability distribution using numerical simulation techniques.[1] Process generators have been developed for a variety of univariate distributions as well as for the multivariate normal distribution (Naylor et al., 1966; Newman and Odell, 1971). More recently, King (1979) describes the development of a "workable procedure for the generation of random variates from multivariate probability distributions with

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[1] Numerical simulation techniques are described in Naylor et al. (1966), and Manetsch and Park (1977).

non-normal marginal distributions" (p. 209).

Corn-related system-exogenous inputs to CRNMOD (corn yield and available work days) are generated using BTAGEN (BeTA distribution process GENerator), a multivariate process generator with beta-distributed marginal distributions. The beta distribution has the probability density function of the form:

$$(5.2) \qquad f(y) = \begin{cases} \dfrac{y^{\alpha-1}(1-y)^{\beta-1}}{B(\alpha,\beta)} & \alpha,\beta > 0;\ 0 \le y \le 1 \\ 0 & \text{Elsewhere} \end{cases}$$

where: $B(\alpha,\beta) = \dfrac{\Gamma(\alpha)\Gamma(\beta)}{\Gamma(\alpha+\beta)}$ and $\Gamma(X)$ is the gamma function.

The original version of this multivariate beta process generator was developed by King (1979) and was later generalized by Hoskin (1981) who incorporated algorithms which permit the α and β shape parameters of each marginal distribution to take on non-integer values.[1] Estimates of these beta shape parameters in BTAGEN (real or integer) are given by:

$$(5.3) \qquad \alpha = \mu_y \left[\frac{\mu_y(1-\mu_y)}{\sigma_y^2} - 1 \right]$$

[1] The present version of the process generator, BTAGEN, is a reworking and improved design of the King and Hoskin software. A brief user guide to BTAGEN is contained in Appendix C, and in Parsch (1981). Theoretical underpinnings and numerical techniques employed are described in King (1979) and Hoskin (1981).

$$\beta = (1 - \mu_y)\left[\frac{\mu_y(1-\mu_y)}{\sigma_y^2} - 1\right] \tag{5.4}$$

where μ_y and σ_y^2 are the mean and variance of y, transformed to lie on the interval [0,1] (Derman et al., 1973).

Selecting a process generator. The appropriateness of the probability distribution and the corresponding process generator used in a stochastic process model cannot be overstated. The representativeness of the time series data generated with a stochastic process model is entirely embodied in the probability density function of the random variable being modeled. This is in sharp contrast to the white box approach of ALFMOD in which the accuracy of yield estimates was largely dependent on biological and physiological relationships defined in the phenological model.

Choice of the appropriate process generator is largely determined (1) by the shape of the marginal distributions of the processes being modeled; and (2) by whether all stochastic variables being modeled can be assumed to be statistically independent. If the assumption of statistical independence can be maintained, the process may be modeled using a univariate distribution; by contrast, processes which exhibit either serial or contemporaneous dependence[2] require a multivariate probability distribution.

The overriding consideration in choosing BTAGEN for the present study is the flexibility of the beta distribution in accommodating

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[2] See Section 3.5.2 and Anderson (1974a).

both normality and skewness in the sample distributions of the corn-related variables being modeled. A study by Day (1965) shows that corn yields in Mississippi are non-normal and positively skewed. A later study by Hoskin (1981) using Michigan data demonstrates some evidence of non-normal corn yields, but "the evidence is not overwhelming" (p. 170). Regardless of the empirical documentation, one of the advantages of constraining variables to a beta specification in stochastic process modeling is that the beta density function takes on a wide variety of forms. For $(\alpha = \beta) = 1$, for example, the density function is uniform; for $(\alpha = \beta) < 1$, it is U-shaped; for $(\alpha = \beta) > 1$, it is dome-shaped and approaches a symmetrical bell-shaped curve as $(\alpha = \beta)$ increases. By contrast, the beta distribution becomes asymmetrical (skewed) whenever $\alpha \neq \beta$.

A second consideration in choosing BTAGEN for the present study was to accommodate the possibility of interdependency between the stochastic corn-related variables. For those cases where dependency is hypothesized to exist, non-zero correlation coefficients are estimated and used as inputs to BTAGEN, along with estimates of the parameters of the beta marginal distributions. This procedure is discussed in Section 5.5.

5.4.3 Defining the Stochastic Corn Production Variables

The partitioned vector of system-exogenous inputs Z^c provides CRNMOD with representative time series data of corn-related stochastic variables generated by the process generator, BTAGEN. The primary problem which presents itself is the conceptualization of a stochastic corn production model which addresses the issues cited in Section 5.2. In specific, the problem is posed in the question: "How can variables be defined such that the process model embodies both the dynamics of corn yield, as well as the impact of timeliness of planting and harvest operations on these dynamics?" In answer to this question, two categories of stochastic variables are simulated in order to generate the vector Z^c: corn yield, and available field work days during each, the planting period and harvest period.

Corn yields. The dynamics of corn yield relationships can be represented by defining a matrix Y describing corn yield as a function of date of planting and date of harvest. Let the corn season be segmented into p (j = 1,2,...p) planting periods and h (i = 1,2,...h) harvest periods. If periods j and i each designate a range of calendar dates in spring and fall, then individual elements of Y, specify yields of corn planted in period j and harvested in period i. If the type of corn yield measurement is subscripted k (k = 1,2 for silage yield and grain yield, respectively)[1] then the matrix Y has dimensions (k * p * h) and each element can be designated y_{kij} as in equation 5.5 which defines matrix Y.

$$Y = [y_{kij}] \qquad \begin{matrix} (k = 1,2) \\ (i = 1,2,\ldots h) \\ (j = 1,2,\ldots p) \end{matrix} \tag{5.5}$$

From an experimental design perspective, Y can be viewed as resulting from a two-factor experiment with factors date-of-planting and date-of-harvest set at p and h different levels, respectively, for both corn grain and corn silage. Assuming the experiment is conducted over a period of n (t = 1,2,...n) years, an n-observation sample distribution for each matrix element y_{kij} is obtained. Hence, each element

[1]The notation for k is consistent with equation 3.1 where k = 3 represents alfalfa.

of Y is a random variable with a specified probability distribution which can be described by its moments. In this context, Y can itself be envisioned as being a multivariate probability distribution describing both corn grain and silage yields as functions of date of planting and harvesting. This probability distribution Y is described by the moments of its marginal distributions, as well as by the correlation coefficients between them.

Available field working days. Using subscripts i and j as defined previously, vectors for the available field working days during corn planting (ADP) and harvesting (ADH) can be defined as in equations 5.6 and 5.7:

$$(5.6) \qquad ADP = [adp_j] \qquad (j = 1,2,...p)$$

$$(5.7) \qquad ADH = [adh_i] \qquad (i = 1,2,...h)$$

Individual elements of vectors ADP and ADH can be defined as follows: adp_j designates the number of calendar days in planting period j which meet specifications of a set of criteria which indicate that soil-climatic conditions are suitable for planting; adh_i designates the number of calendar days in harvest period i which meet a similar set of criteria for corn harvest operations. Since year-to-year variations in weather patterns will cause the number of available days in each planting and harvest period to vary, each element of ADP and ADH is a random variable with a specified probability distribution described by its sample moments. Similar to Y, ADP and ADH can each be envisioned as multivariate probability distributions, described by the moments of their marginal distributions and the correlation coefficients between distributions of the individual random variables.

5.4.4 Generating Variates of the System-exogenous Input Vector

Given the definition of stochastic variables for corn yield and available work days as described in the previous section, simulation of the t-th system-exogenous input vector Z_t^c over an n (t = 1,2,...n) year period consists of generating n variates from each of the multivariate distributions Y_t, ADP_t, and ADH_t (t = 1,2,...n) using the process generator, BTAGEN. By this description, the vector Z_t^c is simply a composite made up of all corn-related stochastic variables as shown in equation 5.8:

$$(5.8) \qquad Z_t^c = [Y_t, ADP_t, ADH_t] \qquad (t = 1,2,...n)$$

It should be recognized that generation of the vector Z_t^c represents only the first stage of a two-stage simulation process. As a system-exogenous input vector, Z_t^c (similar to the corresponding Z_t^a for alfalfa) represents an intermediate set of variables which is used to drive second-stage model algorithms which determine the quantity of feedcrops available as feed (DM_k) in the production function of equation 3.1. This second stage set of algorithms which simulates the corn planting-harvesting process describes the workings of the CRNMOD module of DAFOSYM. This conversion of system inputs (controllable and exogenous) into the final feedcrop vector produced (DM_k) is described in Section 5.6.

5.5 Data Requirements for BTAGEN

For the three multivariate distributions being modeled (Y, ADP, ADH), the corn planting and harvesting seasons were segmented into five and six calendar periods, respectively. The planting season was assumed to range between April 20 and June 15, and was segmented into

10-day periods, except for period 5 which covered June 1-15. The harvest season was ranged over the period September 1 through November 30, and was segmented into 15-day periods. Segmentation of the planting and harvest season into these periods was not arbitrary, but was based on available data for corn yield and available field working days.

Input data requirements for BTAGEN consist of: (a) parameter estimates (mean, variance, upper bound, lower bound) of each of the beta marginal distributions; and (b) non-zero correlation coefficients reflecting non-independence of the stochastic variables being modeled. This implies that the conceptual model presented in Section 5.4.3 requires that parameters be estimated for 71 corn-related marginal probability distributions. Due to a lack of available corn yield data, a total of only 17 distribution parameters was estimated.

Two important considerations in selecting data describing the distributions were: (1) that all yield and available days estimates be representative of Soil Management Group II (e.g., Brookston-Conover clay loam) in southern Michigan, and (2) that parameter estimates reflect the same corresponding calendar periods used to segment the planting and harvest season.

5.5.1 Corn Yield Distribution Parameters

In general, there is a dearth of data available for estimating parameters of corn yield distributions as a function of date of planting and date of harvest. Equation 5.5 designates Y as being a matrix of dimensions (k * p * h). For the five planting and six harvest periods defined above (p = 5; h = 6), this implies that a multiple-year experiment consisting of 30 treatments for each corn silage and corn grain (k = 1,2) would have to be conducted in order to generate the 60 corn yield distributions required by the model of Section 5.4.3. In fact, data for only six corn yield distributions (five for corn grain, one for corn silage) was available for use in this study.

Corn grain yields. Parameter estimates for data collected over a 10-year period (1954-1963) by Rossman and Cook (1966) are presented in Table 5.1. Columns 1-5 show corn grain yields for a "basket" of hybrids planted between April 20 and June 15. Column 6 presents sample statistics for corn grain yield tests conducted at the same location 1966-1980 (Rossman, various dates). Average planting date for the 1966-1980 period was May 4. All yields reported in Table 5.1 are based on October 1-15 harvest, the period in which highest yields are consistently obtained in East Lansing. All sample statistics in Table 5.1 were calculated on the residuals of fitted (ordinary least squares) regression detrending lines. It is noteworthy that the more recent data comprising column 6 shows a higher mean but lower variance than column 2 (which has similar planting and harvest dates).

Using the column 6 data as a "baseline", an adjusted set of date of planting distribution parameters was calculated for use in BTAGEN and is presented in Table 5.2. The approach used in generating Table 5.2 was to replace column 2 of Table 5.1 with the updated values for mean and coefficient of variation from column 6. Subsequently, mean, coefficient of variation, and upper bound and lower bound for the remaining dates of planting were then adjusted such that their standing relative to column 2 in the original Rossman-Cook

Table 5.1 Sample Distribution Parameters for Date of Planting Studies for Corn Grain, Conover Clay Loam, East Lansing, Michigan

		Planting Period					
		(1)	(2)	(3)	(4)	(5)	(6)
		April 21-30	May 1-10	May 11-20	May 21-31	June 1-15	May 1-10
(1)	$\overline{X}$[1]	106.3	109.5	99.6	91.1	80.5	116.6
(2)	S	16.2	18.2	23.0	23.0	23.4	12.4
(3)	CV	.152	.166	.231	.253	.291	.106
(4)	BL	87.0	81.6	55.6	50.7	40.7	92.2
(5)	BU	136.0	142.4	135.1	126.8	125.0	137.5
(6)	PCT[2]	.971	1.000	.909	.832	.732	1.065

Columns 1-5 are based on date of planting studies (1954-1963) reported by Rossman and Cook (1966). Column 6 is based on 1966-1980 test plot data reported by Rossman (various dates). All samples were planted during the specified planting periods, but harvested October 1-15. Plant population = 19,200.

[1]The following notation is used: $\overline{X}$ = mean (bu/a), S = standard deviation, CV = coefficient of variation, BL = lower bound (bu/a), BU = upper bound (bu/a). Each data set was detrended using ordinary least squares regression. Sample statistics are based on residuals from the fitted line.

[2]Percent of May 1-10 yield. PCT = $\overline{X}_j/\overline{X}_2$

Table 5.2 Sample Distribution Parameters for Corn Grain (Date of Planting) Adjusted for Use in BTAGEN[1]

		Planting Period				
		(1)	(2)	(3)	(4)	(5)
		April 21-30	May 1-10	May 11-20	May 21-31	June 1-15
(7)	$\overline{X}$[2]	113.2	116.6	106.1	97.0	85.7
(8)	S	11.0	12.4	15.7	15.7	15.9
(9)	CV	.097	.106	.148	.162	.186
(10)	BL	92.6	86.9	59.5	54.0	43.3
(11)	BU	144.8	151.7	143.8	135.1	133.1
(12)	PCT	.971	1.000	.909	.832	.732
(13)	$\hat{\alpha}$	1.72	2.66	3.40	3.00	3.26
(14)	$\hat{\beta}$	2.64	3.14	2.76	2.65	3.65

[1] All adjusted parameters are based on data in Table 5.1, using the 1966-1980 sample of column 6 as the baseline. Notation for rows and columns is identical to Table 5.1. $\hat{\alpha}$, $\hat{\beta}$ = estimated beta distribution parameters (equations 5.3, 5.4).

[2] Formulae for calculating adjusted values found in rows 7-11 are presented below. Subscripts represent row (i) and column (j) numbers, Tables 5.1 and 5.2:

(a) $\overline{X}_{7j} = \overline{X}_{1j} * PCT_{66}$

(b) $S_{8j} = CV_{9j} * \overline{X}_{7j}$

(c) $CV_{9j} = CV_{3j} * (CV_{36}/CV_{32})$

(d) $BL_{10j} = (BL_{4j}/\overline{X}_{1j}) * \overline{X}_{7j}$

(e) $BU_{11j} = (BU_{5j}/\overline{X}_{1j}) * \overline{X}_{7j}$

data set was maintained. Specific formulae used to calculate these adjustments are found in equations a-e in Table 5.2.

No distribution parameters were available for corn grain yield as a function of date of harvest.

Corn silage yields. No date of planting corn silage data sets comparable to those presented in Table 5.1 were available for use in the present study. Generally, published data for corn silage shows that yield decreases as planting and harvesting is delayed (see Section 5.2.1), but few systematic studies have recorded silage yields over a range of planting dates and number of years as comprehensively as the Rossman-Cook grain yield data. Despite those studies which do reveal impact of date of planting or harvest on silage yield, the underlying curtailed length of the test plot time series (2-3 years) does not permit suitable estimates of mean or variance reflecting a distribution which describes across-year variation.

The sole corn silage data set obtained for use in BTAGEN was collected at East Lansing, Michigan 1966-1980 (Rossman, various dates). All plots were Conover clay loam with an average planting date of May 2 and harvest date of September 10 over the 15-year sample. Yield data for this sample, averaged over all hybrids tested was: $\overline{X}$ = 6.26 tons/acre (dry matter); S = .562; CV = .090; lower bound = 5.57; upper bound = 7.28; $\hat{\alpha}$ = .49; and $\hat{\beta}$ = .72. Parameter estimates are calculated on the residuals from a fitted regression detrending line.

Adapting to the lack of data. The lack of sufficient date of planting and date of harvest time series data for corn silage and corn grain yields necessitated a modified approach to simulating corn yield matrix Y. This modified approach consists of a supplemental algorithm in which the six randomly generated corn yield variates (five for corn grain, one for corn silage) are multiplied by yield factor constants in order to arrive at corn grain and corn silage yield estimates for all ($k * p * h = 60$) elements of Y. Tables 5.3 and 5.4 display yield factors for corn grain and corn silage, respectively. Each yield factor is "pegged" to one of the stochastic corn variables in that each factor reflects corn yield in a specific planting-harvesting combination as a percentage (decimal) of the randomly generated variate. Comments in Tables 5.3 and 5.4 explain the yield factor algorithm in greater detail. Yield factors for both corn grain and corn silage were based on subjective estimates (Black, 1974) of the date of planting-date of harvest relationships. However, these factor estimates were revised by the author for use in the present study, based on the literature review of Section 5.2.1.

For both corn grain and corn silage, use of factors rather than random variables to fill out remaining elements of the multivariate Y matrix incorporates the underlying assumption that there is perfect correlation between the calculated element and the stochastic variate from which it is generated. The validity or invalidity of this assumption awaits appropriate data for testing. It should be noted, however, that certain serial and contemporaneous correlations[1] between

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[1]Serial dependency is reflected by correlation between grain yields planted in two different periods; contemporaneous dependency is reflected by correlation between grain yield and silage yield of corn planted in the same period.

Table 5.3 Corn Grain Yields and Yield Factors by Planting Date and Harvest Date

	(1) April 21-30	(2) May 1-10	(3) May 11-20	(4) May 21-31	(5) June 1-15
(1) September 1-15	0	0	0	0	0
(2) September 16-30	1.02	0	0	0	0
(3) October 1-15	113.2*	116.6*	106.1*	97.0*	85.7*
(4) October 16-31	.98	.98	.98	.98	.98
(5) November 1-15	.93	.93	.94	.95	.97
(6) November 16-30	.87	.90	.90	.91	.92

Row 3 elements of Table 5.3 marked (*) are sample means (bu/acre) of the Table 5.2 stochastic variates generated by BTAGEN. All other elements of Table 5.3 show yield factors a_{ij} which reflect grain yield in each planting-harvesting element as a percentage (decimal) of the randomly generated yield in row 3. Designating corn grain yields y_{kij}, the modified yield factor algorithm simulates grain yield in each planting-harvesting combination as

$$y_{kij} = y_{k3j}(\text{BTAGEN}) * a_{ij} \qquad \begin{array}{l}(k = 2)\\(i = 1,2,4,5,6)\\(j = 1,2,\ldots 5)\end{array}$$

where y_{k3j}(BTAGEN) is the BTAGEN randomly generated stochastic variate for any given simulation year. A yield factor of 0 prohibits harvesting in that matrix element.

Source: Yield factors (a_{ij}) based on Black (1974).

Table 5.4 Corn Silage Yield Factors by Planting Date and Harvest Date

	(1) April 21-30	(2) May 1-10	(3) May 11-20	(4) May 21-31	(5) June 1-15
(1) September 1-15	1.00	6.26*	0	0	0
(2) September 16-30	1.00	1.00	.98	.96	0
(3) October 1-15	.98	.98	.96	.94	.90
(4) October 16-31	.94	.94	.94	.90	.87
(5) November 1-15	.88	.88	.90	.87	.82
(6) November 16-30	.81	.82	.86	.82	.78

The row 1 column 2 element marked (*) of Table 5.4 is the sample mean corn silage yield (tons/acre, dry matter) generated by BTAGEN from a sample distribution with parameters: $\bar{X} = 6.26$; S = .562; CV = .090; lower bound = 5.57; upper bound = 7.28 (based on Rossman, 1966-1980). All other elements of Table 5.4 show yield factors b_{ij} which reflect silage yield in each planting-harvesting element as a percentage (decimal) of the randomly generated yield. Designating corn silage yields y_{kij}, the modified yield factor algorithm simulates silage yield in each planting-harvesting combination as

$$y_{kij} = y_{k12}(\text{BTAGEN}) * b_{ij} \qquad \begin{array}{l} (k = 1) \\ (i = 1,2,\ldots 6) \\ (j = 1,2,\ldots 5) \end{array}$$

where y_{k12}(BTAGEN) is the BTAGEN randomly generated stochastic variate for any given simulation year. A yield factor of 0 prohibits harvesting in that matrix element.

Source: Yield factors based on Black (1974).

grain and silage yields are accounted for by this method (see Section 5.5.3). Additionally, as corn planting is delayed, the characteristic increased yield variances shown in Table 5.2 are transferred throughout the yield matrix by the yield-factor calculation procedure which describes this algorithm.

5.5.2 Available Work Day Distribution Parameters

A time series of observed suitable field work days for East Lansing, Michigan was not available for estimating distribution parameters for use in BTAGEN. Hence, the Rosenberg-Tulu (Rosenberg et al., 1982) simulation model was used to generate the appropriate time series so that sample statistics for each of the random variable distributions comprising ADP and ADH could be estimated. This suitable-days model was recently submitted to validation tests and was found to predict with less than 15% error. Model explanation, including criteria for suitable work day categories, is found in Rosenberg et al. (1982) and Tulu (1973).

Table 5.5 displays the parameter estimates for sample distributions of available field work days. Suitable field work days for both corn planting and harvest criteria on well-drained, loamy soil were simulated over a 29-year period (1949-1977) using East Lansing weather data. The Table 5.5 parameter estimates are used to generate stochastic variates for ADP and ADH in BTAGEN.

5.5.3 Correlation Coefficients: Interdependent Corn Distributions

Statistical interdependence between the generated stochastic variates is accommodated in BTAGEN with user-inputted estimates of

Table 5.5 Sample Distribution Parameters for Suitable Work Days, Corn Planting and Harvesting

	Corn Planting					Corn Harvesting					
	April 21-30	May 1-10	May 11-20	May 21-31	June 1-15	Sept. 1-15	Sept. 16-30	Oct. 1-15	Oct. 16-31	Nov. 1-15	Nov. 16-30
$\overline{X}$[1]	6.00	7.78	7.42	8.73	11.5	12.69	11.59	12.21	11.96	9.91	5.71
S	2.90	2.14	2.76	2.44	2.38	1.98	2.62	2.60	3.16	4.13	4.23
CV	.483	.275	.373	.279	.207	.156	.226	.213	.264	.417	.741
BL	1	2	1	3	5	10	6	6	5	1	0
BU	10	10	10	11	15	15	15	15	15	15	15
$\hat{\alpha}$	.77	1.30	.84	.85	1.96	.31	1.10	1.08	.78	1.06	.75
$\hat{\beta}$	.61	.50	.34	.34	1.06	.27	.67	.48	.34	.60	1.22
n	25	27	28	26	28	26	27	28	28	23	24
Days	10	10	10	11	15	15	15	15	16	15	15

Suitable work days were simulated for a well-drained loamy soil with East Lansing, Michigan weather data, using the Rosenberg-Tulu model (Rosenberg et al., 1982). Distribution parameters are based on model output for a 29-year simulation.

[1] The following notation is used: $\overline{X}$ = mean (days); S = standard deviation; CV = coefficient of variation; BL = lower bound; BU = upper bound; $\hat{\alpha},\hat{\beta}$ = estimates of beta distribution parameters (equations 5.3, 5.4); n = sample size (years); Days = calendar days in critical period.

correlation coefficients of the modeled distributions.[1] In principle, all 71 corn-related marginal probability distributions comprising Y, ADP, and ADH could be envisioned as being interdependent; e.g., available planting days in each of j (j = 1,2,...5) periods could be hypothesized to be correlated not only with available days in other planting periods, but also with (a) available days in each i-th (i = 1,2,...6) harvest period, and with (b) corn grain and corn silage yields for each ij plant-harvest combination. A single correlation matrix of dimensions (71 * 71) would describe interdependence between the two categories of variables modeled.

Due to lack of data for the marginal distributions (see Section 5.5.2), only a fraction of the potential large number of off-diagonal correlation coefficients in the lower triangular correlation matrix was calculated. As a result, although Y, ADP and ADH could be viewed conceptually as comprising a single multivariate beta distribution, they are, in effect, modeled in the present study as three smaller independent multivariate probability distributions, each with beta distributed marginals.

Available working days correlations. Simulated time series output of available field work days in East Lansing, Michigan from the Rosenberg-Tulu model (Rosenberg et al., 1982) was used to estimate sample correlation coefficients between successive planting and

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[1]The correlation coefficient ρ_{xy} between random variables X and Y is defined ρ_{xy} = covariance $(X,Y)/\sigma_x\sigma_y$, where σ is the standard deviation. The numerical simulation procedure employed in BTAGEN rests on the hypothesis that correlation coefficients between the marginal distributions are maintained as the distribution is successively transformed from normal to uniform to beta. See King, Appendix A, (1979).

harvesting periods. Results of these sample estimates are presented in Tables 5.6 and 5.7. Of the 29 years simulated, only those years with no missing data in any of the planting or harvest periods were used. Hence, the sample size for calculating planting and harvest period coefficients was 19 and 20 years, respectively.

In general, Table 5.6 shows little correlation between successive planting periods; by contrast, a somewhat higher positive correlation is demonstrated between successive harvest periods in Table 5.7. Phillips (p. 210, 1973) has suggested the following interpretation of the absolute value of correlation coefficients: .0-.2 = no relationship; .2-.4 = low to modest relationship; .4-.6 = moderate relationship; .6-.8 = substantial relationship; .8-1.0 = high degree of association. Based on this interpretation, all available planting day correlations were set to zero in BTAGEN. Similarly, correlation coefficients for successive available harvest days were rounded to the following values: .5 for any two successive harvest periods; .2 for periods separated by a single period; .3 for periods separated by two periods; .4 for periods separated by three periods; and, .5 for periods separated by four periods. Additionally, correlation coefficients between planting and harvest periods, and between planting periods, harvest periods and corn yields were set to zero, implying independence of Y, ADP, and ADH.

<u>Corn grain correlations</u>. Estimates of yield correlation for corn grain planted in successive planting periods are presented in Table 5.8. Estimates are based on the residuals of the detrended Rossman-Cook (1966) time series described earlier in Table 5.1. Table 5.8 shows strong association between corn grain yields planted

Table 5.6 Estimated Correlation Coefficients for Available Field Work Days, Corn Planting Period

Planting Period	April 21-30	May 1-10	May 11-20	May 21-31	June 1-15
April 21-30	1.000				
May 1-10	.188	1.000			
May 11-20	.139	.156	1.000		
May 21-31	-.134	.175	.057	1.000	
June 1-15	.291	.117	-.182	.136	1.000

Based on 19 years' time series data simulated for well-drained loamy soil, East Lansing, Michigan, using Rosenberg-Tulu simulation model (Rosenberg et al., 1982).

Table 5.7 Estimated Correlation Coefficients for Available Field Work Days, Corn Harvest Period

Harvest Period	Sept. 1-15	Sept. 16-30	Oct. 1-15	Oct. 16-31	Nov. 1-15	Nov. 16-30
September 1-15	1.000					
September 16-30	.306	1.000				
October 1-15	.000	.497	1.000			
October 16-31	.118	.359	.280	1.000		
November 1-15	.257	.241	.045	.858	1.000	
November 16-30	.546	.466	.472	.444	.488	1.000

Based on 20 years' time series data simulated for well-drained loamy soil, East Lansing, Michigan, using Rosenberg-Tulu simulation model (Rosenberg et al., 1982).

Table 5.8 Estimated Correlation Coefficients for Yield of Corn Grain Planted in Five Successive Planting Periods

Planting Period	April 21-30	May 1-10	May 11-20	May 21-31	June 1-15
April 21-30	1.000				
May 1-10	.942	1.000			
May 11-20	.875	.957	1.000		
May 21-31	.889	.974	.980	1.000	
June 1-15	.791	.935	.920	.956	1.000

All estimates are calculated on the residuals from detrending (OLS) regression lines fitted through ten years' data (Rossman and Cook, 1966) collected at East Lansing, Michigan, 1954-1963.

in successive periods. In BTAGEN, the correlation coefficients for corn grain yields were arbitrarily modified and set to .96, .92, .91, and .80 for planting periods separated by 0, 1, 2, and 3 successive periods, respectively.

Correlation between corn grain and corn silage. Correlation coefficients reported in Tables 5.6 - 5.8 reflect serial dependence between corn-related random variables. Contemporaneous dependence may also be hypothesized to exist between corn grain and corn silage yields in any given year. A correlation coefficient of .70 was calculated between the residuals of the detrended 15-year (1966-1980) time series of corn silage and corn grain (Rossman, various dates) yields reported in Section 5.5.1. Because only a single time series for corn silage was available, this correlation coefficient is assumed to be a valid estimate of yield correlation between corn silage and corn grain planted in each of the five planting periods described earlier.

5.5.4 Correlation Coefficients: Interdependence of Corn Yield and Alfalfa Yield

A question which has not been dealt with up to this point is: "Is it inappropriate to develop a dairy forage systems model which uses both a phenological crop growth model and a stochastic process model to generate concurrent yield estimates of alfalfa and corn, respectively?" Difficulties could arise using this hybrid research approach if corn yields and alfalfa yields are historically correlated. Although the multivariate process generator accommodates corn-related interdependencies with the use of correlation coefficients, any historical contemporaneous correlation between corn and alfalfa cannot be accommodated in the present version of DAFOSYM because alfalfa and corn yields are generated by independent algorithms.

In order to verify whether this modeling approach generates empirically appropriate results, i.e., independence of simulated corn and alfalfa yields, correlation coefficients were estimated between corn grain, corn silage, and alfalfa yields observed at East Lansing, Michigan on Brookston-Conover soils over the period 1970-1979. The estimated coefficients for corn grain and corn silage versus alfalfa are presented in Tables 5.9 and 5.10, respectively. Estimates were calculated of both an average of all hybrids of corn and all varieties of alfalfa tested, and of individual hybrids and varieties.

In general, the estimated correlation coefficients (based on the residuals of each series) show virtually no contemporaneous correlation between corn and alfalfa yields. These results support similar conclusions reported by Hoskin (p. 77, 1981). Although this result may seem questionable, it should be recalled that yields of corn and alfalfa are determined by phenological events which occur at different periods throughout the growing season for each individual crop. Hence, a good year for alfalfa is not necessarily a good year for corn. This point is made clearer by noting values of correlation coefficients between short versus long-season hybrids and the individual alfalfa varieties.

5.6 CRNMOD: The Corn Production Algorithm

The production function of equation 3.1 (Section 3.4.5) established that the vector of feedcrops produced and available

Table 5.9 Estimated Correlation Coefficients, Corn Grain and Alfalfa Yields, East Lansing, Michigan

		1	2	3	4	5	6	7	8	9	10	11
1	CGALL[1]	1.000										
2	CSALL	.707	1.000									
3	ALFALL	-.002	-.161	1.000								
4	VERNAL	-.043	-.167	.973	1.000							
5	P520	.076	-.229	.925	.900	1.000						
6	SARANAC	-.097	-.173	.979	.976	.873	1.000					
7	M280	.892	.433	.082	.011	.120	-.061	1.000				
8	M333	.915	.828	.056	.010	.149	-.044	.832	1.000			
9	F4444	.962	.796	-.077	-.086	-.001	-.182	.835	.879	1.000		
10	P3780	.946	.567	.092	.084	.183	.002	.947	.821	.934	1.000	
11	M407	.979	.817	.128	.046	.146	.019	.942	.921	.938	.893	1.000

All estimates are calculated on the residuals from detrending (OLS) regression lines fitted through each data series. Corn grain (Rossman, various dates) and alfalfa data (Tesar, 1979) was observed at test plot trials, East Lansing, Michigan. Average planting date was May 1 and harvest date was October 4 for corn grain. Average harvest dates for alfalfa: June 1, July 10, August 25, and October 20. Sample sizes range between 7 and 10 observations.

[1] Notation for Tables 5.9 and 5.10 is:

CGALL, CSALL: average over all hybrids tested; corn grain, silage
ALFALL: average over all alfalfa varieties tested
VERNAL: alfalfa
P520: Pioneer 520 alfalfa
SARANAC: alfalfa
M280, M333: Michigan 280, Michigan 333 (short season corn)
F4444: Funk G-4444 (medium season corn)
P3780: Pioneer 3780 (medium season corn)
M407: Michigan 407 (medium season corn)

Table 5.10 Estimated Correlation Coefficients, Corn Silage and Alfalfa Yields, East Lansing, Michigan

		1	2	3	4	5	6	7	8	9	10	11
1	CGALL[1]	1.000										
2	CSALL	.707	1.000									
3	ALFALL	-.002	-.161	1.000								
4	VERNAL	-.043	-.167	.973	1.000							
5	P520	.076	-.229	.925	.900	1.000						
6	SARANAC	-.097	-.173	.979	.976	.873	1.000					
7	M280	.698	.887	.248	.247	.193	.246	1.000				
8	M333	.627	.859	.477	.407	.333	.428	.859	1.000			
9	F4444	.642	.832	.011	.005	-.193	.003	.629	.799	1.000		
10	P3780	.746	.522	-.037	-.009	-.070	-.065	.715	.509	.573	1.000	
11	M407	.707	.922	.329	.288	.179	.248	.817	.921	.910	.544	1.000

All estimates are calculated on the residuals from detrending (OLS) regression lines fitted through each data series. Corn silage (Rossman, various dates) and alfalfa data (Tesar, 1979) was observed at test plot trials, East Lansing, Michigan. Average planting date was May 1 and harvest date was September 4 for corn silage. Average harvest date for alfalfa: June 1, July 10, August 25, October 20. Sample sizes range between 7 and 10 observations.

[1] For notation, see footnote 1, Table 5.9.

for consumption by the dairy herd (DM) is a function both of the vector of system-exogenous inputs (Z) and the vector of system-controllable inputs (X) representing the user-inputted farm resource base. Discussion in the foregoing sections of the present chapter has explained how the partitioned vector Z^c (equation 5.8) is randomly generated for the corn silage and high-moisture corn crops using the process generator, BTAGEN. The remaining sections discuss the CRNMOD module, which has two basic functions: (1) simulating the planting-harvesting-storage processes which convert the Z and X vectors into corn feedstuffs available for the dairy herd (DM); and (2) accounting for corn-related resource use and on-farm fixed (FC) and variable (VC) production costs.[1] Recalling the discussion of Section 3.4.6, both the DM production function of equation 3.1, as well as the FC and VC cost functions of equations 3.2 and 3.3 are among the most important relationships of the DAFOSYM model because each has a direct bearing on the system performance measure of equation 3.4.

5.6.1 Material Flows: Simulating the Corn Planting-Harvesting-Storage Processes

Corresponding to the planting and harvesting periods defined in Section 5.5, corn production processes are simulated in CRNMOD at time increments of 10 and 15 days in spring and fall, respectively. Annually, the area (hectares) planted to corn in each of five planting

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[1] The corresponding algorithm which simulates alfalfa harvest-storage and accounts for alfalfa-related resource use and costs is described in Savoie (1982).

periods $hapltd_j$ ($j = 1,2,\ldots 5$) is related to both the randomly generated number of available field work days (adp_j) reflecting weather conditions in period j, and the farm resource base X, as shown in equation 5.9.

$$hapltd_j = f_1(adp_j, rtplt(X), ha(X)) \qquad (j = 1,2,\ldots 5) \tag{5.9}$$

Recalling that X is a user-inputted vector describing the farm resource base[1], the two elements in X which affect $hapltd_j$ are the size of the planting equipment which affects planting rate (rtplt), and the area intended for corn planting (ha). Because the planting season is defined between April 20 and June 15, any intended area not planted by the end of period 5 is assumed to remain unplanted.

In fall, the underlying assumption for the corn harvest sequence in CRNMOD is that corn silage is harvested first, followed by high-moisture corn. Once silo storage structures are filled, any residual corn area is then custom-harvested for cash grain sales. Given the calendar demarcation of the harvest season, silage harvest can begin as early as September 1. However, corn not harvested by November 30 is assumed to be a loss.

Using the familiar subscript k = 1 for corn silage, and k = 2 for high-moisture corn, the area of corn planted in planting period j ($j = 1,2,\ldots 5$) and harvested in harvest period i ($i = 1,2,\ldots 6$) can be defined as in equation 5.10:

$$hahrv_{kij} = f_2(hapltd_j, adh_i, strg_k(X), rthrv_k(X)) \tag{5.10}$$

$$\begin{array}{l}(k = 1,2)\\(i = 1,2,\ldots 6)\\(j = 1,2,\ldots 5)\end{array}$$

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[1]User inputs to both CRNMOD and ALFMOD are described in Appendix B.

Equation 5.10 describes three primary constraints--planting, harvesting, storage--which determine the area of corn harvested in each planting-harvesting combination:

1. The area planted in the j-th planting period ($hapltd_j$) determines the maximum area which can be harvested in period i at corn yield level y_{kij} (see equation 5.5).
2. The total area of corn which can be harvested in any period i is limited by the randomly generated number of available field work days (adh_i) reflecting weather conditions in period i, as well as by the user-inputted size of harvesting equipment which affects harvest rate ($rthrv_k$).
3. The total area harvested for each, corn silage and high-moisture corn, is limited by the user-inputted silo storage capacity available for corn silage and high-moisture corn ($strg_k$). Once storage structures are filled, the algorithm forces remaining unharvested corn area to be custom-harvested and sold as cash grain.

Once the corn harvest and storage processes of equation 5.10 have been simulated, the quantity of corn silage and high-moisture corn available for consumption by the dairy herd is determined as indicated in equations 5.11 and 5.12:

$$dm_{kij} = f_3(hahrv_{kij}, y_{kij}, losses_k(X)) \tag{5.11}$$

$$DM_k = \sum_i \sum_j dm_{kij} \qquad \begin{array}{l} (k = 1,2) \\ (i = 1,2,\ldots 6) \\ (j = 1,2,\ldots 5) \end{array} \tag{5.12}$$

Equation 5.11 represents an accounting of the dry matter quantity of each, corn silage and high-moisture corn, harvested in each planting-harvest combination (dm_{kij}). Randomly drawn yields for each planting-harvest combination (y_{kij}) are multiplied by the corresponding area harvested ($hahrv_{kij}$). Crop losses ($losses_k$) are subtracted and reflect dry matter losses incurred at each the harvest, storage, and feeding phases of processing the feedcrops. Loss rates assumed in the model are shown in Table 5.11. Once losses have been accounted for, equation 5.12 represents the operational counterpart of the production function of equation 3.1, i.e., DM_k reflects the state variable of feed (corn silage, high-moisture corn) available for use by the dairy herd for a one-year feeding period.

5.6.2 Resource Use and Cost Accounting

The variable on-farm corn production costs which are accounted for in CRNMOD can be divided into three basic categories: machinery costs (repair and maintenance, fuel); labor charges (field operations, feeding); and direct cropping costs (fertilizer-seeds-chemicals, custom harvest, cash corn drydown). Fixed costs in the form of an annual charge for use of corn-related durable assets (machinery, storage structures) are also accounted for. Accounting methods for each cost category are described in turn.

Machinery costs. Cost of fuel and repair and maintenance charges for all tractors and implements used in corn planting, high-moisture corn harvesting and high-moisture corn silo filling are accounted for

Table 5.11 Harvest, Storage, and Feeding Loss Rates for Corn

	Crop Yield	Harvest Loss	Stored Yield	Storage Loss	Feed Fed	Feeding Loss	Effective Yield
Corn Silage	1.0	.060	.940	.100	.846	.050	.804
High-moisture Corn	1.0	.035	.965	.050	.917	.030	.889
Custom Harvest	1.0	.075	.925	---	---	---	.925

All yield losses are measured as dry matter losses (decimal). Storage losses for corn silage and high-moisture corn assume upright concrete stave silos.

Source: Logan and Hillman (1975), McGuffey and Hillman (1976), Hoglund (1964).

based on estimated resource use of machinery.[1] Estimated resource use of machinery is measured in annual hours of machine operation using standard engineering formulae. Corn planting rate (rtplt) and high-moisture corn harvest rate (rthrv) are determined using the general formula of equation 5.13:

$$\text{(5.13)} \qquad rate(ha/hr) = (s * w * fe)/10$$

where: s = field operating speed; w = implement operating width; and fe = effective field efficiency. Constant operating speeds (km/hr) and field efficiencies (dec.) assumed for planting (4.8, .55) and high-moisture corn harvest (4.0, .60) are based on White (1978). Implement operating width (m) is user-inputted. Machinery operating hours for high-moisture corn silo filling are based on a blower throughput capacity of 35 tons/hr, dry matter (Fogarty, 1982).

Annual repair and maintenance charges (rm) for individual tractors and implements are calculated as a fraction of investment cost and annual hours of use as shown in equation 5.14:

$$\text{(5.14)} \qquad rm = rmf * p * (hours/yr)$$

where: p = purchase price of the machine; and rmf = a factor denoting repair and maintenance charges as a fraction of investment cost per hour of machine use. Factors (rmf) assumed for tractors (.00012), corn planters (.0007), picker-shellers (.00032) and blowers (.00025)

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[1]The machinery complement data bank in the FORHRV module contains all but two machinery implements of the modeled farm resource base: the corn planter and corn picker-sheller. Thus, because the corn silage forage harvester (chopper) is contained in FORHRV, machinery and labor costs for corn silage harvest, silo filling, and corn silage feeding are not accounted for in CRNMOD. Machinery cost and engineering relationships in CRNMOD are limited to the corn planting and high-moisture corn activities. For a description of corn silage machinery and labor cost accounting, see Savoie (1982).

are taken from Hunt (1977, p. 69).

Annual fuel cost for the corn operations is calculated at a constant .2226 liters (diesel)/hr per PTO-KW of tractor power for each field operation and silo filling (ASAE Yearbook, 1980, p. 241). Fuel price/liter is a user input.

Labor charge. Labor charges for corn planting, high-moisture corn harvesting and silo filling operations are based on estimates of labor hours expended and a user-inputted wage rate. A user-inputted manhours/hour variable--reflecting the number of laborers employed in parallel planting or harvest operations--is multiplied by the annual cumulative machinery hours for the relevant field operation in order to determine total field and silo-filling labor hours. Implicit in this accounting procedure is that the field operation (e.g., picking-shelling) is the limiting activity during the harvest process, and that all other laborers employed (e.g., silo-filling personnel) are paid for the same number of hours as the field personnel.

Estimated labor required for silo unloading and feeding is calculated as a function of materials fed on a dry weight basis. Estimated time assumed for unloading and feeding high-moisture corn is .324 hours/ton dry matter based on Norell (1979). This unloading-feeding rate reflects the time required to unload the ensiled material into a stationary mixer, and then to unload the mixer onto a platform conveyor system.

Direct cropping costs. Direct cropping costs consist of a charge for fertilizer-seeds-chemicals, as well as charges incurred whenever residual corn is custom-harvested (Section 5.6.1). Charges for fertilizer-seeds-chemicals are a user input, and should reflect annual expenditures on a per hectare basis for fertility levels consistent with simulated yield levels.

Two charges are incurred for residual corn harvested for cash grain sales:

1. A user-inputted custom hire rate ($/ha) is charged for all custom-harvested corn. The model assumes a 6-row (76 cm/row) combine harvests at operating speeds and field efficiency suggested by White (1978). Custom hire rate includes all harvest costs, as well as a grain hauling charge.
2. A grain drydown charge is imposed on all corn custom-harvested. The assumed moisture content of grain corn as a function of planting date and harvest date is given in Table 5.12. A user-inputted drydown charge ($/point/bushel of moisture removed) reduces the moisture content of all custom-harvested corn to 15.5%.

Fixed costs. Fixed costs in CRNMOD reflect an annual use charge for durable assets employed in the production of corn. Corn-related durable assets which are accounted for in CRNMOD include machinery (planter and picker-sheller)[1] and the silo storage structures (including unloaders) for high-moisture corn and corn silage. Annualized costs of these investments are calculated using a capital recovery factor based on user-inputted discount rate, asset life, investment cost, and salvage value.

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[1] All other farm machinery fixed costs are accounted for in FORHRV. See Savoie (1982).

Table 5.12 Moisture Content of Corn Grain, Planting Date by Harvest Date

	April 21-30	May 1-10	May 11-20	May 21-31	June 1-15
September 1-15	.30	.32	---	---	---
September 16-30	.28	.30	---	---	---
October 1-15	.26	.26	.28	.30	.32
October 16-31	.24	.26	.27	.30	.31
November 1-15	.21	.23	.25	.28	.29
November 16-30	.20	.22	.23	.24	.27

Estimates reflect the proportion (decimal) of total grain wet weight consisting of water. Based on Black (1974).

5.7 Linkage of the Corn and Alfalfa Algorithms

The discussion surrounding model development in Chapter 5 has treated corn production as being largely independent from alfalfa production. In spite of the fact that two very different approaches have been utilized to model these crops, the corn and alfalfa software algorithms are linked in a manner which characterizes the impact of a multiple-cropping enterprise on the annual sequence of cropping activities. Two algorithm linkages describe potential interaction between alfalfa and corn activities in DAFOSYM:

1. The model assumes that alfalfa first-cut harvest cannot begin until all intended area for corn has been planted (or until the end of planting period 5 has been reached). Delayed corn plantings, due either to bad weather or undersized planting equipment, reduces not only corn yields, but affects the yield-quality of the alfalfa crop to be harvested. Implicitly, the delayed alfalfa harvest will have the effect of delaying subsequent alfalfa cuttings throughout the cropping season.

2. The model assumes that corn silage harvest cannot begin until the third cutting of alfalfa has been harvested. In mid-Michigan, the recommended date for third cutting alfalfa is mid- to late August. Although corn silage harvest cannot begin prior to September 1 each year (beginning of harvest period 1), an extension of the alfalfa harvest beyond this date will necessarily delay the beginning of corn harvest. Implicitly, this delay in corn silage harvest will delay the high-moisture corn harvest which immediately follows.

These modeled linkages not only permit DAFOSYM to mimic an important aspect of real dairy forage systems, but permit assessment of the dynamic impact of field operation timeliness between crops.

CHAPTER VI

MODEL APPLICATION: EVALUATING DAIRY FORAGE SYSTEM DESIGN

6.1 Introduction

The model research objective of DAFOSYM is to conduct experiments which permit the evaluation of dairy forage system alternatives (Section 3.2). The purpose of the present chapter is to demonstrate the use of the model by presenting the results of six simulation experiments which analyze alternative dairy forage system designs.

The key variable in the design of a hypothetical dairy forage system is the forage ration fed to the lactating herd. Given the wide range over which dairy cattle can substitute feeds, various nutritionally-equivalent rations--each containing an alternative mix of feedstuffs--can be specified for the milking herd. Subsequently, for any given herd size, milk production level and cropland base, an alternative dairy forage system can be designed to provide the appropriate levels of each homegrown feedcrop consistent with that ration's requirements. From the design perspective, three important variables change with each alternative ration specified, and it is these three variables which give rise to each alternative dairy forage system: (1) the crop mix or relative area grown to each feedcrop; (2) the storage system required to handle the differing combinations of feedstuffs under each system; and (3) the machinery configuration required to process the alternative crop enterprise combinations in each system.

In the present study, the experiments use as their primary control variable the ratio of corn silage:alfalfa[1] contained in the forage portion of the lactating herd feed ration. Six alternative rations, ranging between 0% and 100% corn silage (in increments of 20%) are specified for the milking herd.[2] For each alternative ration specified, an alternative dairy forage system is subsequently designed and simulated over a 26-year period. The objective in conducting these experiments is to rank the performance of each alternative system in terms of its risk-return tradeoffs using second degree stochastic efficiency criteria. The ranking of the simulated system alternatives under these criteria has implications for determining which system design is the preferred choice of all managers/decision makers who prefer more income to less, but who are risk averse as well.[3]

A total of six experiments (labeled A-F), each consisting of between five and seven 26-year simulation runs using Michigan weather and yield data, is reported in this chapter. The experiments include analysis of the following systems:

A. Six alternative rations for a 120-cow herd (154.8 ha) fed homegrown forages (corn silage, alfalfa) and high-moisture corn (Systems A1-A6).

B. Six alternative rations for an 80-cow herd (104.7 ha) fed homegrown forages and high-moisture corn (Systems B1-B6).

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[1]Each alternative ration is identified by the dry matter fraction of forage consisting of corn silage--the remainder of the forage being alfalfa. Hence, a ration containing 40% corn silage, 60% alfalfa is simply referred to as a 40% corn silage ration.

[2]Development of the six rations is described in Appendix G.

[3]See Appendix F.

C. Five alternative rations for a 120-cow herd (101.7 ha) fed homegrown forages and purchased corn grain (Systems C1-C5).

D. Five alternative rations for a 120-cow herd fed homegrown forages and high-moisture corn; low corn prices (Systems D1-D5).

E. Five alternative rations for a 120-cow herd fed homegrown forages and high-moisture corn; high corn prices (Systems E1-E5).

F. An 80% corn silage ration for a 120-cow herd fed homegrown forages and high-moisture corn; seven alternative machinery configurations (Systems F1-F7).

The series of experiments reported in this chapter demonstrates the capability of DAFOSYM to evaluate the broad range of systems called for in Section 2.6. The experimental emphasis of this chapter on overall dairy forage system design and on corn-related control variables complements the simulation results reported by Savoie (1982) whose experiments emphasized alfalfa-only rations (i.e., 0% corn silage) and alfalfa-related management strategies (e.g., maturity at mowing, number of cuts, increased drying rate, etc.).[1]

6.2 Model Inputs for Simulation Runs

As explained in Section 3.3.1, the responsibility for the appropriate design layout for evaluating alternative systems rests with

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[1]The author and Savoie (1982) use different feed disappearance models to derive their respective results. Each feed disappearance model was designed to facilitate analysis of the respective issues addressed by each author. The dairy forage feed model used in all experiments reported in the present chapter is described in Appendix G.

the researcher using the DAFOSYM model. User-controlled inputs to the simulation model[1] can be categorized under two headings: (a) system design inputs reflecting the resource base of the farm to be simulated; and (b) economic variables reflecting the market conditions in which the system operates. Choice of the input variables used in the six simulation experiments reported in this chapter is described by addressing each input category in turn.

6.2.1 System Design Inputs

System alternatives are introduced to the model by changing the levels of control variables which reflect the resource base of the farm system to be simulated. These system design inputs[2] describe the feed storage system, the crop mix, and the machinery complement of each hypothetical dairy forage system to be simulated.

Feed storage system. For all systems simulated it is assumed that alfalfa, corn silage, and high-moisture corn are stored in upright concrete stave silos.[3] Assumed storage requirements under six alternative rations for the 120-cow and 80-cow systems analyzed are presented in Table 6.1. All storage configurations were estimated based on the annual feed requirements of Table G.3 augmented to include capacity for feeding and storage losses (Table 5.2 and Savoie (1982)--Sections 5.5 and 5.6). Once the annual feed storage requirements (tons/yr, DM) for each feedstuff were estimated, silo sizing

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[1]User-controlled inputs are described in detail in Appendix B.

[2]System design inputs are referred to as the vector X in Chapters 3 and 5.

[3]When haylage silos are filled, any remaining alfalfa is harvested as small rectangular bales.

Table 6.1 Annual Feed Storage Requirements and Silo/Unloader Investment Costs for Six Rations, Two Herd Sizes, with and without Homegrown High-moisture Corn

	Corn Silage		High-moisture Corn		Alfalfa			
% CS	T/yr[1]	$	T/yr[1]	$	T/yr[1]	$	Total $ w/ HMC	Total $ w/o HMC
120-cow system:								
0	0	0	306	20908	763*	81873	102781	81873
20	296	34352	269	19678	536*	65180	119210	99532
40	406	43036	244	19454	451	46185	108675	89221
60	491*	61654	220	18310	367	39887	119851	101541
80	575*	70604	201	17737	286	35302	123643	105906
100	647*	76488	187	16865	212	28101	121454	104589
80-cow system:								
0	0	0	204*	22512	508*	63419	88931	--
20	197	26599	179*	23623	357	38837	89059	--
40	265	32590	163*	22678	301	36283	91551	--
60	328	38244	147*	21733	244	30442	90419	--
80	383	40936	134*	20788	191	25899	87623	--
100	431	44085	125*	19843	141	21524	85452	--

All silos were sized and costed using Tables B.1-B3. (*) reflects two silos for the respective feedstuff. Investment costs are 1981 dollars.

[1]Metric tons, dry matter. Alfalfa storage capacity is 75% of annual feed requirements.

and number of silos was determined using the following guidelines:

1. Individual feedstuffs were stored in separate silos.
2. The smallest possible number of silos (each with the largest possible diameter) was chosen for each feedstuff, providing that the following sizing constraints were met:
   -- silo height must include 10' space for settling and unloader;
   -- (height * .25) $\leq$ diameter $\leq$ (height * .40); and
   -- minimum feedstuff removal must be $\geq$ 2 inches/day to avoid excessive feed spoilage.
3. Multiple silos per feedstuff must be of identical size and meet requirements in (2).
4. Haylage storage capacity was set at 75% of the annual haylage feed usage requirement.

The above guidelines assure appropriate silo size and number with respect to the annual quantity of each feed to be stored. The fourth restriction reflects the fact that haylage requires less annual storage space per ton because haylage silos get multiple use throughout the extended three-month harvest season during which haylage silos are being filled. In the present case, haylage silos were assumed to be filled 1.33 times annually. All silo sizings and investment costs were based on Appendix Tables B.1-B.3.

Crop mix. Because the DAFOSYM system performance measure accounts for neither the value of cropland nor the cow-unit flows depleted in production (see Section 3.4.6), each configuration of farm resources simulated for a specific experiment was assumed to include: (a) an equal number of livestock units, and (b) an equivalent area of land available for cropping. Given the relative yields of alfalfa, corn silage, and high-moisture corn reported in Chapters 4 and 5, rations containing 0% corn silage require the greatest total area of cropland to feed a herd of a specified size. Hence, all systems evaluated for any specific experiment were assumed to have available a land base equivalent to that of a comparable 0% corn silage system with any remaining "residual" crop area to be grown to corn for cash grain sales.

Area of individual crops assumed for each the 120-cow and 80-cow systems with homegrown high-moisture corn, and for the 120-cow system without homegrown high-moisture corn, are presented in Tables 6.2 and 6.3. Respective standing yields of corn silage, high-moisture corn, and alfalfa of 13.83, 5.97, and 11.40 tons/ha (dry matter) were used in calculating crop area.[1] These yields were the average yields of the respective crops obtained on trial runs of the simulation model over a 26-year period. The alfalfa yield of 11.40 tons/ha assumes a 3-cut system with harvest beginning on May 24, July 5, and August 20 (using the calendar date criterion, see Section 4.6). Under the assumption that alfalfa remains in the rotation for four years, all model runs harvest only 75% of the total alfalfa area on the third cutting each year in order to accommodate an implicit summer seeding (late July-early August) of alfalfa, which, in effect reduces overall alfalfa yield.

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[1]Comparable English measurements are: 6.17 t/A, 112.6 bu/A, and 5.09 t/A, respectively. Reference to tons/ha and tons/acre designates metric and English units, respectively.

Table 6.2 Feedcrop Enterprise Mix for a 120-cow Herd Fed Alternative Rations, with and without Homegrown High-moisture Corn (ha)

% CS	Crop Area (ha)				Total	CS + A	Corn
	CS[1]	HMC	A	CG			
With Homegrown HMC:							
0	0	53.1[2]	101.7	0	154.8	101.7	53.1
20	22.8	46.7	71.5	13.8	154.8	94.3	83.3
40	31.3	42.4	60.1	21.0	154.8	91.4	94.7
60	37.8	38.2	48.9	29.8	154.8	86.8	105.9
80	44.3	35.0	38.1	37.4	154.8	82.4	116.7
100	49.8	32.4	28.2	44.3	154.8	78.1	126.6
Without Homegrown HMC:							
0	0	0	101.7	0	101.7	101.7	0
20	22.8	0	71.5	7.3	101.7	94.3	30.1
40	31.3	0	60.1	10.3	101.7	91.4	41.6
60	37.8	0	48.9	14.9	101.7	86.8	52.8
80	44.3	0	38.1	19.3	101.7	82.4	63.5

[1]Notation used is: CS = corn silage; HMC = high-moisture corn; A = alfalfa; CG = cash corn grain.

[2]Crop area is based on average standing yields of: CS = 13.83; HMC = 5.97; A = 11.40, all in tons/hectare, dry matter.

Table 6.3 Feedcrop Enterprise Mix for an 80-cow Herd Fed Six Rations, with Homegrown High-moisture Corn (ha)

% CS	Crop Area (ha)				Total	CS + A	Corn
	CS[1]	HMC	A	CG			
0	0	35.4	69.3	0	104.7	69.3	35.4
20	15.2	31.5	48.6	9.4	104.7	63.8	56.1
40	20.4	28.3	41.0	15.0	104.7	61.4	63.7
60	25.2	25.5	33.3	20.7	104.7	58.6	71.4
80	29.5	23.3	26.0	25.9	104.7	55.5	78.7
100	33.2	21.6	19.2	30.6	104.7	52.4	85.5

[1]Same notation as for Table 6.2.

Machinery complement. Each of the systems analyzed was provided a complete forage harvesting machinery complement as well as corn planting and harvesting equipment. Individual machinery implements and tractors for the 120-cow and 80-cow systems are presented in Table 6.4. All tractors and forage equipment were selected from the machinery data base defined in Savoie's FORHRV module (1982); corn equipment is defined in Table B.4.

The primary difference between the machinery complements of Table 6.4 is that the 80-cow system includes medium-sized forage harvesting equipment (mower-conditioner, rake, chopper, baler) as opposed to the large capacity complement of the 120-cow system. All forage harvest operations include three wagons and assume that three persons and three tractors (field, transport, unloading) are engaged in parallel harvesting activities.

For any given herd size, as ration was varied from 0% to 100% corn silage, all systems were assumed to have the identical machinery complement, with the following exceptions:

1. A 6-row (4.5m) corn planter was used on the 0%, 20%, and 40% corn silage systems, whereas an 8-row (6.0m) planter was assumed for the 60%, 80%, and 100% systems.
2. The 120-cow system with no homegrown high-moisture corn (experiment C) assumes no picker-sheller, and only a 4-row planter for all five forage systems.
3. Experiment F assumes a diverse range of planting and harvesting equipment for an 80% corn silage system.[1]

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[1]These are described in greater detail in Section 6.3.4.

Table 6.4 Machinery Complement, 80 and 120-cow Systems

	Description	80-cow System (104.7 ha)			120-cow System (154.8 or 101.7 ha)		
		Capacity	MCODE[1]	Investment	Capacity	MCODE[1]	Investment
1	Tractor 1	80 kw	14	$ 32000	80 kw	14	$ 32000
2	Tractor 2	60 kw	13	24000	60 kw	13	24000
3	Tractor 3	30 kw	11	12000	30 kw	11	12000
4	Mower Conditioner	2.9m	41	6000	3.9m	42	9700
5	Rake	2.9m	70	2700	2.9m	70	2700
6	Chopper Base	11t/hr	132	8000	14t/hr	133	10500
7	- Hay Head	--	150	1400	--	151	2200
8	- 2-row Corn Head	1.5m	142	2800	1.5m	142	2800
9	Forage Wagon (3)	7.2t	251	27000	7.2t	251	27000
10	Forage Blower	50t/hr	241	2700	50t/hr	241	2700
11	Baler	11t/hr	102	10000	14t/hr	103	11000
12	Bale thrower	--	170	2000	--	170	2000
13	Bale Wagon (3)	3.6t	180	4200	3.6t	180	4200
14	Elevator	--	230	3000	--	230	3000
15	Picker-sheller	2.25m	--*	11000	2.25m	--*	11000
16	Base Machinery Complement			$148800			$156800

(Table 6.4 continued on next page)

Table 6.4 (Continued)

17	Corn Planter	3.0m	--*	$ 6080	3.0m	--*	$ 6080
18	Corn Planter	4.5m	--*	9120	4.5m	--*	9120
19	Corn Planter	6.0m	--*	12160	6.0m	--*	12160
20	Total (16 + 18)[2]			$157920			$165920
21	Total (16 + 19)[2]			--			168960
22	Total (16 + 17 - 15)[2]			--			151880

[1]Machine implements designated with MCODE (items 1-14) are defined in Savoie's FORHRV data base (1982). Implements designated * (items 15, 17-19) are defined in Table B.4.

[2]Line 20 machinery investment is assumed for all rations for the 80-cow system (experiment B) and for the 0, 20, and 40% systems for the 120-cow herd with homegrown high-moisture corn (experiments A, D, E). Line 21 investment is assumed for the 60, 80, and 100% systems for the 120-cow herd with homegrown high-moisture corn (experiments A, D, E). Line 22 investment is used for all 120-cow non-high-moisture corn systems (experiment C).

It should be noted that for any given experiment, total cropland area remains constant as rations progress from 0% to 100% corn silage (Tables 6.2, 6.3). Similarly, although there are large swings in the areas given individually to corn silage and alfalfa as ration changes, total forage area (corn silage + alfalfa) changes little due to the offsetting compensation of alfalfa's reduced area by the increased area given to corn silage. Implicitly, since alfalfa and corn silage employ the same harvest equipment (e.g., chopper, tractors, self-unloading wagons, blower) the question of tradeoffs related to forage harvest equipment is therefore less pronounced as rations are altered for a given herd size--crop area configuration.[1]

6.2.2 Input Prices

All user-inputted prices in the demonstration runs reflect 1981 price levels. When 1981 prices were not directly available, inputted prices were indexed to 1981 levels such that the appropriate relative price relationships between inputs were maintained.

Assumed machinery investment costs of all tractors and implements are provided in Table 6.4. Sources of investment costs of corn planters and picker-shellers are described in Appendix Table B.4 of the present study. Investment cost sources of all other machinery items are defined in Savoie (Appendices A and B, 1982).

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[1] For this reason, the simulation results reported in this study emphasize the impact of timeliness of corn planting and harvesting on system output. Simulation run results of alfalfa harvest capacity with respect to alfalfa area are reported in Savoie (Section 9.2, 1982).

Investment costs of silos (alfalfa, corn silage, high-moisture corn) were estimated using Table B.3. Silos were assumed to be available in two-foot increments for both diameter and height. All surplus alfalfa harvested as (rectangular) baled hay was charged a marginal storage cost of \$8/ton/yr.

Both medium and long-term interest rates for all model runs were set at 6%. This value reflects a real opportunity cost on capital invested in machinery and storage structures. 6% is an estimate of the 1981 real interest rate derived by subtracting USDA's 1981 price deflator (9%) from the average 1981 3-month Treasury bill rate (15%). Although this value is an arbitrary estimate of the real interest rate, it reflects an approximate 3% real growth required return, plus an additional 3% time preference discount. Depreciable life (years) of storage structures and machines was set at 25 and 7 years, respectively; annualized fixed costs were based on 100% and 90% of the investment in storage structures and machines reflecting a 0% and 10% salvage value for these durable assets, respectively.

Price of diesel and gasoline fuel was set at \$.299 and \$.350 per liter, respectively (Michigan Agricultural Statistics, 1981). A drydown charge for all residual corn area harvested as corn grain was \$.03/point/bushel, based on Nott et al. (1981). All labor accumulated in the model for field operations and feeding was paid \$5.00/hour.

Cash costs (fertilizer, seed, chemicals) charged against all area of crops grown were based on Nott et al. (1981) and are presented in Table B.5. Fertilizer application rates were adjusted to reflect maintenance of nutrient removal from the soil at yield levels presented earlier in Chapters 4 and 5.

All simulation runs were assessed custom charges for the optional corn tillage (PTILLC) and alfalfa establishment (PTILLA) user-input variables. Values for PTILLC and PTILLA, as well as the charge for custom combining of residual corn area, were based on Schwab and Gruenewald (1978) and are presented in Table B.6. Non-zero custom corn tillage and alfalfa establishment charges were deemed to be important in the simulation runs because relative area given to each crop changes as rations are altered from 0% to 100% corn silage.

The assumed buy and sell prices for all feedcrops grown as well as for purchased supplements (soybean meal, NPN) used in the simulation runs are presented in Table B.7. Because no market price is readily available for high-moisture corn and corn silage due to their bulk and perishability after removal from storage, arbitrary prices were set for these commodities. The buy price of high-moisture corn was set equal to the buy price of dry corn grain in all model runs.[1] By contrast, the buy price of corn silage was estimated based on a procedure described by Woody and Black (1978) which indexes corn silage price to production costs and price of cash corn. Sell prices for all bulky homegrown feedcrops were arbitrarily set at 80% of buy prices. Because the price of forages often reflects geographically local or "thin" markets, two of the experiments (D and E) analyze system performance under low and high corn prices. This enables the evaluation of model results under alternative relative prices of feed commodities.

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[1]Prices were set equivalent on a dry-matter basis.

6.3 Simulation Results

Each set of system alternatives outlined for experiments A-F in Section 6.1 was simulated using the DAFOSYM model. Each of the 34 individual runs consisted of a 26-year simulation using inputted values described in Section 6.2. Subsequently, for each experiment a pairwise comparison was made between the individual cumulative distributions of net feed costs (NFC) generated for each simulation. The cumulative distributions were then ranked by second degree stochastic dominance criteria using a software package developed by King and Robison (1981). System rankings as well as highlight summary output from the six experiments are presented below.

6.3.1 Alternative Rations for Two Herd Sizes, All Feedcrops Homegrown

Rankings of six alternative systems designed to provide rations containing 0-100% corn silage (20% increments) for a 120-cow and 80-cow herd are presented in Table 6.5 (experiments A and B). For all systems, high-moisture corn, corn silage and alfalfa are homegrown. Experiments A and B are benchmark experiments in that they demonstrate use of DAFOSYM to analyze the impact on system economic performance of producing feed rations which reflect the entire spectrum of forage substitutability for dairy cows.

Noteworthy of the Table 6.5 results is that systems low in corn silage (e.g., 20% systems) are preferred both to systems containing high levels of corn silage and to systems with no corn silage at all. For both the 120-cow and 80-cow herds, risk (as measured by the coefficient of variation and range of net feed costs in Table 6.5) increases monotonically with the level of corn in the system. How-

Table 6.5 Ranking of Six Alternative Systems for a 120-cow and 80-cow Herd Fed Homegrown Forages and High-moisture Corn

Rank	System: % Corn Silage	Net Feed Costs (NFC), $				
		Sample Mean	CV[1]	Upper Bound	Lower Bound	Range
120 Cows (154.8 ha):						
1	A2-20%	92704	.049	102442	84469	17773
2	A3-40%	93256	.058	104539	82604	21935
	A1-0%	93967	.048	103370	87888	15482
3	A4-60%	96045	.060	106066	84507	21559
4	A5-80%	98719	.065	110129	85573	24556
5	A6-100%	101206	.072	113708	87082	26626
80 Cows (104.7 ha):						
1	B2-20%	70168	.043	75048	63838	11210
2	B3-40%	71186	.046	76383	64133	12250
3	B4-60%	71999	.051	78316	63606	14710
4	B1-0%	72785	.040	79156	68997	10159
5	B5-80%	73211	.056	80582	64208	16374
6	B6-100%	74396	.064	82465	64614	17851

All rankings are based on a 26-year simulation sample using second degree stochastic dominance criteria.

[1]Coefficient of variation.

ever, in spite of the fact that the preferred 20% systems result in both the lowest mean and lowest upper bound values for net feed costs, highest net returns in "best" years over the 26-year simulation (as measured by the minimum lower bound on net feed costs) are attained with the 40% corn silage system.

Table 6.6 shows in greater detail the composition of mean net feed costs generated for each of the six 120-cow systems (A1-A6) over the 26-year run. In assessing why system risk increases with the proportion of corn in the farm plan, it is important to note both the relative weighting as well as the annual variability of each of the 11 summary cost categories comprising net feed costs in Table 6.6.[1] Though comprising a large proportion of the row 12 net feed costs for all six systems, rows 1, 2 and 7 (storage fixed costs; machinery fixed costs; fertilizer, seed and chemical cash costs) do not vary on an annual basis and hence do not contribute to system risk. By contrast, the row 3-6 cost categories (fuel, repair-maintenance, labor) do vary year-to-year as a function of crop area and quantity of feeds produced on the farm, but each of these cost categories embodies a relatively small share of annual net feed costs. Moreover, a glance across any of the individual cost rows 1-7 shows that these categories contribute little to differences in net feed costs when comparing systems A1-A6. Hence, the conclusion must be drawn that the remaining cost categories 8-11 are the major contributors to differences in both mean level and variability of net feed

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[1]DAFOSYM output includes sample mean, standard deviation, and coefficient of variation for each cost category. See Appendix I.

Table 6.6 Composition of Sample Mean Net Feed Costs under Six Alternative Rations for a 120-cow Herd Fed Homegrown Forages and High-moisture Corn, $ (154.8 ha)

	Cost Category	System - % Corn Silage					
		A1-0%	A2-20%	A3-40%	A4-60%	A5-80%	A6-100%
1	Feed Storage[1]	$ 8173	$ 9393	$ 8582	$ 9434	$ 9723	$ 9517
2	Machinery[1]	23950	24418	24418	24934	24934	24934
3	Fuel	3311	3233	3158	3037	2928	2819
4	Repair/Maintenance	7016	6763	6613	6372	6145	5918
5	Labor (field)	5417	5339	5256	4874	4715	4557
6	Labor (feeding)	4668	4277	4111	3866	3649	3431
7	Fert., seed, chemicals	29617	30845	31297	31617	31929	32198
8	Custom Charges[2]	7429	9719	10765	11941	12977	13911
9	Corn Grain Drying	254	1353	2016	2874	3499	4029
10	Feed Purchases[3]	6034	7898	12654	19300	25677	31890
11	Cash Corn Sales	(1902)	(10534)	(15615)	(22203)	(27457)	(31999)
12	Net Feed Costs	$ 93967	$ 92704	$ 93256	$ 96045	$ 98719	$101206

All values are sample means based on a 26-year simulation. Rows 1-10 are costs; row 11 is a return.

[1]Annual fixed costs.

[2]Corn tillage, alfalfa establishment, and residual cash corn harvest.

[3]Surplus homegrown feedcrop sales less purchase of deficit feeds and feed supplements.

costs when comparing across alternative dairy forage system designs.

A close inspection of cost categories 8-11 across the six systems reveals two trends in the simulated data:

1. As systems become more corn-oriented, each of these cost categories comprises a relatively larger proportion of annual net feed costs. Increases in mean values of rows 8, 9, and 11 (custom charges, grain drying, cash corn sales) as systems progress from 0% to 100% corn silage reflect greater residual cropping area grown for cash corn sales in the high corn silage systems (see Section 6.2.1).[1] By contrast, the charges for feed purchases (row 10) increase across systems A1-A6 primarily due to the large expenditures on purchased protein supplements (soybean meal, NPN) required by the predominantly corn silage systems.

2. As systems become more corn-oriented, the variance of cost categories 8, 9, and 11 increases.[2] The increased variability exhibited across systems A1-A6 for cash corn sales, corn drying and custom charges (rows 8, 9, 11) is due to two factors. First, yields of corn silage and high-moisture corn are positively correlated in the model (Section 5.5.3); second, the area (and quantity) of corn actually harvested for cash grain sales is dependent on the yields of corn silage and high-moisture corn (Section 5.6.1). Because the cropping

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[1] Row 8 reflects custom charges for alfalfa establishment, corn tillage, and harvest of residual corn for cash sales. Even if no charges were incurred for harvest of cash corn, row 8 values would nevertheless be less for predominantly alfalfa systems since establishment charges are incurred only once during the stand as opposed to corn tillage charges which are incurred annually for each corn hectare grown.

[2] Estimated cost variance is not indicated in Table 6.6.

area for cash corn sales is literally a residual area harvested only after the corn silage and high-moisture corn storage structures are filled, any variability in yields of the latter two feedcrops has little or no effect on the annual quantity of corn silage and high-moisture corn actually harvested. Instead, all corn yield variability is projected onto the residual area to be harvested for cash sales.

For example, in low yield years, a greater number of hectares is harvested as both corn silage and high-moisture corn before storage structures are filled, leaving a small residual cropping area for cash sales. Due to the positive correlation between corn silage and high-moisture corn yields, the effect is magnified as relative area of crops grown to corn increases. For systems high in corn silage, the reduced cash sales of corn in low yield years do not offset the relatively high "fixed" costs of purchased protein required in the ration. As systems become higher in corn area, greater swings in year-to-year cash corn sales are observed, and when combined with higher expenditures on protein purchases, result in greater variability of annual net feed costs.

This concept is more clearly demonstrated in Figure 6.1 which shows sample cumulative distributions of net feed costs plotted for the 0, 20, 40, and 80% corn silage systems for the 120-cow herd.[1] The lower tail of the 40% system lies to the left of that of the 20% system, whereas its upper tail lies to the right of the 20% system. This implies that in worst (low yield) years, the 40% systems will

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[1]The net feed cost axis is reversed in order to allow ease of interpretation of CDF's consistent with discussions in the literature and with the ordering rules provided in Appendix F.

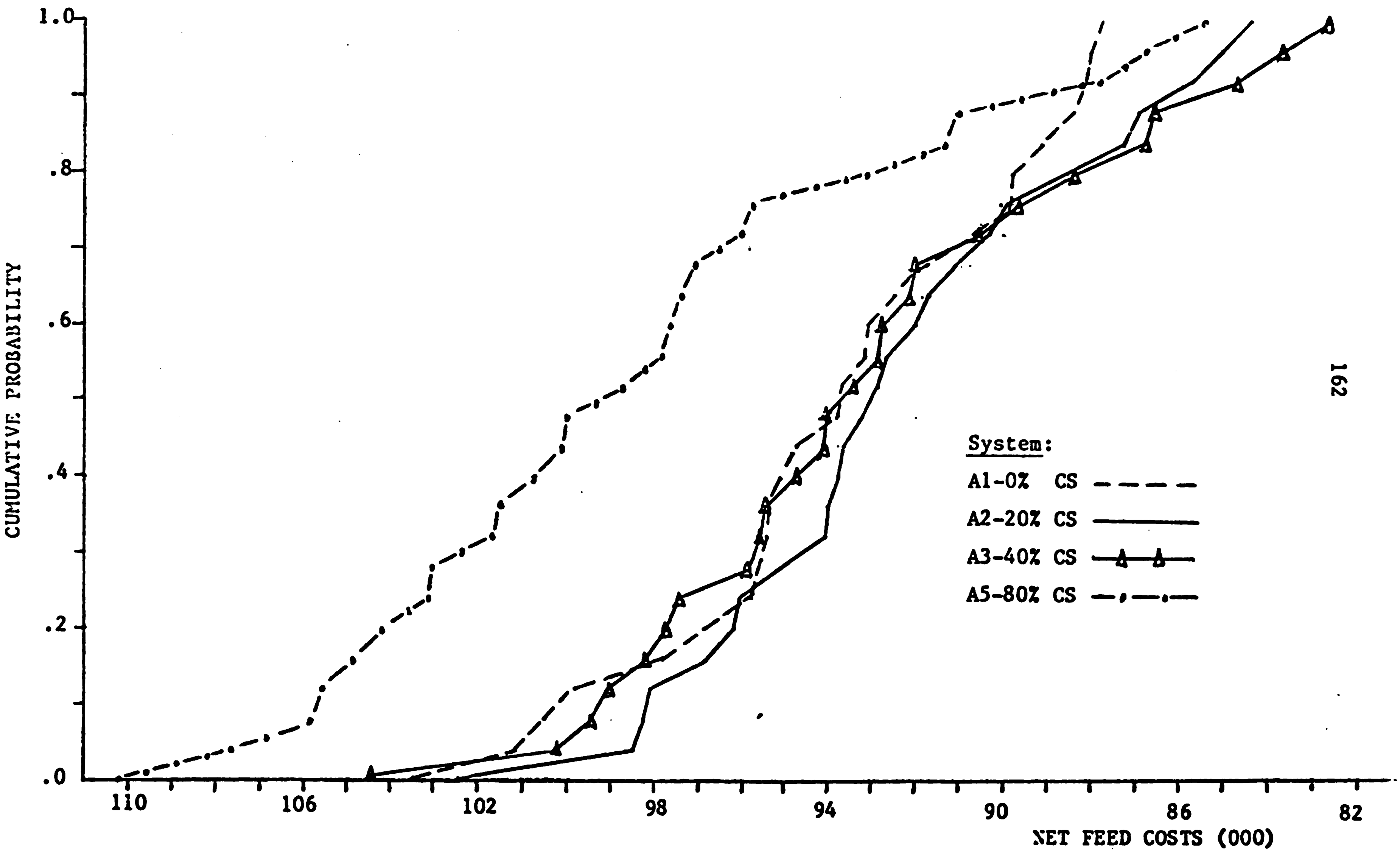

Figure 6.1 Cumulative Density of Net Feed Costs for Four Alternative Forage Systems

result in higher costs, but also that in best (high yield) years, it will result in lower net feed costs than the preferred 20% system.

Although the 20% system is second degree stochastic dominant over the 40% system, it is first degree dominant over the 80% corn silage system. This implies that the 80% system is riskier than the 20% system and always results in higher net feed costs. Nevertheless, although the 80% CDF always lies to the left of that of the 20% system, the gap between the two narrows as cumulative probability increases. This implies that in "worst" years (at the lower tail of each CDF), the high corn silage system is relatively worse off than during "best" years when net feed costs incurred under the two systems (80% and 20%) differs by a relatively small amount ($1100).

6.3.2 Alternative Forage Rations Using Purchased Corn Grain

Rankings of five alternative forage systems for a 120-cow farm which purchases corn grain instead of growing high-moisture corn are presented in Table 6.7 (experiment C). Composition of the sample mean net feed costs for the five systems is shown in Table 6.8. The basic features distinguishing the design of the experiment C systems from those of experiment A are: (a) total crop area and relative crop mix is altered (Table 6.2); (b) investment in storage structures is reduced (Table 6.1); and (c) investment and size of corn machinery is reduced. As in experiment A, experiment C systems were constrained to contain an equivalent total cropping area by providing each system a residual cropping area which is marketed as cash grain. However, the area of corn grown relative to alfalfa in experiment C systems is diminished.

The most noteworthy differences between the purchased corn systems (C1-C5) and those described in experiment A are the following:

Table 6.7 Ranking of Five Alternative Systems for a 120-cow Herd Fed Homegrown Forages and Purchased Corn Grain (101.7 ha)

Rank	System: % Corn Silage	Net Feed Costs (NFC), $				
		Sample Mean	CV[1]	Upper Bound	Lower Bound	Range
1	C3-40%	110311	.023	115325	105435	9890
	C2-20%	110314	.023	116521	106918	9603
2	C1-0%	111036	.038	121355	104633	16722
	C4-60%	112531	.029	120106	106687	13419
	C5-80%	114762	.031	121123	107244	13879

All rankings are based on a 26-year simulation sample using second degree stochastic dominance criteria.

[1] Coefficient of variation

Table 6.8 Composition of Sample Mean Net Feed Costs under Five Alternative Rations for a 120-cow Herd Fed Homegrown Forages and Purchased Corn, $ (101.7 ha)

	Cost Category	System - % Corn Silage				
		C1-0%	C2-20%	C3-40%	C4-60%	C5-80%
1	Feed Storage[1]	$ 6538	$ 7854	$ 7061	$ 8002	$ 8336
2	Machinery[1]	20538	22035	22035	22035	22035
3	Fuel	2597	2615	2604	2549	2491
4	Repair/Maintenance	5879	5724	5647	5486	5318
5	Labor (field)	4028	4157	4199	4171	4139
6	Labor (feeding)	4211	3864	3737	3531	3344
7	Fert., seed, chemicals	19913	21140	21594	21913	22229
8	Custom Charges[2]	3017	5020	5786	6662	7493
9	Corn Grain Drying	0	787	1060	1463	1863
10	Feed Purchases[3]	44318	42586	44137	47673	51622
11	Cash Corn Sales	(0)	(5467)	(7549)	(10955)	(14108)
12	Net Feed Costs	$111036	$110314	$110311	$112531	$114762

All values are sample means based on a 26-year simulation. Rows 1-10 are costs; row 11 is a return.

[1] Annual fixed costs.

[2] Corn tillage, alfalfa establishment, and residual cash corn harvest.

[3] Surplus homegrown feedcrop sales less purchase of deficit feeds and feed supplements.

1. Only two rankings are distinguished by second degree stochastic dominance criteria. This reflects the fact that from a risk-returns perspective, systems C1-C5 are not as distinct from one another as was the case with systems A1-A6. This reduced difference between purchased corn systems results in an efficient set consisting of both the 20% and 40% systems. Implicitly, the cumulative distributions for all five purchased corn systems lie relatively close to one another.

2. Absolute level of mean net feed costs for all five purchased corn systems is approximately $16,800 higher than for the 120-cow high-moisture corn systems. The tradeoff between the two sets of systems is that with purchased corn, the same 120-cow herd is fed with only 101.7 hectares of homegrown crops as compared with the 154.8 hectares required for the high-moisture corn systems. This implies that on average, a system C farmer could afford to pay annual rent of up to $316/ha (at the assumed prices) for the additional land required under the high-moisture corn systems analyzed above.

3. Variability of net feed costs is reduced from levels exhibited in experiment A. With all corn grain purchased at a deterministic (constant) price and with less cropping area of corn relative to alfalfa, all five systems experience reduced risk levels. Nevertheless, although experiment C systems exhibit increasing risk relative to one another as corn silage is augmented from 20% to 80%, the highest variability in net costs is incurred under the 0% corn silage system. This all-alfalfa system (no corn silage, no high-moisture corn) results in the lowest net feed costs in "best" years when alfalfa yield is high because little protein is purchased and

cash sales of surplus alfalfa help reduce the high expenditures on purchased corn. However, in "worst" years of low alfalfa yields, large expenditures on purchased alfalfa result in the highest net feed costs across all systems. Unlike those systems containing at least some corn silage, all-alfalfa systems offer no chance of having a "bad alfalfa--good corn silage" year[1] which would permit some of the high expenditures on corn grain to be offset by cash corn sales. In essence, the 0% corn silage system with no homegrown high-moisture corn reflects a totally undiversified cropping system which has less flexibility for adjustment in years of adverse weather.

6.3.3 Alternative Forage Rations with Corn Prices at Two Levels

The bulkiness and perishability of harvested forage crops and high-moisture corn tends to result in feedcrop cash prices which are geographically localized, or at best, more difficult to assess than for crops which have a well-defined cash market. Nevertheless, from a modeling viewpoint, the choice of relative feedcrop prices is important when comparing alternative forage systems, since the varying levels of each crop purchased and sold will affect net feed costs and rankings of the systems tested.

Two experiments (D and E) were conducted in order to test the sensitivity of experiment A model output to changes in the relative price levels of alfalfa and corn. Rankings of five alternative systems for a 120-cow herd fed homegrown forages and high-moisture

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[1]Recall that alfalfa and corn yields are uncorrelated in the DAFOSYM model. See Section 5.5.4.

corn under low ($2.50/bu) and high ($3.50/bu) corn price levels are presented in Table 6.9. Design of all systems in Table 6.9 is identical to systems A1-A5 with the exception that buy and sell prices of corn silage and high-moisture corn are proportionately adjusted relative to the altered cash corn price levels as described in Table B.7.

Noteworthy comments concerning the results of Table 6.9 are the following:

1. System rankings have shifted slightly from the experiment A (120-cow, $3.00/bu corn) rankings presented earlier in Table 6.5. As expected, lower relative corn prices ($2.50/bu) tend to disadvantage high corn silage systems due to reduced revenues from cash corn sales and, hence, systems lowest in corn silage are preferred. By contrast, when corn prices are increased to $3.50/bu, the new rankings show that preferred systems include more corn silage.[1] Although it can be hypothesized that even higher relative corn prices (e.g., $4.00/bu) might at some point reverse the order of the rankings, it should be recalled that all of the 120-cow systems in experiments A, D, and E sell cash corn whenever corn yields are high. Hence, changes in the rankings might be less dramatic than expected with changing corn prices.

2. An increase (decrease) in the price of corn relative to alfalfa increases (decreases) the variability of net feed costs.

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[1]Note that both upper and lower bound values are significantly reduced for 80% systems when corn prices are increased from $2.50/bu to $3.50/bu (Table 6.9). By contrast, the same variables are barely affected for the 0% system over the same price range.

Table 6.9 Ranking of Five Alternative Systems for a 120-cow Herd with Corn Prices at Two Levels (154.8 ha)

Rank	System: % Corn Silage	Net Feed Costs (NFC), $				
		Sample Mean	CV[2]	Upper Bound	Lower Bound	Range
Corn = $2.50/bu[1]						
1	D1-0%	94095	.043	103644	88365	15279
	D2-20%	94460	.040	102807	88012	14795
2	D3-40%	95858	.046	105425	87246	18179
3	D4-60%	99745	.048	108111	90470	17641
4	D5-80%	103294	.050	112777	92651	20126
Corn = $3.50/bu[1]						
1	E3-40%	90517	.071	103607	77716	25891
	E2-20%	90856	.059	102058	80739	21319
2	E4-60%	92149	.075	103914	78228	25686
	E1-0%	93823	.049	103081	87057	16024
3	E5-80%	93902	.083	107340	78120	29220

All rankings are based on a 26-year simulation sample using second degree stochastic dominance criteria.

[1]Prices of corn silage and high-moisture corn are adjusted proportionately relative to cash corn as described in Appendix Table B.7.

[2]Coefficient of variation.

As corn prices increase (decrease), expenditures on feed purchases and returns from cash corn sales (lines 10-11, Table 6.6) comprise larger (smaller) proportions of annual net feed costs. Hence, variability in these feed cost components is either magnified or diminished as corn prices increase or decrease relative to the price of alfalfa.

6.3.4 Alternative Machinery Configurations for an 80% Corn Silage System

One of the potential impacts of choosing a machinery complement of insufficient capacity is the cost associated with not planting and harvesting crops in a timely fashion. Delayed field operations generally result in reduced yields for corn (see Section 5.2) or reduced quality for alfalfa (see Section 4.2.1).

Because greater initial investment outlays as well as higher unit operating costs are associated with increased machinery capacity, a final experiment (F) was conducted in order to demonstrate how increased expenditures on machinery capacity influence the net feed costs of a 120-cow system which produces homegrown forages and high-moisture corn. The system selected for analysis was the 80% corn silage forage system of experiment A.

Seven individual simulations of this 120-cow (154.8 ha) 80% corn silage system (A5) were run, each with an alternative corn planting and/or corn harvesting machinery configuration. Results of these simulations are provided in Tables 6.10 and 6.11. Systems F1-F7 reflect machinery capacity of approximately increasing magnitude. Each system is identified by a three-digit number representing the size (in number of rows) of the corn planter, chopper, and picker-

Table 6.10 Ranking of Seven Alternative Machinery Configurations for a 120-cow Herd Fed an 80% Corn Silage Ration (154.8 ha)

Rank	System: Machinery Capacity	Net Feed Costs (NFC), $				
		Sample Mean	CV[1]	Upper Bound	Lower Bound	Range
1	F6 (8-2-3)[2]	98719	.065	110129	85573	24556
2	F4 (6-2-3)	99216	.072	111871	85974	25897
3	F5 (8-2-2)	100064	.076	121562	86586	34976
	F7 (8-3-3)[3]	101169	.064	112759	88176	24583
4	F2 (6-2-2)	100547	.082	122832	86730	36102
	F3 (4-2-3)	102885	.073	114525	88574	25951
5	F1 (4-2-2)	104080	.081	125111	89189	35922

All rankings are based on a 26-year simulation sample using second degree stochastic dominance criteria.

[1]Coefficient of variation

[2]The three digits represent the size (number of rows) of the corn planter, corn chopper, and picker sheller. Systems F1-F7 are labeled in approximate increasing size of machinery capacity.

[3]The three-row chopper in system F7 has both a larger throughput capacity and is powered by a 100 KW tractor as opposed to the 80 KW tractors which power the 2-row choppers. This larger capacity chopper is also used to harvest alfalfa haylage.

Table 6.11 Composition of Sample Mean Net Feed Costs under Seven Alternative Machinery Configurations for a 120-cow Herd Fed an 80% Corn Silage Ration, $ (154.8 ha)

	Cost Category	System - Machinery Capacity						
		F1 4-2-2	F2 6-2-2	F3 4-2-3	F4 6-2-3	F5 8-2-2	F6 8-2-3	F7 8-3-3
1	Feed Storage[1]	$ 9718	$ 9717	$ 9718	$ 9717	$ 9723	$ 9723	$ 9715
2	Machinery[1]	23712	24248	23902	24418	24764	24934	26974
3	Fuel	3320	3105	3141	2931	3102	2928	3090
4	Repair/Maintenance	6559	6363	6344	6153	6354	6145	6518
5	Labor (field)	5837	5296	5500	4969	5043	4715	4635
6	Labor (feeding)	3632	3646	3633	3647	3649	3649	3654
7	Fert., seed, chemicals	31929	31929	31929	31929	31929	31929	31929
8	Custom Charges[2]	12801	12874	12881	12953	12889	12977	12977
9	Corn Grain Drying	3288	3246	3635	3533	3178	3499	3499
10	Feed Purchases[3]	26057	25853	25955	25757	25713	25677	25633
11	Cash Corn Sales	(22793)	(25730)	(23754)	(26791)	(26281)	(27457)	(27457)
12	Net Feed Costs	$104080	$100547	$102885	$ 99216	$100064	$ 98719	$101169
	Machine Investment	$141680	$144720	$142680	$145720	$147760	$148760	$160960

All values are sample means based on a 26-year simulation. Rows 1-10 are costs; row 11 is a return. Three-digit numbers define machine capacity in rows (planter - chopper - picker sheller).

[1] Annual fixed costs.

[2] Corn tillage, alfalfa establishment, and harvest of residual cash corn.

[3] Surplus homegrown feedcrop sales less purchase of deficit feeds and feed supplements.

sheller.[1] All remaining machines in the complement are identical for all model runs, except for system F7 in which the 80 kw tractor is exchanged for a 100 kw tractor to power the increased capacity 3-row chopper.

The rankings of Table 6.10 demonstrate that an increase in planting capacity from 4 rows to 8 rows, and an increase in high-moisture corn harvest capacity from 2 rows to 3 rows results in the least cost system with minimal risk. This preferred system F6[2] outranks systems of smaller capacity (F1-F5), as well as system F7, whose increased overhead costs do not sufficiently compensate for reduced timeliness costs, and whose increased capacity does not sufficiently reduce system risk.

It is of interest to note that with the 4-row planting system (F1), average completion date of corn planting was May 26, with 6 years out of 26 being finished after June 1. The latest completion date for 4-row corn planting was June 15. Since harvest of first-cut alfalfa was scheduled to begin May 24 each year, delayed corn plantings caused delayed initiation of alfalfa first-cut harvest in 14 out of 26 years. Average first-cut starting date for alfalfa for the 4-row planting systems was May 29. By increasing planting capacity to 6 rows, average completion date of planting was moved up to May 16, and conflicts with alfalfa harvest initiation occurred in

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[1] In practice, the number of rows on corn planting and harvesting equipment is matched such that one is an integer multiple of the other. For demonstration purposes, this assumption was violated in these model runs.

[2] System F6 is identical to system A5 described earlier (Tables 6.5, 6.6).

only 2 years out of 26.

None of the simulations in experiment F results in delayed initiation of corn silage harvest. All systems consist of a relatively small alfalfa cropping area with high alfalfa harvest capacity permitting third-cut harvest completion before September 1. Nevertheless, Table 6.10 demonstrates that all two-row picker-sheller systems (F1, F2, F5) result in upper bound net feed costs in excess of all three-row picker-sheller systems. This is due to the fact that high-moisture corn harvest is not completed in 1 year out of 26 for all two-row systems. Average completion date of corn harvest for these systems is October 30, with 10 years out of 26 being completed after November 1. By contrast, 3-row picker-shellers cause average completion of corn harvest to be moved up to October 23.

Cumulative distributions from simulated systems F1, F2, F5, and F6 are plotted in Figure 6.2. Several points are noteworthy.

1. The impact of not finishing corn harvest in one year out of 26 shows up as an elongated left tail for the two-row picker-sheller systems (F1, F2, F5).

2. The sole difference between systems F1, F2, and F5 are a 4-row, 6-row, and 8-row planter, respectively. Although none of these systems finishes corn harvest in the "worst" year, the cumulative distributions for F2 and F5 lie to the right of that for F1. This improved performance is due primarily to the earlier average planting dates of these larger capacity systems, resulting in increased yields and reduced costs over a broad number of years.

3. Proceeding from left to right, the gap between all cumulative distributions narrows. This reflects the fact that in "bad" years,

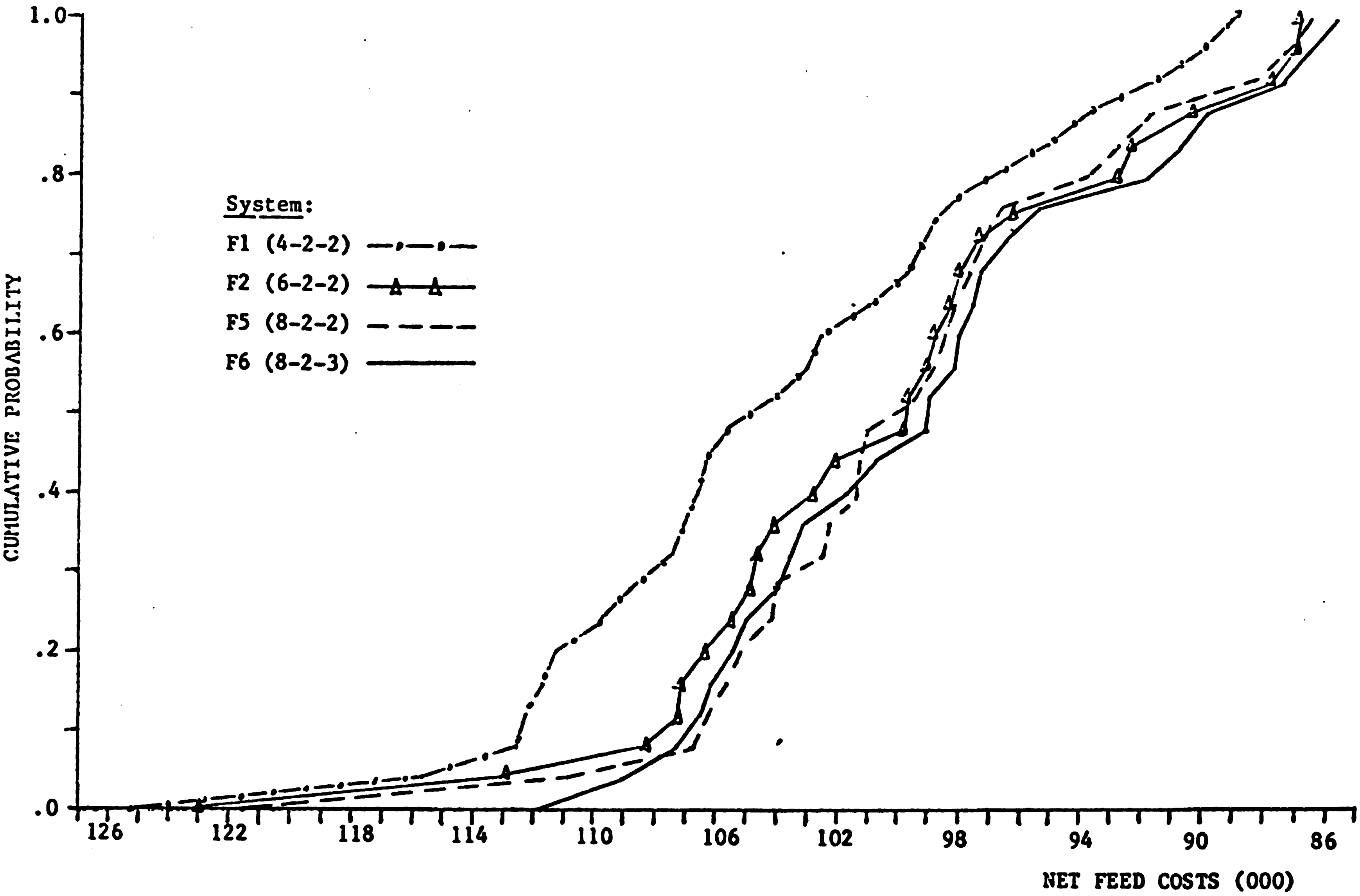

Figure 6.2 Cumulative Density of Net Feed Costs for Four Machinery Configurations

small capacity systems are penalized more than systems with larger capacity, but that in "good" years, differences between systems are minimal.

6.4 Comment on Simulation Experiment Results

The purpose in conducting the dynamic simulation experiments described in Section 6.3 was to provide the reader with insight as to the types of analyses which can be undertaken using DAFOSYM. It was demonstrated that the model can be used to compare risk-return trade-offs for a broad array of problem categories. The model is suitable for making a comprehensive comparison of alternative dairy forage systems in which all input design variables (e.g., crop mix, herd size, machinery configuration, feed storage) are altered. Likewise, it can be used to isolate the effect of a change in a single variable (prices, machine size) on system output.

While the discussion in this chapter emphasized various aspects of corn production in the broader context of dairy forage system design, Savoie (1982) demonstrates model applications oriented towards alfalfa production in the context of management strategies (e.g., date of harvest, number of cuttings per season). Moreover, although the abbreviated discussion in Section 6.3 has stressed simulation results primarily in terms of economic variables (e.g., net feed costs), the model generates output which permits analysis and interpretation to be directed equally well towards resource use and material flows.

The general thrust of the experiments comparing alternative forage systems showed that rations high in alfalfa are preferred over high corn silage systems when viewed from the risk-returns perspective. In specific, experiments A-E demonstrated that 20% corn silage systems either dominated all other systems (experiments A, B), or at least were members of the efficient set for experiments in which no single system design dominated all others (experiments C, D, E). Two cautionary comments can be made with regard to these results.

Alfalfa quality. None of the simulation experiments reported above incorporates the full potential of modeled relationships developed in the ALFMOD and ALHARV modules. The present version of DAFOSYM employs a temporary dairy forage feed utilization model whose primary shortcoming is that it estimates annual feed disappearance based on pre-formulated balanced rations (see Appendix G). Because these rations do not incorporate the ALFMOD-ALHARV simulated estimates of alfalfa quality (protein, digestibility), the results reported in this chapter primarily reflect risk-return tradeoffs resulting from crop yield and yield variability, while ignoring the impact of alfalfa quality and its variability on system output.

It should be noted, however, that in all simulation runs reported in experiments A-F, alfalfa production and harvesting techniques were held constant in order to minimize variation in simulated alfalfa quality across systems. This has the effect of reducing bias in the simulated output by generating results which control for alfalfa quality across treatments. Whereas all simulated systems did not result in identical estimates of alfalfa quality over the 26-year runs, the maximum difference between simulated sample means across all systems was .7% and 1.2% for crude protein and digestibility, respectively.

Once alfalfa quality is incorporated into a future version of the feed disappearance model, it is uncertain what the net effect will be on the simulation results, primarily because all forage systems tested in Section 6.3 incorporate alfalfa as part of the farm plan. One reasonable hypothesis, however, is that simulated net feed costs of systems high in alfalfa will exhibit greater variability due to this additional risk factor.

Commodity prices. The design of the alternative forage systems in experiments A-E incorporated an increased area of residual cash corn as rations progressed from 0% to 100% corn silage. Whereas the residual cash corn area concept was necessitated by the experimental design of the study, it should be recognized that as more corn is grown for cash sales, market (price) risk becomes an increasingly important factor which has impact on the system performance measure, net feed costs. Indeed, even without cash corn sales, systems high in corn silage exhibit a high degree of commodity market dependence due to large quantities of purchased protein in the form of soybean meal.

Whether the absence of stochastic commodity prices produces a significant downward bias in simulated estimates of the variance of high corn silage systems depends in part on the magnitude of corn and soybean meal price variability, as well as on the degree of correlation between corn price, soybean meal price, and corn yield. Because commodity prices are deterministic in DAFOSYM, the impact of market risk on dairy forage system design remains a topic beyond the realm of investigation of the present version of the model.

CHAPTER VII

CONCLUSION

7.1 Summary of Research Objective and Method

The present study stemmed from a need to provide investigators with a research tool capable of analyzing technical and economic issues of dairy forage production in the context of the whole farm. In response to this need, a systems approach was taken in developing DAFOSYM (DAiry FOrage SYstems Model), a computerized simulation model which can be used for analyzing alternative system design, technology, or management at the farm-firm level. Development of DAFOSYM was undertaken as a joint venture between the author and Savoie (1982). The present study described the author's contribution to model design, development, testing, and implementation; corresponding contributions of Savoie are described in the companion dissertation (1982).

Three issues were cited as being important guidelines which directed the design of the model developed for this study: (1) The model is generic in that it enables a complete spectrum of forage systems (ranging from all-alfalfa to all-corn silage) to be analyzed; (2) the model accounts for dynamic system interactions (timeliness of field operations, daily weather pattern dynamics) which affect quantity/quality tradeoffs of feedcrops produced for the dairy herd; and (3) the model provides a measure of both the level of profitability and riskiness associated with any system by generating a sample probability distribution of the system performance measure, net feed costs.

As a dynamic state variable model, DAFOSYM simulates four on-farm production activities which describe the interface of the crop/livestock subsystems of a commercial dairy farm: crop growth-yield, crop planting-harvesting, feedcrop storage-handling, and feedcrop disappearance. As a bio-engineering economic model, three categories of variables are monitored throughout the simulation: material flows of feedcrops produced, resource use associated with these flows, and cost/returns associated with the depletion of resources. Whereas production processes are simulated at a minimum time increment of one day, the accounting period of the system performance measure is one year. Hence, a multiple-year simulation results in a cumulative distribution function of net feed costs incurred under each system being analyzed. This model output is appropriate for use in experiments whose goal it is to compare alternative system designs, management strategies, or technology by ranking system alternatives for their risk-return tradeoffs using stochastic efficiency criteria.

Given the nature of the model, it is anticipated that it will serve as a catalyst for interdisciplinary research and communication. To the various disciplines involved in dairy forage research, it provides an efficient vehicle for evaluating the sensitivity of farm system level economic output to subsystem level technical and economic input parameters. It is also anticipated that the model presented in this study and Savoie (1982) will serve as a basis for further model refinements, alterations and improvements. To this end, model development took a modular approach, and user-oriented documentation was provided.

7.2 A Review of Procedures Used in Model Development

The author's primary contributions to model development of DAFOSYM consist of the design, implementation, and testing of the model components described in this study. Implementation of model software is described in Appendices A-E. Contributions to the design and development of model content are summarized below.

1. A phenological alfalfa growth model was adapted for use in the context of whole farm simulation. Adaptation included the recoding of the model into FORTRAN, addition of a crop quality component, and expansion of the model algorithm to enable multiple-day harvest periods (with a corresponding crop regrowth-reset mechanism) and multiple-year simulation capability. The model simulates growth and yield of alfalfa plant components on a one-day time increment.

2. A series of alfalfa quality prediction equations was estimated using least squares regression techniques. The equations predict concentration of crude protein and digestibility (IVDMD) of plant leaf and stem components as a function of herbage composition. Cumulative heat units were rejected as an unsuitable index of plant maturity, and hence, were deemed to be an inappropriate argument in quality prediction equations.

3. A 26-year daily weather data file was developed for East Lansing, Michigan. The data file is used to drive the alfalfa growth model over multiple-year simulations.

4. The alfalfa growth model was statistically validated under Michigan conditions. Validation procedures employed ordinary least squares regression to compare the weekly time path of simulated yields with Michigan data. In addition, standard t-tests compared end-of-year

simulated yields with three alfalfa varieties grown in Michigan.

5. A phenological corn growth model was examined, tested, and rejected for use as a tentative corn yield prediction component of DAFOSYM.

6. A stochastic process model was identified as an appropriate alternative for simulating the dynamics of corn production processes. A multivariate stochastic process generator with beta distributed marginals was adapted for use in the present study.

7. Stochastic corn production variables were identified (corn yield, available days for planting and harvest). Marginal distribution parameters of these variables were estimated, based on detrended Michigan yield data, and on output generated by an independent available-days simulation model.

8. Correlation coefficients were estimated in order to assess the level of serial and/or contemporaneous interdependence between the stochastic corn production process variables. Additionally, correlation coefficients between improved alfalfa varieties and corn hybrids were estimated in order to ascertain the validity of using both a phenological growth model and a stochastic process model as components of a larger system simulation.

9. A planting-harvesting-storage/feeding algorithm for corn silage, high-moisture corn, and cash corn grain was devised. Production processes are simulated in 10-day (planting) and 15-day (harvest) time increments; resource use, costs, and interdependencies with alfalfa field operations are accounted.

10. A temporary dairy forage feed disappearance model was developed, based on pre-formulated rations generated with a linear

programming algorithm. The feed disappearance component permitted testing of the present first generation version of DAFOSYM.

7.3 Empirical Results

The present study makes a research contribution to the development of an empirically sound simulation model which can be used as a research tool in future investigations. Although the series of simulation experiments in Chapter 6 were presented primarily to demonstrate application of DAFOSYM in evaluating a broad spectrum of alternatives, the results are noteworthy in themselves.

The simulation results of Chapter 6 showed that systems low in corn silage (i.e., 20%) were preferred to high corn silage systems when comparing expected values and variability of net feed costs. By contrast, the budgeting analyses of corn silage vs. alfalfa systems reviewed in Chapter 2 generally indicated that systems high in corn silage (i.e., CS - 50%) resulted in the greatest average returns on the highly productive soils.

Differences in results may be attributable to differences in experimental design, research method, and assumed relative price and yield relationships for the various studies. In addition, several of the budgeting studies (Nott, 1973, 1974; Black et al., 1974; Knoblauch, 1979b; Parsch, 1980) assume a lower energy density for alfalfa in comparison with values assumed in developing the feed disappearance model in the present study.[1] Likewise, it should be noted that differences between treatment (sample mean) net feed costs were relatively small for some experiments reported in Chapter 6, and that certain cautions were urged in the interpretation of the results (Section 6.4). Nevertheless, a certain credence is given to the DAFOSYM results by the various instances of large well-managed dairy farms in the mid-Michigan area which are primarily low corn silage systems. Additionally, some researchers have observed a return to systems high in alfalfa primarily due to improved alfalfa harvest and storage technology which not only facilitates mechanization and labor reduction, but also reduces the risk of feeding low quality alfalfa.[2]

7.4 Recommendations for Future Research

Recommendations for continued research can be classified into two categories: (1) those which recommend refinements or improvements to existing model components; and (2) those which suggest expansions or additions to model algorithms or model research objectives. Each category is discussed in turn.

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[1] The budgeting studies reported in Chapter 2 assume feedcrop nutrient density based largely on 1972 National Research Council (NRC) estimates. By contrast, nutrient density of feedcrops for the present study (Table G.1) is based largely on updated NRC estimates (NRC, 1978). The most notable difference in the two data sets is that NEL for mid-bloom alfalfa has been augmented from 44 Mcal/lb. to 56 Mcal/lb. in the more recent NRC version, whereas comparable values for corn grain have decreased slightly. The implications are that the position of alfalfa systems relative to systems high in corn silage has improved since less purchased energy is required, hence reducing net feed costs.

[2] Dr. J.W. Thomas, Department of Animal Sciences, Michigan State University, notes that this trend has been especially evident in the past five years.

7.4.1 Existing Model Component Refinements and Improvements

1. Feed disappearance model. The dairy forage feed disappearance model must be expanded to include ration balancing on an annual basis as a function of simulated quantity and quality of farmgrown feedcrops. Ideally, the ration balancer would be driven by an optimization algorithm (e.g., simplex) and would accommodate both altered levels of relative feedstuff disappearance, as well as altered levels of milk production, in response to changes in the quantity/quality composition of feedcrops produced. Refinements in this area reap the greatest returns from future research because the alfalfa modules (ALFMOD, ALHARV) already generate intermediate model output which would accommodate a more sophisticated feed disappearance model. In essence, this improvement represents "completion" of the first generation version of DAFOSYM in that alfalfa's conversion into a marketable product (milk) is treated at a uniform level of model sophistication throughout the farm production system (see Sections 1.4, 6.4, G.3).

2. Alfalfa quality research. There has been a tendency in the literature to report alfalfa quality experiments for first-cut growth only. The small number of studies which have conducted research on later summer cuttings (Section 4.2.1) show quality level and rate of quality change to be significantly different from that of spring growth. Future alfalfa test plot research should emphasize quality estimates of summer cuttings as well as for spring growth. Models, such as DAFOSYM, which trace crop quality from field to cow require empirical data for developing model relationships and for model validation. Such research would also enable the estimation of crop quality prediction equations using cumulative heat units as arguments

(see Sections 4.5.1, 4.6).

3. Corn yield research. Although a large quantity of data is available which shows the impact of date of planting on corn grain yields, the corresponding data for corn silage yields is relatively sparse. Additionally, compared to the date of planting studies, there is relatively less data demonstrating the impact of date of harvest on both silage and grain yields. Future corn yield research must take account of these added dimensions if dairy forage crop management studies are to be served. Experimental design of corn yield research should attempt to estimate a greater number of the "non-optimal" elements of corn yield equation 5.5 (Sections 5.4.3, 5.5.1). This additional data would not only provide a more sound empirical base for the stochastic corn model, but would be useful as well for validation of improved phenological corn models as they are evolved. Such research must also distinguish research results according to maturity genotypes if the management prescriptions resulting from the research are to be correspondingly explicit with regard to hybrids.

4. Labor accounting. Labor costs were accounted for by calculating labor requirements for individual subsystems on an hourly basis. In reality, this procedure may not reflect the fact that on large commercial dairy farms (whether family-operated or not), a fixed labor pool is often available for performing the majority of tasks throughout the year. Such a labor pool is paid a fixed return and additional wages are paid primarily in peak season (for additional help), if at all. Since labor is accounted for in small discrete units, the present version of DAFOSYM accurately reflects differences in labor resource use across simulated systems (treatments). However,

labor accounting alterations would be necessary if model output were to reflect the fixed nature of the farm-firm labor pool.

7.4.2 Additions to Model Components and Model Research Objectives

1. Stochastic prices, market risk. By research design, the realm of investigation of DAFOSYM emphasizes the impact of technology and weather-related risk on system output. Questions related to the impact of prices and markets are largely ignored in order to facilitate analysis and interpretation of before-the-farm-gate production management factors. From the viewpoint of both risk and returns, commodity markets may have as much impact on dairy forage system outcome as any of the factors accounted for in the present version of DAFOSYM. Inclusion of a stochastic commodity price module which accounts for corn and soybean meal price distributions and correlations could be hypothesized to have differential impact on potential systems to be tested (see Section 6.4). Although inclusion of such a model component may have significant impact on simulation output, it should be recognized that expansion of the model to include stochastic prices represents a diversion from the present model research objective, which is to compare system alternatives primarily from the viewpoint of technology and production management.

2. Institutional impacts. The present version of DAFOSYM does not address the impact of institutional factors such as taxes and financing on dairy forage system alternatives. Hence, comparisons of system design and management do not incorporate the effects of tax benefits, cash flow, equity position, etc., on system output. Similar to point (1) above, it is likely that these factors would have

significant impact on simulation experiment results, but it must be simultaneously recognized that the model research objective is altered if such a model component is included.

3. Alfalfa-related production issues. In spite of the level of modeling sophistication of the alfalfa modules (ALFMOD, ALHARV), no account is taken of the impact of overwintering or standlife on alfalfa yields. Similarly, since crop nutrient uptake is only accounted for and not simulated in the model, impact of alfalfa nitrogen fixation on soil fertility and soil structure is ignored. These factors become especially important whenever simulation experiment treatments consist of varying the ration fed (and implicitly, the crop mix) under the assumption that crops are rotated from year to year.[1]

4. Simulation of tillage. Tillage is accounted for in the model only insofar as a custom charge is assessed for tillage operations of area grown to either corn or alfalfa. This assures an absence of bias in cost-accounting alternative systems consisting of different mixes of area grown to each crop. Thus, a potential shortcoming of

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[1]Attempts to evaluate the impact of alfalfa-corn rotations on simulation output can be undertaken in the present version of DAFOSYM by adjusting input values for corn yield parameters (Appendix C) and cropping cash expenses (reflecting increased nitrogen credit; Table B.5). Adjustments to these inputs should incorporate a weighting which reflects the fraction of total corn area affected by the rotation sequence. However, caution is advised when making adjustments to corn yield inputs since yield parameters other than expected value (i.e., variance, upper bound, lower bound) may be affected when crops are rotated. Additionally, consideration should be given to (a) whether input parameters for available corn work-day distributions require a corresponding adjustment due to altered soil structure, and (b) whether the assumption of zero covariance can be maintained (Section 5.5.4) between alfalfa and corn yields whenever crops are rotated.

the model is the implicit assumption that tillage operations do not conflict with the timeliness of planting either the alfalfa or corn crops. Expansion of the model to accommodate these issues necessitates both a tillage simulation algorithm, and an available-days tillage criterion in both the fall and spring periods for corn, and in the spring and summer periods for alfalfa.

5. Fourth-cut alfalfa. The question of whether it is economically feasible to take a fourth cut of alfalfa (mid-October) depends on whether the marginal benefits derived from the harvest outweigh the marginal costs of taking the harvest. In a corn-alfalfa system, part of the costs incurred with fourth-cut alfalfa are timeliness costs arising from conflicts causing delayed corn silage and/or high-moisture corn harvest. The present version of DAFOSYM does not permit evaluation of management policies related to this issue. Inclusion of this topic requires expansion of the model to include feedback controls reflecting management choices which weigh on a daily basis the tradeoffs incurred from alternative harvesting sequences of the crops involved.

6. Corn quality. Corn quality is assumed constant in the present version of DAFOSYM. Although the literature shows post-dent stage corn quality to be much less variable than alfalfa over the harvesting period, future expanded corn modules (e.g., phenological growth models) may find it worthwhile to simulate corn quality changes (especially digestibility of silage), grain moisture content, and grain development, in order to enable analyses which entail a more detailed level of crop management factors.

Model building is a dynamic process wherein subsequent iterations consist of incorporating model improvements and refinements which evolve from continuing research. Given the research objective, a model might never be finished, but instead may require continuous development in order to serve changing needs and reflect the discoveries of on-going research.

APPENDICES

APPENDIX A

DAFOSYM SOFTWARE OVERVIEW

A.1 Permanent File Storage and Execution Procedure

DAFOSYM is a FORTRAN V computer simulation program compatible with the CDC Cyber 750 hardware system. Figure A.1 contains a listing of the control statements required for batch execution of the program.[1] Execution of DAFOSYM requires a total of 10 permanent files to be attached. Five files contain FORTRAN coding; the remaining five contain input data required by the model. Each is discussed in turn.

FORTRAN coding files. FORTRAN coding for each of the five software modules described in Section 3.7 is stored in both binary and editor (EW) form on individual disc files. Execution requires that each of the five binary coded FORTRAN files be attached to local files bearing the module names used throughout this study, as in lines 110-150 (Figure A.1). Binary and editor files corresponding to the local file modules are:

Module	Binary	Editor (EW)
FORHRV	FORHRVBIN	FORHRVEW
ALHARV	ALHARVBIN2	ALHARVEW
ALFMOD	ALFMODBIN	ALFMODEW
CRNMOD	CRNMODBIN	CRNMODEW
BIGMOD	BIGMODBINCOW	BIGMODBINLP

[1] Control statements assume that the user ID has been authorized the use of the initialization procedure, WOLBBINIT, designed by Paul Wolberg, Department of Agricultural Economics, Michigan State University.

```
10=*JOBCARD*,RG1,JC2000,L100,CM200000,INIT.
12=*DISPOSE,**,A.
20=ATT,DATA1,MACHINPUTLP.
30=ATT,DATA2,MGTALFINPUTLP.
40=ATT,DATA3,ALFCRNINPUTLP.
50=EDITOR,E=DATA1.
60=EDITOR,E=DATA2.
70=EDITOR,E=DATA3.
80=ATT,WEATHR,ELANSWTHR5378.
90=ATT,BMATRX,BMATRIXLP.
100=RETURN,DATA1,DATA2,DATA3.
110=ATT,FORHRV,FORHRVBINLP.
120=ATT,ALHARV,ALHARVBIN2LP.
130=ATT,ALFMOD,ALFMODBIN.
140=ATT,CRNMOD,CRNMODBIN.
150=ATT,BIGMOD,BIGMODBINCOW.
160=LOAD,FORHRV.
170=LOAD,ALHARV.
180=LOAD,ALFMOD.
190=LOAD,CRNMOD.
200=LOAD,BIGMOD.
220=EXECUTE.
230=EXIT,C,S.
240=REWIND,ZZZZZMP.
245=COPYCF,ZZZZZMP,OUTPUT.
250=*EOS
260=SAVE,MACH,NS.
270=*EOS
280=SAVE,MGTALF,NS.
290=*EOS
300=SAVE,ALFCRN,NS.
310=*EOS
```

Figure A.1 Cyber 750 Control Statements for Batch Execution of DAFOSYM

Modules FORHRV and ALHARV were programmed by P. Savoie and are described in the companion dissertation (Savoie, 1982). Software description in this Appendix will be limited to the remaining three modules, which were programmed by the author.

Input data files. Two categories of input data are required to run the simulation model: (1) user-controlled data, and (2) non-user-controlled data. These two categories of data roughly correspond to the conceptual matrices X and Z described in Chapters 3 and 5.

User-controlled data describes the specific farm resource base and management plan of the farm system being analyzed in the simulation. This data is stored on three editor files which are attached to local files, as in lines 20-40 in Figure A.1. Each of these editor data files is read by a separate read subroutine located in the individual FORTRAN modules. Hence, each user-controlled data file contains a specific category of input variables. Editor data files, their corresponding read subroutines, and the module location of the read subroutines are:

Data file	Read subroutines	Module
MACHINPUTLP (MACH)[1]	READ	FORHRV
MGTALFINPUTLP (MGTALF)	MGTINF	ALHARV
ALFCRNINPUTLP (ALFCRN)	ALFIN	ALFMOD
ALFCRNINPUTLP (ALFCRN)	CRNIN	CRNMOD
ALFCRNINPUTLP (ALFCRN)	COWMOD	BIGMOD

Information required for the first two user input files is described in Savoie (1982). User information for ALFCRNINPUTLP is described in

[1]Permanent data file names are followed in ( ) by local file names which define input/output unit numbers in the FORTRAN coding.

Appendix B of the present study.

Non-user-controlled input data consists of the daily historical weather data required for the alfalfa growth model, and the matrix of stochastic variates generated by the BTAGEN process generator (see Sections 5.4-5.5). These two sets of input data represent the system-exogenous input vector (Z) to the model. Data files, their corresponding read subroutines and module locations are:

Data file	Read subroutines	Module
ELANSWTHR5378	BIGMOD (main)	BIGMOD
BMATRIXLP	CORN	CRNMOD

It should be noted that it is these two data files which restrict the validity of DAFOSYM output to the mid-Michigan area. The weather data in ELANSWTHR5378 was collected at the East Lansing, Michigan, weather station. Development of ELANSWTHR5378 is described in Appendix D.

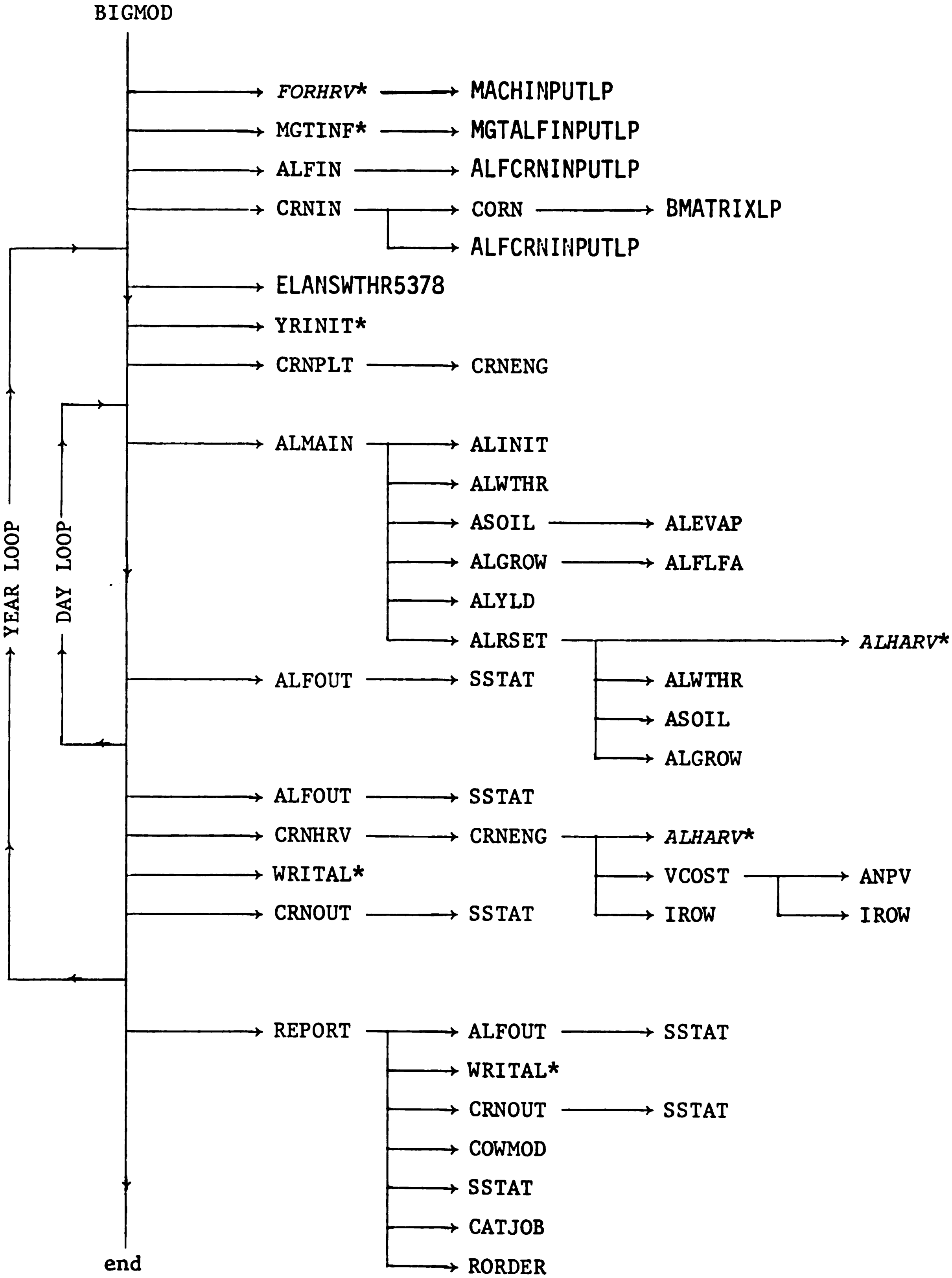
The BMATRIXLP data file consists of a (26 * 17) matrix generated using the BTAGEN stochastic process generator. Each row contains one year's data consisting of 17 randomly generated stochastic variates (available work days, corn yields). BTAGEN is itself a FORTRAN V computer program which is described in Parsch (1981), and in Appendix C. For the present study simulating East Lansing, Michigan conditions, the author ran BTAGEN, using as inputs the beta distribution parameters described in Section 5.5. Outputs from this run were written onto a disc file which comprises BMATRIXLP. Subsequent runs of BTAGEN could be undertaken to generate a new time series of exogenous corn inputs, implying that the BMATRIXLP variates are only theoretically "non-user-controlled".

Execution. Due to the 26-year "size" of the two non-user-controlled data files, model execution is limited to a 26-year daily simulation. A 26-year annual growing season simulation requires approximately 172K of computer memory and 40-50 seconds CP execution time.

A.2 Software Hierarchy and Description

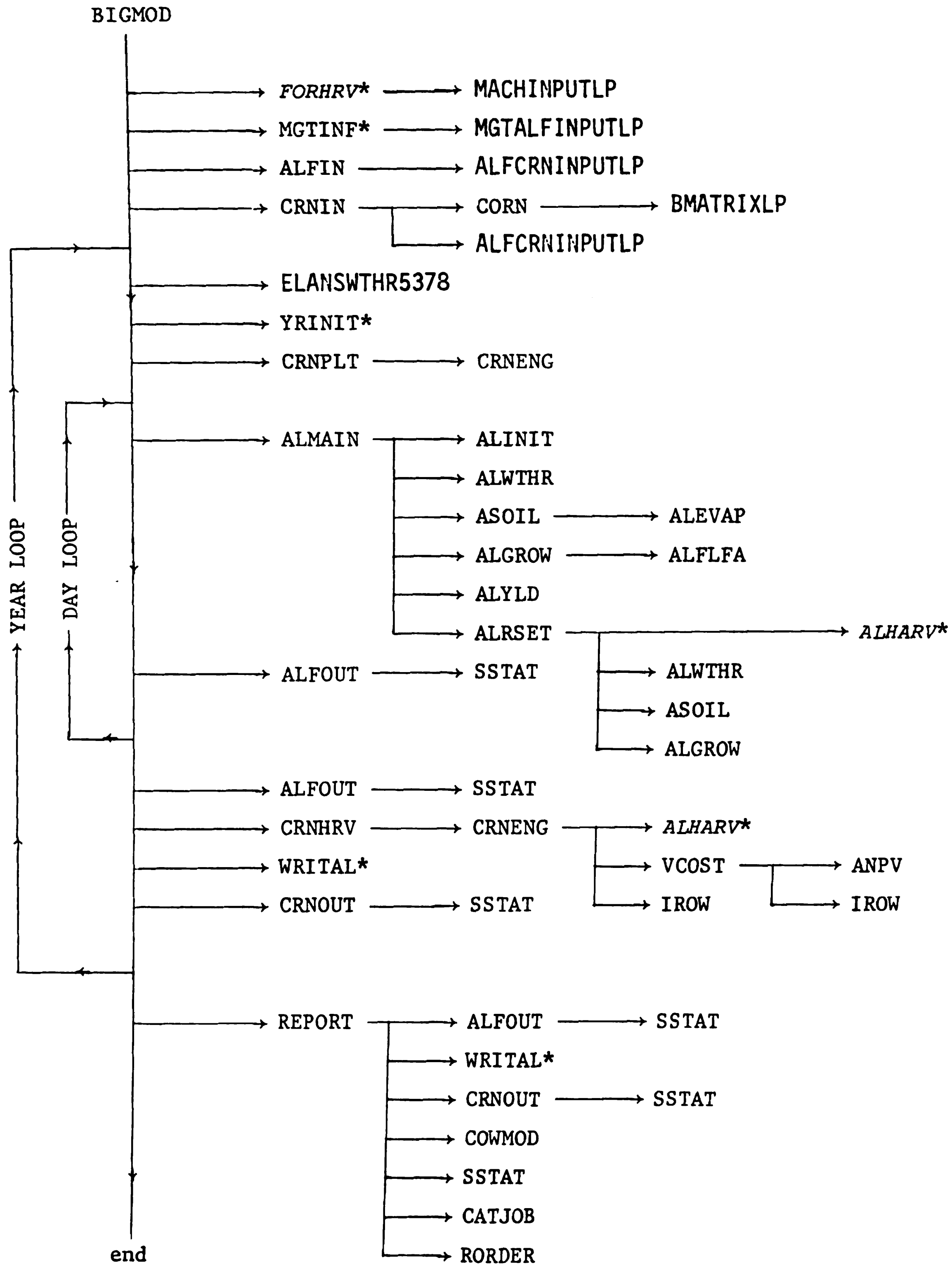
FORHRV, ALHARV, ALFMOD, and CRNMOD contain the core FORTRAN coding of the DAFOSYM model (see Section 3.7). These four basic modules are controlled by a fifth module BIGMOD, which contains the simulation time loops, and which controls the calling sequence to each of the individual modules and subprograms. ALFMOD, CRNMOD, and BIGMOD consist of 17, 12, and 5 subprograms, respectively. Editor files of these three modules contain approximately 1150, 1000, and 550 coding statements, respectively, 30% of which are comments.

Neither a complete user guide to program software, nor a detailed description of the simulation algorithm is intended here. Rather, what follows is a brief glossary of each of the author's subprograms contained in modules ALFMOD, CRNMOD and BIGMOD. The hierarchy of the calling sequence between these subprograms is contained in Figure A.2. This glossary and hierarchy figure, together with comments in the software, should prove useful for readers with FORTRAN knowledge who intend to study algorithms in greater detail. For the reader who is primarily interested in model execution from a user's viewpoint, Appendix B describes input requirements. It should also be noted that model runs result in clearly formatted hard copy output (see Appendix I).



*See Savoie (1982).

Figure A.2 Software Hierarchy Calling Sequence, DAFOSYM



*See Savoie (1982).

Figure A.2 Software Hierarchy Calling Sequence, DAFOSYM

Subprogram glossary--ALFMOD.

ALF2LP: main calling program for alfalfa-related routines whenever the alfalfa growth model is run independently of DAFOSYM. (See Appendix E.) When run as part of DAFOSYM, the subprogram is inactive, and is replaced by BIGMOD.

ALFIN: reads all user-inputted alfalfa control variables from permanent file ALFCRNINPUTLP. (Further described in Appendix B.)

ALMAIN: secondary executive calling program which controls sequences of calls to the core phenological crop growth subroutines.

ALINIT: initializes alfalfa state variables at beginning of each simulation year.

ALWTHR: calculates daily weather-related variables, e.g., cumulative growing degree days, day length, etc.

ASOIL: calculates soil moisture stress, available water in the soil profile, solar radiation.

ALEVAP: calculates evapotranspiration based on a model by Ritchie (1972).

ALGROW: contains basic rate and state equations for the five basic components of alfalfa plant yield. (See Section 4.3.1.)

ALYLD: converts output of ALGROW to either metric or English units; contains equations for estimating alfalfa quality. (See Section 4.5.)

ALRSET: contains calendar date criterion for initiation of alfalfa harvest; calls module ALHARV whenever time to harvest is appropriate; stores temporary state variables during harvest; and resets the alfalfa regrowth mechanism at a date halfway between the beginning and end of the harvest.

ALFLFA: block data subprogram containing plant growth-related physiological and environmental variables.

ALTEST: a test subroutine which replaces ALHARV whenever the crop growth model is run independently of DAFOSYM. Whenever DAFOSYM is run, ALTEST is inactivated. (Described further in Appendix E.)

SKIP: a search routine which finds the appropriate record on ELANSWTHR5378 weather data file; permits simulation to begin at points other than the first year of the data file.

SSTAT: calculates mean, standard deviation, coefficient of variation, and skewness coefficient of a sample distribution.

ALFOUT: stores master output matrix YALF (yield, quality, cutting-by-cutting, year-to-year); prints out either daily or end-of-simulation output for all ALFMOD generated variables.

BCTEMP: a print control mechanism.

TABLI: a table-look up interpolating function (Manetsch and Park, 1977).

Subprogram glossary--CRNMOD.

CRNPRG: main calling program for the corn-related routines whenever the stochastic corn model is run independently of DAFOSYM. (See Appendix E.) When run as part of DAFOSYM, this subprogram is inactive and is replaced by BIGMOD.

CRNIN: reads all user-inputted corn control variables from permanent file ALFCRNINPUTLP. (Further described in Appendix B.)

CORN: reads in the matrix of stochastic variates generated by the BTAGEN process generator and written onto disc file BMATRIXLP; initializes corn state variables.

CRNPLT: called at beginning of each harvest year, this routine determines the area of corn planted in each of five planting periods; determines julian date when planting is finished.

CRNHRV: determines the area and quantity of corn silage and high-moisture shelled corn harvested in each of six harvest periods for corn planted in each of five planting periods. (See Section 5.6.1.) Determines when storage silos are filled; determines area and quantity of corn harvested for cash sales if storage structures are filled; calculates required drydown of cash corn; determines last julian date of harvest.

CRNENG: determines corn planting rate, harvest rate for corn silage, high-moisture corn, and cash corn; calculates corn machine hours, fuel use, and labor use for corn field operations and silo filling; determines labor requirements for feeding corn. (See Section 5.6.2.)

VCOST: calculates costs related to corn production. (See Section 5.6.2.) Costs accounted for include: variable planting and harvest costs of machines; labor costs; charges for fertilizer-seed-chemicals, cash corn drydown, and custom harvesting. Fixed costs accounted for include annualized charges of corn silo storage structures, planter, and picker-sheller.

CRNOUT: outputs simulation results at end of each year or at end of simulation run.

SSTAT: sample statistics calculations. (Same as for ALFMOD.)

ANPV: calculates an annualized user cost for durable assets using a capital recovery factor formula.

MISC: block data storage for all corn variables and other miscellaneous variables used throughout DAFOSYM.

IROW: searches machinery code array (MCODE) in FORHRV data bank to find appropriate machinery coefficients.

Subprogram glossary--BIGMOD.

BIGMOD: main executive calling program for the DAFOSYM model; opens all local files for reading in data and writing output; contains simulation time loop for years and days; reads in daily weather historical data from ELANSWTHR5378; controls sequence of calls to all subprograms.

COWMOD: a simplified (temporary) dairy-feed disappearance accounting model; places a value on forages produced by calculating on-farm feed utilization, purchased supplements, and sales of surplus homegrown crops; reads in buy/sell prices for feeds, herd size and ration specification from ALFCRNINPUTLP. Inputs read are discussed in Appendix B. COWMOD is based on a linear programming ration balancer. Model is further described in Appendix G.

REPORT: organizes DAFOSYM output into summary end-of-simulation resource use and cost matrices; writes out all summary matrices onto hard copy.

CATJOB: writes out selected summary arrays generated in REPORT onto permanent disc storage. Newly-created permanent file name contains computer run sequence number for idenfication purposes.

RORDER: organizes simulation output arrays (e.g., system performance measure, NFC) into a sample cumulative distribution by ranking observations from lowest to highest value.

APPENDIX B

GUIDE TO USER-CONTROLLED INPUT DATA FILE

Three of the five data files required for execution of DAFOSYM contain user-controlled inputs which describe characteristics of the farm resource base and provide simulation control parameters (see Appendix A.1). Inputs to modules FORHRV and ALHRV are read from two permanent user data files MACHINPUTLP and MGTALFINPUTLP which are described in detail in Savoie (1982). Inputs to ALFMOD, CRNMOD and the feed disappearance subroutine in BIGMOD (see Appendix G) are all read sequentially from a single permanent data file ALFCRN-INPUTLP. The individual calling subroutines which read data from ALFCRNINPUTLP are ALFIN (ALFalfa INput), CRNIN (CoRN INput), and COWMOD (COW MODel). Software of each of these subroutines contains a comment statement section which defines the user input data required for that subroutine. Likewise, each of these read subroutines writes out the user-inputted data in titled format. The following sections provide supplemental information to the three read subroutines. The discussion assumes a working knowledge of FORTRAN.

B.1 ALFMOD Inputs: Subroutine ALFIN

The software listing of the commented read section of subroutine ALFIN is provided in Figure B.1. Input formats for all integer and real variables are (12I10) and (12F10.0), respectively. Supplemental explanation to user variables which are read in follows.

```
C     ***********************************************
      SUBROUTINE ALFIN(IFEED,ICDF)
C     ***********************************************
C
C     THIS SUBROUTINE READS IN ALL CONTROL VARIABLES FOR TEST RUNS
C     OF THE ALFALFA SIMULATION MODEL.
C     (L. PARSCH, DEPT OF AG ECON, MSU, 11/81)
C
C     EXPLANATION OF INPUT VARIABLES.
C       -JDAYF,JDAYL=FIRST AND LAST JULIAN DAY OF EACH YEAR SIMULATED.
C       -JYEARF,JYEARL=FIRST AND LAST CALENDAR YEARS TO BE SIMULATED.
C                      (RANGE IS 1953-1978 INCLUSIVE FOR ELANSWTHR5378).
C       -IPRT1=OUTPUT PRINT INTERVAL (DAYS), OVERRIDE=999.
C       -METRIC=SUMMARY OUTPUT UNITS: O=ENGLISH 1=METRIC.
C       -IFEED,ICDF=SWITCHES FOR DIRECT-DISC CATALOGING OF THE AFEED AND
C                TCOST MATRICES AS SEPARATE PERMANENT FILES FOR USE IN
C                FURTHER ANALYSES (O=NO,1=YES).
C       -AWFC=AVAILABLE WATER AT FIELD CAPACITY/RELEVANT SOIL PROFILE
C            DEPTH (MM)
C       -AWINIT=AVAILABLE WATER/PROFILE AT BEGINNING OF SIMULATION YEAR.
C       -AWFS=AVAILABLE WATER FRACTION AT ONSET OF PLANT STRESS.
C       -NCUTS=NUMBER OF CUTTINGS/YEAR, MAXIMUM=4.
C       -BGNCUT=JULIAN DATE FOR INITIATION OF CUTTINGS 1-4, OVERRIDE=365.
C       -NDAYSC,NDAYSH=NUMBER OF DAYS OVER WHICH CUTTING, HARVESTING
C                      TAKES PLACE.  SET BOTH-1 FOR TESTING AGAINST
C                      EMPIRICAL PLOT DATA.
C       -DUMMY1=DUMMY VARIABLE USED ONLY AS COLUMN INDICATOR IN INPUT FILE.
C
      COMMON/ALF123/SLA,DTL,SDCLAI,XLDLAI,CSF,DTS,XMLOSC,RCTNC,RGR,
     +      XMLBUD,XMLTNC,XFROST,ALCROP,ALSOIL,U,ALPHA,XL,PTF,XLAT,
     +      XIRRIG,AWFC,AWFS,AWINIT,WTHR(365,5),DAY1(39),DEC(39),
     +      DAY2(14),SRAD(14)
      COMMON/CTRL24/BGNCUT(5),NTHYR,NTHCUT,NDAYSC,NDAYSH,YLD(4),
     +      QUAL(3,4),GDDCUM,METRIC,JYEARF,JYEARL,IPRT1,IPRT2,
     +      JDAYF,JDAYL,JPRT,NYRS,IPRT4,NCUTS,JYEAR,JLALHR,CPLANT
      DIMENSION DUMMY1(6)
      DATA NDAYSC/O/,CPLANT/O./
C
      DO 5 I=1,5
5     BGNCUT(I)=365.
C
      READ(5,200)(DUMMY1(I),I=1,6)
      READ(5,100)JDAYF,JDAYL,JYEARF,JYEARL
      READ(5,100)IPRT1,METRIC,IFEED,ICDF
      READ(5,200)AWFC,AWINIT,AWFS
      READ(5,100)NCUTS
      READ(5,200)(BGNCUT(NTHCUT),NTHCUT=1,NCUTS)
C BIG READ(5,100)NDAYSC,NDAYSH
C
      NYRS=JYEARL-JYEARF+1
      IF(JYEARF.GT.1953)CALL SKIP(JYEARF)
C
      WRITE(6,300)
      WRITE(6,302)JYEARF,JYEARL
      WRITE(6,304)JDAYF,JDAYL
      WRITE(6,306)IPRT1,METRIC
      WRITE(6,340)IFEED,ICDF
      WRITE(6,308)AWFC,AWINIT,AWFS
      WRITE(6,310)NCUTS,(BGNCUT(NTHCUT),NTHCUT=1,NCUTS)
C BIG WRITE(6,312)NDAYSC,NDAYSH
C
100   FORMAT(12I10)
200   FORMAT(12F10.0)
300   FORMAT('1',' INPUT VALUES FOR ALFALFA SIMULATION RUN',
     +       ' READ INTO SUBROUTINE ALFIN',/,33('-'))
302   FORMAT(/' FIRST AND LAST SIMULATION YEARS=',I6,I6)
304   FORMAT(' FIRST AND LAST SIMULATION DAY (JULIAN)=',I6,I6)
306   FORMAT(' IPRT1 (PRINT CONTROL) AND OUTPUT UNITS',
     +' (O=ENGLISH 1=METRIC)=',I6,I6)
308   FORMAT(' SOIL MOISTURE PARAMETERS: AWFC,AWINIT,AWFS=',
     +2(1X,F5.0),1X,F4.3)
310   FORMAT(' CUTTING DATES (JULIAN) FOR',I2,' CUTS/YR=',4(1X,F5.0))
312   FORMAT(' CUTTING AND HARVEST PERIOD, DAYS=',I4,I4)
340   FORMAT(' OPTION TO DIRECT-CATALOG AFEED AND TCOST MATRICES=',
     +      2I8)
      RETURN
      END
```

Figure B.1 Software Listing, Subroutine ALFIN

DUMMY1: serves as a column indicator for CRT users; has no impact on simulation; e.g., 123456789.123...etc.

JDAYF, JDAYL, JYEARF, JYEARL: main control for the day and year simulation loops. Days are julian (1-365); years are calendar (1953-1978), corresponding to the weather data file, ELANSWTHR5378.

IPRT1, METRIC, IFEED, ICDF: control parameters. IPRT1 is a print interval output switch (days) for detailed weather, soil, and plant component variables generated in the phenological alfalfa model. For large runs, it is recommended to suppress this option with the 999 override. METRIC should always be set to 1 for (metric) consistency with other modules of DAFOSYM. IFEED is a switch which directly catalogs the TCOST and AFEED matrices of subroutine REPORT onto permanent file. The catalogued file is automatically assigned a name containing the computer sequence run number. ICDF is an inactive variable.

AWFC, AWINIT, AWFS: soil moisture variables defined in ALSIM (Fick, 1981). The variables are: available water at field capacity (mm/profile); available water in the profile on JDAYF (mm/profile); and available water fraction at the onset of plant stress (decimal). For Brookston-Conover type soils, the author recommends values of 200., 200., and .40, respectively (see Section 4.4.1).

NCUTS: number of alfalfa harvests/harvest season. Although the maximum is 4, care must be taken by the user to avoid simultaneous corn harvests with fourth cut alfalfa harvest.

Although permitted by the model, implications for machinery use may be erroneous whenever corn and alfalfa are harvested simultaneously. Hence, 3 cuts maximum for corn/alfalfa systems are recommended, such that alfalfa harvest is completed by early September.

BGNCUT: julian date at which each individual cutting is to begin. This beginning cut date criterion is the earliest possible date at which harvest will begin. Actual date of cutting and/or harvest initiation may be delayed due to adverse weather conditions. The supplementary algorithm which initiates cutting as a function of crude protein (Savoie, 1982) operates within the bounds imposed by BGNCUT.

B.2 CRNMOD Inputs: Subroutine CRNIN

The software listing of the commented read section of subroutine CRNIN is provided in Figure B.2. Input formats for all integer and real variables read in are (12I10) and (12F10.0), respectively, with the exception of the three machinery input lines which are (3F10.0, 3I10). Supplemental explanation to corn-related user variables which are read in follows.

DUMMY2: used as a column indicator for CRT users; has no impact on simulation. Separates CRNIN data from ALFIN data in ALFCRNINPUTLP data file.

IPRT4, NOPNCS: control parameter switches. IPRT4 = 1 prints out within-year corn simulation results (approximately three pages/simulation year) plus end of simulation results. Override is 0, whereby only end of simulation corn results are printed. NOPNCS is the corn silage operation number

```
C
C     ***************************************************
      SUBROUTINE CRNIN(NYRS,IPRT4)
C     ***************************************************
C
C     THIS SUBROUTINE READS ALL INPUT DATA REQUIRED FOR TEST RUNS
C     OF THE STOCHASTIC PROCESS CORN MODEL.  EXPLANATION OF INPUT
C     VARIABLES READ IN FOLLOWS:
C
C       -IPRT4=PRINT OPTION: O=END OF SIMULATION RUN RESULTS ONLY;
C              1=WITHIN YEAR RESULTS + END OF SIMULATION RUN RESULTS.
C       -NOPNCS=CS OPERATION NUMBER WHEN USED W/SAVOIE'S FORHRV (140-149).
C       -HADSRD(3)=AREA TO BE PLANTED TO CS, HMC, CG, HECTARES.
C       -STGCS,STGHMC=STORAGE CAPACITY OF CS, HMC,  TONS DM.
C       -PSTGCS, PSTGHM=INVESTMENT IN STORAGE STRUCTURES (SILOS AND
C                UNLOADERS) FOR CORN SILAGE AND HIGH MOISTURE CORN, ($).
C       -HPDPLT,HPDHRV=CLOCK HRS/DAY AVAILABLE FOR PLANTING AND HARVEST.
C
C       -WIDTH(I)=OPERATING WIDTH OF I-TH FIELD IMPLEMENT, METERS.
C       -PPM(I)=PURCHASE PRICE OF I-TH FIELD IMPLEMENT, $.
C       -XMEN(I)=NUMBER OF PERSONNEL REQUIRED FOR I-TH ACTIVITY,MANHRS/HR:
C              INCLUDES FIELD WORK, TRANSPORTING, UNLOADING.
C       -NTRAC(I)=POWER SOURCE FOR FIELD IMPLEMENT OF WIDTH(I), MCODE.
C       -NTBLOW(I)=POWER SOURCE FOR BLOWER UNLOADING ACTIVITY I OUTPUT,
C             MCODE.
C       -NBLOWR(I)=MCODE FOR BLOWER UNLOADING PRODUCT I.
C       -(I) INDEX FOR ABOVE CORN ACTIVITIES:
C             1=CORN PLANTING  2= CS HARVESTING  3=HMC HARVESTING.
C       -RATEIS,-M,-L=DISCOUNT RATE; SHORT, MEDIUM, AND LONG TERM (DEC).
C       -PLABOR=LABOR CHARGE, $/HR.
C       -PFUELD,-G=PRICE OF DIESEL, GASOLINE FUEL, $/L.
C       -PFSCA1,-A2=CHARGE FOR FERT/SEED/CHEMS FOR ALFALFA SEEDING YR, EST-
C                ABLISHED, $/HA.
C       -PFSCCS,-HM=CHARGE FOR FERT/SEED/CHEMS FOR CS, HMC/CG, $/HA.
C       -PDRYCG=DRYING CHARGE FOR CG SOLD, $/PT/BU.
C       -PHRVCG=CUSTOM HARVEST CHARGE FOR CG SOLD, $/HA.
C       -XLIFE(1),COEFSV(1)=STORAGE STRUCTURE LIFE (YRS), SV/INVEST (DEC).
C       -XLIFE(2),COEFSV(2)=MACHINE LIFE (YRS), SV/INVEST (DEC).
C       -DUMMY2,-3=DUMMY VARIABLES USED AS COLUMN INDICATORS IN INPUT FILE.
C               (E.G.:123456789.123456789.123. . .ETC.)
C
C     (L. PARSCH, DEPT. OF AG. ECON, MSU, 2/82)
C
      COMMON/PRICE/PLABOR,PFUELD,PFUELG,RATEIM,PDRYCG,PHRVCG,COEFSV(3),
     +       PFSCA1,PFSCA2,PFSCCS,PFSCHM,ALFYRS,RATEIS,RATEIL,XLIFE(3)
      COMMON/TILL/PTILLC,PTILLA
C
      COMMON/CRNDT1/BTAGEN(26,17),RTPLT,HAPLTD(26,6),COSTCG(26,2),
     +       JFNHRV(26),JDPLT(6),JDHRV(7),JFNPLT(26),DMCORN(26,3),
     +       CRNYLD(26,3),COEFCS(6,5),COEFCG(6,5),JBGHRV(26),RTHRV(3),
     +       CLOSSH(3),HADSRD(4),STGCS,STGHMC,HPDHRV,HPDPLT,HACORN(26,4),
     +       JFNAL3(26),COEFMC(6,5),BASEMC,DMFEED(26,3),CRNFSC(26),
     +       TWATER(26),CLOSSF(3),RTFEED(4),CLOSSS(3)
C
      COMMON/CRNDT3/WIDTH(3),PPM(3),NTRAC(3),XMEN(3),NTBLOW(3),RMBLOW,
     +       NBLOWR(3),CLAB1,VCM(4,4),FCPICK,FCPLT,RMM(3),RMT,
     +       HRSPLT(4),HRSCS(4),HRSHMC(4),FUEL(4),FUELRT,CLAB2,
     +       NOPNCS,FECG,FECS,FEPLT,FEHMC,SPDCG,SPDCS,SPDHMC,SPDPLT,
     +       RTBLOW,WCOMB,PSTGCS,PSTGHM
      DIMENSION DUMMY2(6),DUMMY3(6)
C
      READ(5,100)(DUMMY2(I),I=1,6)
      READ(5,110)IPRT4,NOPNCS
      READ(5,100)(HADSRD(I),I=1,3)
      READ(5,100)STGCS,PSTGCS,STGHMC,PSTGHM
      READ(5,100)HPDPLT,HPDHRV
      READ(5,120)WIDTH(1),PPM(1),XMEN(1),NTRAC(1)
      READ(5,120)WIDTH(2),PPM(2),XMEN(2),NTRAC(2),NTBLOW(2),NBLOWR(2)
      READ(5,120)WIDTH(3),PPM(3),XMEN(3),NTRAC(3),NTBLOW(3),NBLOWR(3)
      READ(5,100)(DUMMY3(I),I=1,6)
      READ(5,100)RATEIS,RATEIM,RATEIL
      READ(5,100)PLABOR,PFUELD,PFUELG
      READ(5,100)PFSCA1,PFSCA2,PFSCCS,PFSCHM
      READ(5,100)PDRYCG,PHRVCG,PTILLC,PTILLA
      READ(5,100)XLIFE(1),XLIFE(2),COEFSV(1),COEFSV(2)
C
      CALL CORN(NYRS)
```

Figure B.2 Software Listing, Subroutine CRNIN

```
C
      HADSRD(4)=HADSRD(1)+HADSRD(2)+HADSRD(3)
C
C  PRINT OUT ALL DATA READ IN.
C
      WRITE(6,200)
      WRITE(6,210)NYRS,(HADSRD(I),I=1,4)
      WRITE(6,220)STGCS,STGHMC
      WRITE(6,225)PSTGCS,PSTGHM
      WRITE(6,230)HPDPLT
      WRITE(6,240)HPDHRV
      WRITE(6,245)NOPNCS
      WRITE(6,250)
      WRITE(6,255)WIDTH(1),PPM(1),XMEN(1),NTRAC(1)
      WRITE(6,260)WIDTH(2),PPM(2),XMEN(2),NTRAC(2),NTBLOW(2),NBLOWR(2)
      WRITE(6,265)WIDTH(3),PPM(3),XMEN(3),NTRAC(3),NTBLOW(3),NBLOWR(3)
      WRITE(6,270)RATEIS,RATEIM,RATEIL
      WRITE(6,272)PLABOR,PFUELD,PFUELG
      WRITE(6,274)PFSCA1,PFSCA2,PFSCCS,PFSCHM
      WRITE(6,276)PDRYCG,PHRVCG
      WRITE(6,277)PTILLC,PTILLA
      WRITE(6,278)XLIFE(1),COEFSV(1)
      WRITE(6,279)XLIFE(2),COEFSV(2)
      WRITE(6,280)
      WRITE(6,301)((JCOL),JCOL=1,17)
      DO 315 IYR=1,NYRS
315   WRITE(6,300)IYR,(BTAGEN(IYR,JCOL),JCOL=1,17)
      WRITE(6,302)
C
100   FORMAT(12F10.0)
110   FORMAT(12I10)
120   FORMAT(3F10.0,3I10)
200   FORMAT(////,' INPUT VALUES FOR CORN SIMULATION',
     +       ':  SUBROUTINES CRNIN AND CORN ')
210   FORMAT(//,' SIMULATION LENGTH, YEARS=',I4,
     +   /,' AREA INTENDED AS CS HMC CG AND TOTAL(HA)=',4(2X,F6.2))
220   FORMAT(' STORAGE CAPACITY OF CS AND HMC (DM TONS)=',2(1X,F8.2))
225   FORMAT(' INVESTMENT IN STORAGE STRUCTURES FOR CS',
     +       ' AND HMC, $',2(3X,F7.0))
230   FORMAT(' WORK DAYLENGTH, PLANT PD (HRS/DAY)= ',F6.2)
240   FORMAT(' WORK DAYLENGTH, HARVEST PD (HRS/DAY)=',1X,F6.2)
245   FORMAT(' CS OPERATION NO. (140-149 W/SAVOIE MODEL ONLY)=',I4)
250   FORMAT(' CORN MACHINERY INPUT DATA, COLS:  1=WIDTH (M)',
     +       ' 2=PPM ($)  3=XMEN (MANHRS/HR)  4=NTRAC (MCODE)',
     +       '  5=NTBLOW (MCODE)  6=NBLOWR (MCODE)')
255   FORMAT(' CORN PLANTING:',T30,F6.2,F10.0,2X,F3.1,2X,3I4)
260   FORMAT(' CS HARVEST:',T30,F6.2,F10.0,2X,F3.1,2X,3I4)
265   FORMAT(' HMC HARVEST:',T30,F6.2,F10.0,2X,F3.1,2X,3I4)
270   FORMAT(' DISCOUNT RATES CHARGED: SHORT, MEDIUM, LONG-TERM=',3F6.2)
272   FORMAT(' LABOR CHARGE($/HR); DIESEL, GAS CHARGE($/L)=',F6.2,2F6.3)
274   FORMAT(' FERTILIZER/SEED/CHEMICALS ($/HA): SEEDING YEAR ALFALFA,',
     +       'ESTABLISHED ALFALFA, CS, HMC/CG=',4(1X,F7.2))
276   FORMAT(' DRYING CHARGE, CG-SOLD ($/PT/BU);',
     +       ' CUSTOM HARVEST CHARGE, CG ($/HA)=',F6.2,2X,F7.2)
277   FORMAT(' CUSTOM CHARGE FOR PRE-PLANT TILLAGE, CORN; PRE-HARVEST',
     +       ' TILLAGE/SEEDING, ALFALFA ($/HA)=',F6.2,2X,F6.2)
278   FORMAT(' STORAGE STRUCTURE LIFE (YRS); SV/INVEST=',F6.1,F5.2)
279   FORMAT(' MACHINERY LIFE (YRS); SV/INVEST=',F6.1,F5.2)
C
280   FORMAT(//,' MATRIX GENERATED IN BTAGEN, READ FROM CORN:',
     +    ' ROWS=SAMPLE OBSERVATIONS (YRS)',/,
     +    ' COLS: (1-5)=AVAIL DAYS PLANTING  (6-11)=AVAIL DAYS HARVEST ',
     +    ' (12-16)=HMC AND CG YLD, T/HA  (17)=CS YLD, T/HA ',/)
300   FORMAT(I3,17(1X,F6.2))
301   FORMAT(1X,17(1X,I6)/)
302   FORMAT('1')
C
      RETURN
      END
```

Figure B.2 (cont'd.)

defined in the FORHRV (ICODE) machinery data file (see Savoie, FORHRV User's Guide, 1982).

HADSRD: the area intended to be planted each simulation year to corn silage, high-moisture corn, and cash corn grain (hectares). Any non-negative real value for each crop may be entered.

STGCS, PSTGCS, STGHMC, PSTGHM: total capacity and investment cost of storage structures for corn silage (STGCS, PSTGCS); total capacity and investment cost of storage structures for high-moisture corn (STGHMC, PSTGHM). Capacity is entered in tons (metric, dry matter). Investment cost includes both the silo and unloader. Suggested capacities for various size upright stave silos for corn silage are found in Table B.1; capacities of upright silos for high-moisture corn are found in Table B.2. Suggested 1981 investment rates/vertical foot of stave silos are shown in Table B.3. It is the responsibility of the user to size silos consistent with minimum daily feed removal rates to avoid feed spoilage. If either high-moisture corn or corn silage is not grown, storage inputs should be entered as zero.

HPDPLT, HPDHRV: number of hours per day during which corn planting and harvesting, respectively, can take place.

WIDTH(1), PPM(1), XMEN(1), NTRAC(1): machinery input data for corn planting activities. WIDTH is the operating width (meters) of the planter; PPM is the planter investment cost; XMEN is the number of laborers occupied in parallel activities defined in the FORHRV (ICODE) machinery data file (see Savoie, FORHRV User's Guide, 1982).

HADSRD: the area intended to be planted each simulation year to corn silage, high-moisture corn, and cash corn grain (hectares). Any non-negative real value for each crop may be entered.

STGCS, PSTGCS, STGHMC, PSTGHM: total capacity and investment cost of storage structures for corn silage (STGCS, PSTGCS); total capacity and investment cost of storage structures for high-moisture corn (STGHMC, PSTGHM). Capacity is entered in tons (metric, dry matter). Investment cost includes both the silo and unloader. Suggested capacities for various size upright stave silos for corn silage are found in Table B.1; capacities of upright silos for high-moisture corn are found in Table B.2. Suggested 1981 investment rates/vertical foot of stave silos are shown in Table B.3. It is the responsibility of the user to size silos consistent with minimum daily feed removal rates to avoid feed spoilage. If either high-moisture corn or corn silage is not grown, storage inputs should be entered as zero.

HPDPLT, HPDHRV: number of hours per day during which corn planting and harvesting, respectively, can take place.

WIDTH(1), PPM(1), XMEN(1), NTRAC(1): machinery input data for corn planting activities. WIDTH is the operating width (meters) of the planter; PPM is the planter investment cost; XMEN is the number of laborers occupied in parallel activities

Table B.1 Estimated Capacity of Upright Silos for Corn Silage and Haylage, Metric Tons, Dry Matter

Settled Height (ft)[1]	Diameter (feet)										
	10	12	14	16	18	20	22	24	26	28	30
20	7	11	14	19	24	30	36	43	51	59	67
24	10	14	19	24	31	39	47	55	65	75	87
28	12	17	24	32	40	48	58	69	82	94	108
32	14	21	29	37	47	59	71	84	99	115	132
36	17	25	34	44	56	69	83	99	117	136	156
40	20	29	40	52	65	81	97	115	136	157	180
44		34	45	59	74	92	112	132	156	181	208
48		38	51	67	84	104	127	151	177	205	236
52			58	75	95	117	142	169	199	230	264
56			64	84	106	131	158	188	220	256	294
60			71	92	117	144	174	207	248	280	324
64					129	158	190	227	273	308	355
68					141	172	207	246	298	335	385
72								266	323	363	415
76								287	349	391	447
80								308	375	419	479

[1]Calculations are based on 15 lbs DM/ft^3. Adapted from Mid-West Plan Service, p. 49 (1976).

Table B.2 Estimated Capacity of Upright Silos for High-moisture Shelled Corn, Metric Tons, Dry Matter

Settled Height (ft)	Diameter (feet)						
	10	12	14	16	18	20	22
20[1]	16	24	32	42	55	67	81
24	22	30	42	55	69	87	105
28	26	38	53	71	89	107	130
32	32	46	65	83	106	132	158
36	38	57	75	97	126	154	187
40	45	65	89	116	146	180	217
44		75	101	132	166	207	250
48		85	114	150	189	233	284
52			130	168	213	262	318
56			189	189	237	292	353
60				207	262	323	389

Calculations assume 30% moisture content high-moisture corn @ 1.41 ft^3/bu. Adapted from Dum et al., 1971.

[1]Add 10' to include space for settling and unloader.

Table B.3 Estimated Investment Cost Rates, Concrete Stave (Upright) Silos, 1981

Diameter (ft.)	ft^3/vertical ft.	$\$/ft^3$	$/vertical ft.
10	78.5	2.19	172.29
12	113.1	1.86	210.89
14	153.9	1.53	236.17
16	201.1	1.27	255.57
18	254.5	1.12	286.13
20	314.2	.98	307.52
22	380.1	.92	349.97
24	452.4	.86	390.30
26	530.9	.83	440.11
28	615.8	.80	490.35
30	706.8	.74	524.80

All estimates include the price of a top unloader. Estimates based on surveys by Nott (1980) and Benson (1979) indexed to reflect 1981 prices using USDA farm building index (1981/1980 = 1.05; 1981/1979 = 1.14).

for planting operations; NTRAC is the machinery code number (MCODE, see Savoie, 1982) of the power source for the planter. For consistency with yield data, 76 cm. corn rows should be assumed. The power source for the planter should be one of the tractors already declared in the operations matrix ICODE of FORHRV. Suggested investment costs for corn planters and pickers are given in Table B.4.

WIDTH(2), PPM(2), XMEN(2), NTRAC(2), NTBLOW(2), NBLOWR(2): machinery input data for corn silage operations. WIDTH(2) and PPM(2) are the operating width (meters) and investment cost of the forage harvester, respectively. XMEN(2) is the number of laborers occupied in all corn silage parallel harvest operations, i.e., field, hauling, and silo filling. The remaining three variables are the machinery codes (MCODE, see FORHRV User's Guide, Savoie, 1982) for the forage harvester power source, the blower power source, and the blower. When used with Savoie's FORHRV (DAFOSYM), all variables in this input read line are inactivated except for WIDTH(2), and, hence, should be set to zero. WIDTH(2) should nevertheless be set to its appropriate value (meters) unless no corn silage is to be harvested.

WIDTH(3), PPM(3), XMEN(3), NTRAC(3), NTBLOW(3), NBLOWR(3): machinery input data for high-moisture corn operation. WIDTH(3) and PPM(3) are the operating width (meters) and investment cost of the picker-sheller, respectively. XMEN(3) is the number of laborers occupied in all high-moisture corn parallel harvest operations, i.e., field, hauling and silo

Table B.4 Estimated Investment Costs, Corn Planters and Picker-shellers, 1981

Planter[1]	Investment, $
2-row, std., pull	1780
4-row, air, mtd.	7040
4-row, plateless	7430
6-row, std., pull	6780
6-row, air, pull	9180
8-row, air, pull	11550
8-row, flexible bar	14200
12-row, flexible bar	20960
Average, $/row	1520
Picker-sheller[2]	
1-row, pull with mtd. sheller	8370
2-row, pull, picker-sheller	10010
3-row, pull, picker-sheller	11080

[1]Source: Midwest Farm Planning Manual, Iowa State University Press, Ames, Iowa, 1979. Based on 1978 prices multiplied by USDA index of prices paid for machinery (1981/1978 = 1.35).

[2]Source: Official Guide: Tractors and Farm Equipment, National Farm and Power Equipment Dealers Association, Lansing, Michigan, Fall, 1981.

filling. The remaining three variables (NTRAC, NTBLOW, and NBLOWR) are the machinery codes (MCODE, FORHRV User's Guide, Savoie, 1982) for the picker-sheller power source, the blower power source, and the blower. These latter three inputs should already have been declared in the FORHRV data base operations matrix (ICODE).

DUMMY3: same as DUMMY1, DUMMY2, above.

RATEIS, RATEIM, RATEIL: short, medium, and long-term discount rates, respectively, used in calculating capital recovery factors for durable assets. Medium and long-term discount rates are charged against machinery and storage structures, respectively. (Short-term discount rate is inactive.)

PLABOR, PFUELD, PFUELG: The hourly labor wage rate (PLABOR) is charged for all crop-related labor hours. PFUELD and PFUELG are the price of diesel and gasoline fuel, $/liter.

PFSCA1, PFSCA2, PFSCCS, PFSCHM: annual cash costs of fertilizer, seed, and chemicals for establishment-year alfalfa (summer, clear-seeded), established alfalfa, corn silage, and high-moisture corn, respectively, all in $/ha. An additional charge is imposed on harvested alfalfa area to account for establishment costs of alfalfa. The model assumes alfalfa is summer-seeded and remains in the rotation for four years. Hence, each hectare of established alfalfa is charged PFSCA2 + (25% * PFSCA1) in order to account for establishment cash costs. Fertilizer-seed-chemical costs for corn silage and high-moisture corn should reflect fertilizer requirements to support nutrients removed. Suggested estimates for these four input variables are summarized in Table B.5.

PDRYCG, PHRVCG, PTILLC, PTILLA: Custom charges. PDRYCG is the charge for cash-corn drydown ($/point of moisture removed/bu); PHRVCG is the custom charge for combining all residual corn harvested for cash sales ($/ha). PHRVCG should reflect all custom charges (field machinery, operator, hauling) for a six-row grain combine. PTILLC and PTILLA are optional rates ($/ha) for custom tillage of corn and alfalfa area, respectively. PTILLC should reflect all pre-planting land preparation costs as well as a charge for cultivation and NH_3 application. PTILLA should reflect a charge for seed-bed preparation and drilling. Additionally, PTILLA may include the cost of fertilizer top-spreading over the assumed 4-year stand life. PTILLC is charged against each hectare of corn; by contrast, PTILLA is charged against 25% of the area in alfalfa since these costs are incurred only once during the stand life. Non-zero values for PTILLC and PTILLA should be entered whenever comparing systems with varying areas planted to each crop. Suggested values for PHRVCG, PTILLC, and PTILLA are provided in Table B.6.

XLIFE(1), XLIFE(2), COEFSV(1), COEFSV(2): XLIFE(1) and (2) are the expected life (years) of storage structures and machinery, respectively; COEFSV(1) and (2) are the salvage values as a percentage (decimal) of investment cost of storage structures and machinery, respectively. These values are used in calculating capital recovery factors for the respective durable assets.

Table B.5 Crop Enterprise Budgets, Cash Expenses, Michigan, Per Acre Basis, 1981

	PFSCHM Corn Grain High Yield 116 bu/a		PFSCCS Corn Silage High Yield 6.26 t/a (DM)		PFSCA1 Clear-seeded Alfalfa Seeding Year		PFSCA2 Alfalfa Established 6.30t/a	
Seeds	(14 lb)	$16.80	(14 lb)	$16.80	(14 lb)	$31.50	(0)	$0.00
Nitrogen	(145 lb)	23.20	(185 lb)	29.60	(0)	0.00	(0)	0.00
P_2O_5	(40 lb)	8.12	(70 lb)	14.00	(80 lb)	16.00	(63 lb)	12.60
K_2O	(31 lb)	3.76	(150 lb)	18.00	(90 lb)	10.80	(285 lb)	34.20
Limestone		4.50		4.50		36.00		---
Insecticide		1.70		1.70		3.00		6.00
Weed Spray		13.05		13.05		8.65		---
Utilities		2.80		5.15		---		---
Total $/acre		$73.93		$102.80		$105.95		$52.80
Total $/ha		$182.60		$253.91		$261.69		$130.42

Source: Based on Nott, et al., 1981. Fertilizer rates based on Vitosh and Warncke, 1979.

Table B.6 Estimated Charges for Custom Field Operations, Michigan, 1981

1. Corn Tillage, Fertilizer Application:	$/ha
Plow, 6-bottom	30.69
Discing	14.85
Harrow, 16 ft.	11.97
Cultivate, 6-row	10.35
NH_3 application	12.25
Total (PTILLC)[1]	$80.11
2. Corn Grain Custom Combining and Hauling:	$/ha
Combining, 6-row	50.42
Hauling ($.058/bu/20 mi)	16.80
Total (PHRVCG)[1]	$67.22
3. Alfalfa Establishment, Fertilizer Application:	$/ha
Plow, 6-bottom	30.69
Discing	14.85
Harrow, 16 ft. (2X)	23.94
Drill with starter fertilizer	22.26
Top-spread (4-yr. stand life)	26.94
Total (PTILLA)[1]	$118.67

All charges based on Schwab and Gruenwald (1978), indexed to 1981 levels.

[1]PTILLC and PTILLA are optional user input values. PHRVCG is charged on all residual corn area harvested for cash sales.

B.3 BIGMOD Inputs: Subroutine COWMOD

The software listing of the commented read section of subroutine COWMOD is shown in Figure B.3. Input format for read lines 1, 3, and 4 is (7F10.0); for line 2 it is (3F10.0,I10). Supplemental explanation to variables which are read in follows.

DUMMY4: serves as a column indicator for CRT users; has no impact on simulation. Separates COWMOD data from CRNIN data in ALFCRNINPUTLP data file.

COWS, AVGMLK, PMILK, NDIET: COWS is the number of mature cow units in the herd, equal to the number of lactating and dry cows. AVGMLK is annual average milk production per cow for the herd (cwt/cow/yr), and PMILK is the raw milk price ($/cwt) at the farm gate. NDIET is the ration to be fed to the lactating cows, defined by the composition of the forage. NDIET takes an integer value between 1 and 6: 1 = 0% corn silage; 2 = 20% corn silage...6 = 100% corn silage. The remainder of the forage consists of alfalfa (see Appendix G).

PFEEDS, PFEEDB: sell price and buy price, respectively ($/ton, metric, dry matter) of all feedstuffs available for the herd. Feedstuffs are: 1 = corn silage; 2 = high-moisture corn; 3 = alfalfa (1); 4 = alfalfa (2), inactive; 5 = soybean meal; 6 = non-protein nitrogen (urea); 7 = cash corn grain (dry). Because neither soybean meal nor NPN is produced on the farm, sell prices for these commodities are inactive, and may be entered as zero. Also, because the cow model does not distinguish a nutrient density or intake difference between

```
C     ***************************************************
      SUBROUTINE COWMOD(NYRS)
C     ***************************************************
C
C  COWMOD IS A SIMPLIFIED DAIRY FEED-USE MODEL. IT PLACES A VALUE ON
C  FEEDS PRODUCED BY DETERMINING THE SURPLUS OR DEFECIT OF FEEDS
C  REQUIRED TO PRODUCE A SPECIFED MILK PRODUCTION. GIVEN A SPECIFIED
C  BALANCED RATION.  FOR A GIVEN BALANCED RATION, SURPLUSES OR DEFECITS
C  ARE ACCOUNTED FOR BY SELLING OR PURCHASING IN EACH FEED-STUFF AT
C  A USER-INPUTTED PRICE.
C  (L. PARSCH, DEPT OF AG ECON, MSU, 4/82)
C
      COMMON/Z7/ALHRFD(26,15),AFEED(26,23)
      COMMON/COWDTA/RATION(7,7),FSUP(26,7),FDMD(7),FBAL(26,7),PFEEDB(7),
     +       PFEEDS(7),FGROSS(26,7),FNET(26,3),COWS,AVGMLK,PMILK,NDIET
      COMMON/SUMRY2/TRESP(26,20),TCOSTP(26,20),TCOST(26,20),
     +       STCOST(4,20),TRES(26,20),SRES(4,20)
      DIMENSION DUMMY4(6)
C
      DATA RATION/ 0.0000, 2.1092, 2.8928, 3.5011, 4.0949, 4.6091, 0.0,
     +             2.3498, 2.0677, 1.8767, 1.6913, 1.5466, 1.4346, 0.0,
     +             7.0114, 4.9322, 4.1466, 3.3724, 2.6301, 1.9473, 0.0,
     +             1.0272,  .7498,  .6124,  .4769,  .3469,  .2275, 0.0,
     +              .0974,  .1486,  .2624,  .4230,  .5806,  .7286, 0.0,
     +              .0    ,  .0231,  .0317,  .0383,  .0448,  .0504, 0.0,
     +              .0    ,  .0    ,  .0    ,  .0    ,  .0    ,  .0    , 0.0/
      DATA FSUP,FNET,FGROSS/182*0.,78*0.,182*0./
C
C  READ IN DATA PERTAINING TO THE SIMPLIFIED COW MODEL.  EXPLANATION
C  OF INPUT VARIABLES:
C   -DUMMY4=DUMMY VARIABLE USED AS COLUMN INDICATOR IN INPUT FILE.
C   -COWS=NUMBER OF COW UNITS IN HERD (MILKING+LACTATING).
C   -AVGMLK=MILK/COW/YR PRODUCED,CWT.
C   -PMILK=$/CWT OF MILK.
C   -NDIET=RATION DEFINED BY CS/FORAGE RATIO FED TO LACTATING HERD;
C         (1-6):   1=0CS 2=20CS 3=40CS...6=100CS.
C   -PFEEDB,-S=PRICES PAID FOR FEEDS BOUGHT OR SOLD; 1=CS 2=HMC
C          3=ALF 4=CP(ALF) 5=SBM 6=NPN 7=CG(DRY), $/DMT,METRIC.
C
      READ(5,100)(DUMMY4(I),I=1,6)
      READ(5,110)COWS,AVGMLK,PMILK,NDIET
      READ(5,100)(PFEEDB(J),J=1,7)
      READ(5,100)(PFEEDS(J),J=1,7)
C
      WRITE(6,115)NYRS
      WRITE(6,120)COWS
      WRITE(6,125)AVGMLK
      WRITE(6,130)NDIET
      WRITE(6,135)PMILK
      WRITE(6,140)(PFEEDS(J),J=1,7)
      WRITE(6,145)(PFEEDB(J),J=1,7)
C
C  CALCULATE FEEDS AVAILABLE TO THE HERD OVER THE NYRS PERIOD.
C
      DO 10 N=1,NYRS
      FSUP(N,1)=AFEED(N,21)
      FSUP(N,2)=AFEED(N,22)
      DO 20 JCOL=1,16,5
      FSUP(N,3)=FSUP(N,3)+AFEED(N,JCOL)
   20 FSUP(N,4)=FSUP(N,4)+(AFEED(N,JCOL)*AFEED(N,JCOL+1))
      FSUP(N,7)=AFEED(N,23)
      DO 30 JFEED=1,6
      FDMD(JFEED)=COWS*RATION(NDIET,JFEED)
      FBAL(N,JFEED)=FSUP(N,JFEED)-FDMD(JFEED)
      IF(JFEED.EQ.4)GO TO 30
      FGROSS(N,JFEED)=FBAL(N,JFEED)*PFEEDS(JFEED)
      IF(FBAL(N,JFEED).LE.O.)FGROSS(N,JFEED)=
     +         FBAL(N,JFEED)*PFEEDB(JFEED)
      FNET(N,1)=FNET(N,1)+FGROSS(N,JFEED)
   30 CONTINUE
      FNET(N,2)=AFEED(N,23)*PFEEDS(7)
      FNET(N,3)=FNET(N,1)+FNET(N,2)
      TCOST(N,11)=FNET(N,1)
      TCOST(N,12)=FNET(N,2)
      TCOST(N,14)=AVGMLK*PMILK*COWS
   10 CONTINUE
C
```

Figure B.3 Software Listing, Subroutine COWMOD

```
      C   ****************************************************
            SUBROUTINE COWMOD(NYRS)
      C   ****************************************************
      C
      C   COWMOD IS A SIMPLIFIED DAIRY FEED-USE MODEL. IT PLACES A VALUE ON
      C   FEEDS PRODUCED BY DETERMINING THE SURPLUS OR DEFECIT OF FEEDS
      C   REQUIRED TO PRODUCE A SPECIFED MILK PRODUCTION. GIVEN A SPECIFIED
      C   BALANCED RATION.  FOR A GIVEN BALANCED RATION. SURPLUSES OR DEFECITS
      C   ARE ACCOUNTED FOR BY SELLING OR PURCHASING IN EACH FEED-STUFF AT
      C   A USER-INPUTTED PRICE.
      C   (L. PARSCH. DEPT OF AG ECON. MSU. 4/82)
      C
            COMMON/Z7/ALHRFD(26.15),AFEED(26.23)
            COMMON/COWDTA/RATION(7.7).FSUP(26.7).FDMD(7).FBAL(26.7).PFEEDB(7).
           +      PFEEDS(7).FGROSS(26.7).FNET(26.3).COWS.AVGMLK.PMILK.NDIET
            COMMON/SUMRY2/TRESP(26.20).TCOSTP(26.20).TCOST(26.20).
           +      STCOST(4.20).TRES(26.20).SRES(4.20)
            DIMENSION DUMMY4(6)
      C
            DATA RATION/ 0.0000. 2.1092. 2.8928. 3.5011. 4.0949. 4.6091. 0.0.
           +             2.3498. 2.0677. 1.8767. 1.6913. 1.5466. 1.4346. 0.0.
           +             7.0114. 4.9322. 4.1466. 3.3724. 2.6301. 1.9473. 0.0.
           +             1.0272.  .7498.  .6124.  .4769.  .3469.  .2275. 0.0.
           +              .0974.  .1486.  .2624.  .4230.  .5806.  .7286. 0.0.
           +              .0   .  .0231.  .0317.  .0383.  .0448.  .0504. 0.0.
           +              .0   .  .0   .  .0   .  .0   .  .0   .  .0   . 0.0/
            DATA FSUP.FNET.FGROSS/182*0..78*0..182*0./
      C
      C   READ IN DATA PERTAINING TO THE SIMPLIFIED COW MODEL.  EXPLANATION
      C   OF INPUT VARIABLES:
      C    -DUMMY4=DUMMY VARIABLE USED AS COLUMN INDICATOR IN INPUT FILE.
      C    -COWS=NUMBER OF COW UNITS IN HERD (MILKING+LACTATING).
      C    -AVGMLK=MILK/COW/YR PRODUCED.CWT.
      C    -PMILK=$/CWT OF MILK.
      C    -NDIET=RATION DEFINED BY CS/FORAGE RATIO FED TO LACTATING HERD:
      C          (1-6):   1=0CS 2=20CS 3=40CS...6=100CS.
      C    -PFEEDB.-S=PRICES PAID FOR FEEDS BOUGHT OR SOLD: 1=CS 2=HMC
      C           3=ALF 4=CP(ALF) 5=SBM 6=NPN 7=CG(DRY). $/DMT.METRIC.
      C
            READ(5.100)(DUMMY4(I).I=1.6)
            READ(5.110)COWS.AVGMLK.PMILK.NDIET
            READ(5.100)(PFEEDB(J).J=1.7)
            READ(5.100)(PFEEDS(J).J=1.7)
      C
            WRITE(6.115)NYRS
            WRITE(6.120)COWS
            WRITE(6.125)AVGMLK
            WRITE(6.130)NDIET
            WRITE(6.135)PMILK
            WRITE(6.140)(PFEEDS(J).J=1.7)
            WRITE(6.145)(PFEEDB(J).J=1.7)
      C
      C   CALCULATE FEEDS AVAILABLE TO THE HERD OVER THE NYRS PERIOD.
      C
            DO 10 N=1.NYRS
            FSUP(N.1)=AFEED(N.21)
            FSUP(N.2)=AFEED(N.22)
            DO 20 JCOL=1.16.5
            FSUP(N.3)=FSUP(N.3)+AFEED(N.JCOL)
      20    FSUP(N.4)=FSUP(N.4)+(AFEED(N.JCOL)*AFEED(N.JCOL+1))
            FSUP(N.7)=AFEED(N.23)
            DO 30 JFEED=1.6
            FDMD(JFEED)=COWS*RATION(NDIET.JFEED)
            FBAL(N.JFEED)=FSUP(N.JFEED)-FDMD(JFEED)
            IF(JFEED.EQ.4)GO TO 30
            FGROSS(N.JFEED)=FBAL(N.JFEED)*PFEEDS(JFEED)
            IF(FBAL(N.JFEED).LE.0.)FGROSS(N.JFEED)=
           +         FBAL(N.JFEED)*PFEEDB(JFEED)
            FNET(N.1)=FNET(N.1)+FGROSS(N.JFEED)
      30    CONTINUE
            FNET(N.2)=AFEED(N.23)*PFEEDS(7)
            FNET(N.3)=FNET(N.1)+FNET(N.2)
            TCOST(N.11)=FNET(N.1)
            TCOST(N.12)=FNET(N.2)
            TCOST(N.14)=AVGMLK*PMILK*COWS
      10    CONTINUE
      C
```

Figure B.3 Software Listing, Subroutine COWMOD

```
      WRITE(6,150)COWS
      WRITE(6,155)
      WRITE(6,161)(FDMD(J),J=1,6),((FDMD(J)/COWS),J=1,6)
C
      WRITE(6,158)COWS
      DO 50 N=1,NYRS
50    WRITE(6,160)N,(FSUP(N,J),J=1,6),N,((FSUP(N,J)/COWS),J=1,6)
C
      WRITE(6,165)NYRS,COWS
      WRITE(6,155)
      DO 60 N=1,NYRS
60    WRITE(6,160)N,(FBAL(N,J),J=1,6),N,((FBAL(N,J)/COWS),J=1,6)
C
      WRITE(6,170)NYRS,COWS
      WRITE(6,175)
      DO 70 N=1,NYRS
70    WRITE(6,180)N,(FGROSS(N,J),J=1,6),FNET(N,1),
     +      N,((FGROSS(N,J)/COWS),J=1,6),(FNET(N,1)/COWS)
C
      WRITE(6,185)
      DO 80 N=1,NYRS
80    WRITE(6,182)N,(FNET(N,J),J=1,3)
C
100   FORMAT(7F10.0)
110   FORMAT(3F10.0,I10)
115   FORMAT('1','SUMMARY OUTPUT FOR',I3,' SIMULATION YEARS:',
     +      ' FEED UTILIZATION SUBCOMPONENT.',//,
     +      ' INPUT VALUES READ INTO SUBROUTINE COWMOD:')
120   FORMAT(' NUMBER OF MILKING COWS (LACTATING + DRY)=',F6.1)
125   FORMAT(' AVERAGE MILK/COW/YR, CWT=',1X,F6.1)
130   FORMAT(' RATION FED TO LACTATING COWS=',I3)
135   FORMAT(' MILK PRICE RECEIVED, $/CWT=',F6.2)
C
140   FORMAT(' PRICES OF FEEDS:          1=CS($/DMT)  2=HMC($/DMT)',
     +      ' 3=ALF($/DMT) 4=CPALF($/DMT)  5=SBM($/DMT)  6=NPN($/DMT)',
     +      ' 7=CGSELL($/DMT)',/,'    FEEDS SOLD=',T25,7(4X,F9.2))
145   FORMAT('    FEEDS PURCHASED=',T25,7(4X,F9.2))
C
150   FORMAT(///' (1) ANNUAL FEED REQUIREMENTS (DMT) FOR',F6.1,
     +      ' COWS.',T68,' (1) ANNUAL FEED REQUIREMENTS PER COW,DMT.',/)
155    FORMAT('      1=CS    2=HMC    3=ALF    4=CPALF    5=SBM    6=NPN   ',
     +      T68,'     1=CS 2=HMC 3=ALF 4=CPALF 5=SBM',
     +      ' 6=NPN   ',/)
158   FORMAT(///' (2) ANNUAL FEED PRODUCED (DMT) FOR ',F6.1,
     +      ' COWS.',T68,' (2) ANNUAL FEED PRODUCED PER COW,DMT.',/)
160   FORMAT(I3,6(1X,F7.2),T68,I3,6(1X,F5.2))
161   FORMAT(3X,6(1X,F7.2),T68,3X,6(1X,F5.2))
C
165   FORMAT('1','SUMMARY OUTPUT FOR',I3,' SIMULATION YEARS:',
     +      ' FEED UTILIZATION SUBCOMPONENT.',//,
     +      ' (3) ANNUAL FEED SURPLUS/DEFECIT PER',F6.1,' COWS,DMT.',
     +      T68,' (3) ANNUAL SURPLUS/DEFECIT PER COW,DMT.',/)
C
170   FORMAT('1','SUMMARY OUTPUT FOR',I3,' SIMULATION YEARS:',
     +      ' FEED UTILIZATION SUBCOMPONENT.',//,
     +      ' (4) GROSS AND NET COSTS/RETURNS FOR FEED',
     +' FOR',F6.1,' COWS,$/YR.',T68,' (4) GROSS AND NET COSTS/RETURNS',
     +      ' PER COW,$/YR.',/)
175   FORMAT('      1=CS    2=HMC    3=ALF   4=CPALF   5=SBM',
     +      '  6=NPN   7=SUM(1-6)',
     +T68,3X,' 1=CS 2=HMC 3=ALF 4=CPALF 5=SBM 6=NPN 7=SUM(1-6)',/)
180   FORMAT(I3,6(1X,F7.0),3X,F8.0,T68,I3,6(1X,F5.0),3X,F6.0)
182   FORMAT(I3,3(1X,F9.0))
185   FORMAT(///' (5) SUMMARY: FEED UTILIZATION SUBCOMPONENT',//,
     +  ' 1=NET FEED(CS,HMC,ALF,SBM,NPN) COSTS/RETURNS,$/YR.',/,
     +      ' 2=CASH CORN(CG) SALES,$/YR.',/,
     +    ' 3=NET PURCHASES/SALES FROM FEEDS/CORN,$/YR.',/)
C
      RETURN
      END
```

Figure B.3 (cont'd.)

high-moisture corn and dry corn grain, it is recommended that the buy price for high-moisture corn be set equivalent to the buy price of corn grain.[1] By contrast, the buy price for corn silage may be indexed to both corn silage production costs and corn cash grain price as suggested by Woody and Black (1978). Sell prices for homegrown feedcrops (corn silage, high-moisture corn, alfalfa) and cash corn should show a price differential reflecting a discount from prices paid when these commodities are purchased. Suggested 1981 values for PFEEDS and PFEEDB are provided in Table B.7.

B.4 Structure of ALFCRNINPUTLP Data File

The three sets of user-controlled input data are stored in ALFCRNINPUTLP in the order presented above, i.e., data read from ALFIN is followed by data read from subroutines CRNIN and COWMOD. Figure B.4 is a sample ALFCRNINPUTLP data file, showing the proper formatting with all three sets of data.

---

[1] Dry matter basis.

Table B.7 Suggested Feedstuff Commodity Prices, Michigan, 1981

	Purchase (PFEEDB)		Sell (PFEEDS)	
	Metric[1]	English	Metric[1]	English
1. Corn silage	$76.34[2]	$22.15/ton	$61.07[3]	$17.72/ton
2. High-moisture corn	139.80[4]	3.00/bu	111.84[3]	2.40/bu
3. Alfalfa (1)	75.00	60/ton	60.00[3]	48/ton
4. Alfalfa (2)	0[5]	0[5]	0[5]	0[5]
5. Soybean meal (44%)	335.65	274/ton[6]	0[5]	0[5]
6. Urea (NPN)	308.70	.14/lb[6]	0[5]	0[5]
7. Cash corn (15.5% MC)	139.80	3.00/bu	132.80	2.85/bu

[1]Metric values are required as model inputs ($/ton, DM). English units are reported on an as-is basis for comparison purposes.

[2]Corn silage prices are based on a procedure suggested by Woody and Black (1978). Calculations assumed a cash corn price of $3.00/bu @ 116.6 bu/acre.

[3]Sell prices of bulky feedcrops are arbitrarily set at 80% of buy price.

[4]Same as for cash corn. See explanation in texts for PFEEDB.

[5]Inactive variables.

[6]Based on Nott et al. (1981).

```
100=123456789.123456789.123456789.123456789.123456789.123456789.
110=        91       285      1953      1978
120=       999         1         1         0
130=      200.      200.      .400
140=         3
150=      144.      186.      232.      365.
160=123456789.123456789.123456789.123456789.123456789.123456789.
170=         0       143
180=     37.85     38.24     29.83
190=    491.38    61654.    220.24    18310.
200=        6.        6.
210=       4.5     9120.        2.        13
220=       1.5    13000.        2.        14        13       241
230=       1.5    10000.        2.        14        13       241
240=123456789.123456789.123456789.123456789.123456789.123456789.
250=       .06       .06       .06
260=      5.00      .299      .350
270=    261.69    130.42    253.91    182.60
280=       .03     67.22     80.11    118.67
290=       25.        7.       .00       .10
300=123456789.123456789.123456789.123456789.123456789.123456789.123456789.
310=      120.      180.     13.00         4
320=     76.34    139.80     75.00    671.50    335.65    308.70    139.80
330=     61.07    111.84     60.00    671.50    335.65    308.70    132.80
```

Figure B.4 Sample Listing, ALFCRNINPUTLP
User Input Data File

APPENDIX C

BTAGEN: SOFTWARE DESCRIPTION, INPUTS, OUTPUTS

BTAGEN is a FORTRAN V coded software package which generates pseudorandom sample observations from a multivariate beta probability distribution. The package employs numerical simulation techniques (Manetsch and Park, 1977; Naylor et al., 1966) to generate sample observations based on user-supplied estimates of parameters of the marginal distributions and correlation matrix. The package was initially developed by King (1979) and was subsequently generalized by Hoskin (1981). The present version of BTAGEN is a reworking and integration of the King and Hoskin software algorithms. It can be used either as an independent package, or can be made a subcomponent of a larger simulation model. A description of the algorithm, theoretical underpinnings, and numerical techniques employed by the model are described in King (1979). A more detailed description of model implementation, including a listing of the complete FORTRAN statement and sample input and output, is found in Parsch (1981).

Software. BTAGEN consists of a main executive calling program (BTAGEN), seven subroutines (MVBETA, COEF, NORVEC, COREL, SSTAT, MDNRIS, MDBETI) and two subprogram functions (TABLI, TABLIE). Two of the subprograms, MDNRIS (inverse standard normal probability distribution function) and MDBETI (inverse beta probability distribution function) are subroutines from the International Mathematical and Statistical Libraries (IMSL), Inc. (1980). These ISML routines need to be available on the hardware system and attached for execution. The executive calling program (PROGRAM BTAGEN) contains all input and output control statements, and is shown in Figure C.1. The entire FORTRAN package (excluding the two IMSL subroutines) contains approximately 325 statements, including comments which describe the algorithms. BTAGEN is stored on magnetic tape at MSU as BTAGENLP. CP compilation time on the CDC Cyber 750 is approximately 1.015 seconds; CP execution time of the (26 * 17) sample generated matrix for the present study (see Chapter 5) was 2.235 seconds.

User inputs. Input data requirements to execute the model are three:

MN, ND: the number of marginal distributions to be specified, and the desired sample size (observations) of each marginal to be generated, respectively.

AMEAN, VAR, BL, BU: mean, variance, lower and upper bound, respectively, of each marginal distribution.

COR: off diagonal, non-zero elements of the lower triangular correlation matrix of the distributions involved.

Model outputs. Output generated by BTAGEN includes seven categories of information:

1. the values for the mean, variance, upper and lower bounds of each marginal inputted by the user;
2. the inputted values for the lower triangular correlation matrix;
3. the cumulative distribution of each marginal at probability increments of 1/n, where n = number of sample observations generated;

```
      PROGRAM BTAGEN
C
C  MAIN CALLING PROGRAM TO GENERATE SAMPLE MULTIVARIATE BETA DIST-
C  RIBUTIONS.  CONTAINS ALL INPUT AND OUTPUT CONTROL.  COMMON BLOCK
C  STATEMENTS HAVE BEEN ARBITRARILY LIMITED TO 20 DISTRIBUTIONS,
C  50 DRAWS PER DISTRIBUTION. (L. PARSCH, DEPT OF AGRIC. ECON.,
C  MICHIGAN STATE UNIVERSITY, 11/81)
C
      REAL K1,K2
      COMMON/BLOCK1/K1(20),K2(20),BL(20),BU(20),AMEAN(20),VAR(20)
      COMMON/BLOCK2/C(20,20),COR(20,20),PAR(20,20),V(20),MN
      COMMON/BLOCK3/Y(20,50),RHO(20,20),CUM(20,110),ND
      DIMENSION YSTAT(3,20)
C
      OPEN(2,FILE='TAPE2')
      OPEN(5,FILE='INPUT')
      OPEN(6,FILE='OUTPUT')
C
C  MN=NUMBER OF VARIABLES WHOSE DISTRIBUTIONS ARE TO BE GENERATED.
C  ND=NUMBER OF SAMPLE OBSERVATIONS PER DISTRIBUTION TO BE GENERATED.
C  FOR EACH SEPARATE VARIABLE, READ IN ITS SAMPLE MEAN, VARIANCE,
C  LOWER AND UPPER BOUND.
C
      READ(5,100)MN,ND
      READ(5,110)(AMEAN(I),VAR(I),BL(I),BU(I),I=1,MN)
      WRITE(6,68)MN,ND
      WRITE(6,70)
      WRITE(6,72)(AMEAN(I),VAR(I),BL(I),BU(I),I=1,MN)
C
      DO 10 I=1,MN
      DO 10 J=1,MN
      COR(I,J)=0.0
      IF(I.EQ.J)COR(I,J)=1.0
10    CONTINUE
C
C  READ IN CORRELATION MATRIX FOR NON-ZERO OFF-DIAGONAL VALUES
C  ONLY.  SET IND=999 WHEN LAST VALUE IS READ IN.
C
15    READ(5,120)I,J,COR(I,J),IND
      COR(J,I)=COR(I,J)
      IF(IND.NE.999)GO TO 15
      WRITE(6,73)
      DO 51 I=1,MN
51    WRITE(6,205)(COR(I,J),J=1,I)
C
      CALL MVBETA
C
C  OUTPUT CONTROL SECTION.
C
      WRITE(6,85)
      DO 25 J=1,ND+1
   25 WRITE(6,205)(CUM(I,J),I=1,MN)
      WRITE(6,88)
      WRITE(6,205)(K1(I),I=1,MN)
      WRITE(6,205)(K2(I),I=1,MN)
C
      WRITE(6,207)
      DO 60 J=1,ND
      WRITE(2,205) (Y(I,J),I=1,MN)
   60 WRITE(6,205) (Y(I,J),I=1,MN)
C
      WRITE(6,75)
      DO 55 I=1,MN
      DO 52 J=1,MN
      IF(J.GE.I) GO TO 54
      CALL COREL(I,J)
   52 CONTINUE
54    IF(J.EQ.I)RHO(I,J)=1.0
   55 WRITE(6,205)(RHO(I,M),M=1,I)
      CALL SSTAT(MN,Y,ND,YSTAT)
      WRITE(6,91)
      DO 63 I=1,3
63    WRITE(6,205)(YSTAT(I,J),J=1,MN)
C
68    FORMAT(1H1,"DISTRIBUTIONS=",I4," DRAWS=",I4,)
70    FORMAT(///," INPUT DATA BY COLS: 1=MEAN 2=VAR 3=BL 4=BU",
     +". EACH ROW REPRESENTS ONE DISTRIBUTION.")
```

Figure C.1 Software Listing, Main Calling Program, BTAGEN

```
      72    FORMAT(4(1X,F12.2))
      73    FORMAT(///" INPUT DATA: CORRELATION MATRIX")
      75    FORMAT(///" CORRELATION MATRIX OF GENERATED MULTIVARIATE",
           +" DISTRIBUTION.")
      88    FORMAT(///" PARAMETERS K1 (ROW 1) AND K2 (ROW 2) FOR",
           +" EACH MARGINAL DISTRIBUTION (COLUMNS).")
      85    FORMAT(///" CUMULATIVE DISTRIBUTIONS OF EACH MARGINAL.",
           +" COLS=INDIVIDUAL DISTRIBUTIONS.")
      91    FORMAT(///" MOMENTS OF SAMPLE GENERATED DISTRIBUTIONS.",
           +" ROWS: 1=MEAN 2=VARIANCE 3=SKEWNESS;  COLS=DISTRIBUTIONS.")
       100  FORMAT(2I10)
       110  FORMAT(4F10.0)
       120  FORMAT(2I10,F10.0,I10)
       205  FORMAT(17(1X,F7.2))
       207  FORMAT(///" SAMPLE OBSERVATIONS: ROWS=SAMPLE DRAWS;",
           +" COLS=INDIVIDUAL DISTRIBUTIONS.")
      C
            END
```

Figure C.1 (cont'd.)

4. the estimated shape parameters (α, β) for each marginal distribution;
5. the sample generated multivariate beta distribution;
6. the lower triangular correlation matrix of the sample generated distribution; and
7. the sample mean, variance, and skewness coefficients for each of the generated marginal distributions.

Outputs (6) and (7) are provided primarily as diagnostic aids in determining whether sample statistics and correlation coefficients converge to their "population" values given in (1) and (2). Number (4) is provided to help visualize the approximate shape of each of the marginal beta distributions being modeled.

Linkage of BTAGEN to DAFOSYM: BMATRX. Although the process generator BTAGEN could be added as a software subcomponent to a larger simulation model, an alternative approach was taken in the present study. BTAGEN was run independently and the generated output matrix was written onto permanent file BMATRIXLP. Subsequent runs of DAFOSYM then read this generated matrix into subroutine CORN for further processing of the simulated time series in CRNMOD. This (26 * 17) randomly generated matrix, BMATRX, contains one row for each year, and one column for each of the corn-related stochastic variables modeled (see Chapter 5). The sample generated BMATRX is presented in Figure C.2. Columns are: 1-5, available days in each planting period; 6-11, available days in each harvest period; 12-16, corn grain yields planted in each planting period (tons/ha, DM); 17, corn silage yield (tons/ha, DM).

MATRIX GENERATED IN BTAGEN. READ FROM CORN: ROWS=SAMPLE OBSERVATIONS (YRS)
COLS: (1-5)=AVAIL DAYS PLANTING (6-11)=AVAIL DAYS HARVEST (12-16)=HMC AND CG YLD. T/HA (17)=CS YLD. T/HA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	9.38	7.92	9.98	7.60	9.90	14.96	14.69	11.41	15.00	14.68	7.70	6.84	6.95	6.29	6.01	5.30	15.68
2	2.52	9.40	9.25	7.94	9.05	13.48	10.25	7.79	10.47	11.85	3.46	5.78	5.92	5.65	5.00	4.08	12.57
3	9.67	8.09	9.93	11.00	8.79	14.89	7.46	8.59	14.17	11.26	5.12	6.17	5.98	5.40	4.90	3.57	12.59
4	6.98	9.99	9.42	6.17	13.59	14.95	14.24	14.76	12.29	8.76	3.86	5.71	6.01	5.93	5.54	5.01	15.34
5	7.37	7.53	9.72	8.48	9.88	14.86	12.15	14.51	15.00	14.16	2.40	5.18	5.40	4.63	4.27	4.23	12.52
6	1.53	5.82	5.83	4.15	9.09	14.95	7.76	7.07	10.70	9.85	5.39	6.94	6.85	5.93	5.61	4.50	12.81
7	7.76	8.67	2.93	3.52	10.14	13.93	11.84	14.99	12.61	10.19	10.67	6.10	6.58	6.35	5.42	4.91	15.23
8	2.78	9.99	9.98	9.67	11.66	15.00	14.85	13.59	14.98	14.47	6.04	5.24	5.50	4.30	3.67	3.57	12.68
9	5.71	9.87	9.42	5.96	11.03	10.01	7.44	9.28	6.88	4.71	2.57	6.78	7.19	6.53	5.74	5.37	14.81
10	8.27	3.10	9.93	10.97	13.90	14.99	13.23	14.36	14.86	7.18	4.92	5.83	6.38	6.33	6.02	5.90	13.78
11	9.95	9.02	8.30	3.50	11.83	15.00	11.19	12.40	14.85	14.67	4.88	5.61	5.98	5.63	4.84	4.38	13.02
12	1.89	3.17	9.97	10.88	12.67	10.00	8.96	12.93	9.14	5.32	.13	6.58	6.86	5.86	5.19	4.75	15.82
13	6.36	9.86	3.22	10.97	8.89	12.57	10.12	7.28	11.60	8.83	.36	6.16	6.02	5.47	5.14	3.95	14.25
14	7.76	8.35	9.93	6.99	12.40	14.71	12.42	8.37	10.69	8.44	.13	5.80	5.84	4.79	4.50	3.90	14.85
15	3.97	4.39	9.66	5.88	11.38	12.82	14.47	14.94	14.84	13.16	13.69	5.74	5.77	5.20	4.82	3.96	12.63
16	8.88	8.36	9.87	10.42	13.85	10.02	8.22	14.62	7.22	4.30	1.67	5.26	5.35	4.33	4.09	3.83	12.50
17	8.84	7.44	7.78	10.45	8.79	13.64	11.14	11.25	14.21	13.98	3.23	6.03	6.24	5.66	5.16	4.56	13.46
18	1.22	3.05	6.59	11.00	13.86	15.00	14.82	14.93	15.00	14.59	1.33	5.70	5.77	5.81	5.48	4.47	12.68
19	4.99	9.35	2.77	10.58	13.44	14.93	14.37	13.84	14.57	11.02	11.90	6.16	6.11	5.77	4.73	3.34	14.81
20	8.67	5.11	7.22	7.04	12.40	10.90	9.08	6.78	5.99	14.15	8.60	6.00	6.24	5.39	4.70	4.17	13.31
21	1.33	4.83	10.00	3.86	10.01	10.01	6.58	9.20	7.26	4.24	1.94	5.45	5.51	4.65	4.62	4.20	13.89
22	3.49	9.97	8.85	10.88	11.98	10.81	6.67	8.69	13.88	14.17	2.86	5.36	5.45	4.78	3.96	3.22	12.88
23	8.74	9.88	9.93	8.03	11.75	14.89	14.93	14.99	14.99	13.09	2.93	7.10	7.15	6.54	6.05	4.99	15.39
24	9.39	6.70	9.31	10.93	13.18	15.00	10.26	10.29	14.79	14.95	13.25	6.43	6.82	6.63	5.73	5.01	13.89
25	4.64	9.77	9.03	6.55	13.58	13.16	6.66	6.81	11.44	6.23	4.36	7.01	7.15	6.76	6.36	5.55	16.15
26	4.51	4.35	10.00	6.24	13.90	15.00	13.52	12.53	13.24	14.67	13.69	5.36	5.38	4.45	4.34	3.87	12.81

Figure C.2 Sample Generated Matrix, BTAGEN

APPENDIX D

WEATHER DATA FILE ELANSWTHR5378

Climatological input data requirements for the two phenological crop growth models described in this study (ALFMOD, CORNF) consist of: maximum daily temperature, minimum daily temperature, daily precipitation, and solar radiation (langleys/day). A data file, ELANSWTHR5378, containing 26 years (1953-1978) of daily observations of these variables for the East Lansing, Michigan weather station, was developed for use with the simulation models.

Solar radiation data. Solar radiation data has been collected on a daily basis for a limited number of years at only two locations (East Lansing, Sault Ste. Marie) in Michigan. Solar radiation data for the East Lansing site was obtained from two sources: one file containing daily solar radiation for the years 1953-71 was obtained from Dr. D.G. Baker, Department of Atmospheric and Oceanic Sciences, University of Michigan; and a second file containing hourly solar radiation for 1966-1978 was obtained from Dr. F. Nurnberger, National Oceanic and Atmospheric Administration, East Lansing, Michigan. The hourly values of the latter file were converted to daily values, and the two sets of solar radiation data were merged into a 1953-1978 data file. The merged data file was then checked for missing or incorrect values (caused by malfunction of solar radiation-sensing equipment at the collection point) which were found to total 7% (680 observations) of the data file. The missing or incorrect values were flagged and subsequently replaced with estimated values linearly interpolated between average daily solar radiation calculated for each of the twelve months over the 26-year period. The midpoint julian day of each month was assigned this average monthly value. The average monthly means (langleys/day) for the 26 years and the respective julian date used in the interpolation procedure (including endpoint corrections) are presented in Table D.1.

Maximum and minimum temperature, precipitation. A data file containing East Lansing, Michigan daily maximum and minimum temperature and daily precipitation for the years 1953-1978 inclusive was obtained from Dr. F. Nurnberger, National Oceanic and Atmospheric Administration, East Lansing, Michigan. Missing values for each of these variables were replaced with estimated values based on a geographical interpolation calculated by weather service personnel.

ELANSWTHR5378 file description. The data files described above were merged into a single file ELANSWTHR5378. The completed data file contains one record per day for the period 1953-1978, inclusive. All February 29 observations have been deleted. Each record contains five values: (1) a six-digit reference for calendar year, month, and day (e.g., June 12, 1968 = 680612); (2) maximum temperature (^{o}F.); (3) minimum temperature (^{o}F.); (4) precipitation (1/100 inches, e.g., ½ inch = 50); and (5) solar radiation (langleys/day). Estimated values for temperature and precipitation are followed by "E"; estimated values for solar radiation are followed by "*". The FORTRAN read format for the file is (F7.0,1X,F4.0,1X,F4.0,1X,F5.0,1X, F4.0,1X).

Table D.1 Average Daily Solar Radiation (Langleys), East Lansing, Michigan, 1953-1978

Month	Langleys/Day	Julian[1]
December	106.9	-15
January	140.5	15
February	221.9	45
March	295.8	75
April	377.6	106
May	479.5	136
June	524.9	167
July	513.0	197
August	448.1	228
September	344.9	259
October	237.1	289
November	130.1	320
December	106.9	350
January	140.5	381

[1] Julian date used for linear interpolation procedure to replace missing and incorrect values in data file ELANSWTHR5378.

APPENDIX E

INDEPENDENT EXECUTION OF ALFMOD AND CRNMOD

The modules ALFMOD and CRNMOD were designed to be executed both as independent simulation programs, and as subcomponents of the larger farming systems model, DAFOSYM. When operated independently, ALFMOD and CRNMOD are referred to as ALF2LP and CRNPRG, respectively. Only slight changes in coding, inputs, and subprograms distinguish the latter independently-run models from the modules ALFMOD and CRNMOD.

ALF2LP: Independent execution of ALFMOD. Execution of ALF2LP consists of simulating the growth of the alfalfa crop as a function of historical weather data contained in ELANSWTHR5378. Modules FORHRV, ALHARV, CRNMOD, and BIGMOD are not executed. Execution of ALF2LP permits testing of the performance of the phenological growth model against actual plot data.

Basic physiological relationships in ALF2LP are identical to those in ALFMOD. That which distinguishes ALF2LP from ALFMOD is the following:

1. Program ALF2LP is activated and becomes the main calling program for the independent simulation.
2. The call statement to module ALHARV in subroutine ALRSET is replaced by a call statement to ALTEST. ALTEST is a test subroutine, activated for use with ALF2LP, which maintains count of the number of days since cutting and harvest began for each cutting. User-specified inputs control length of

the cutting and harvest period. Once these limits have been reached, ALTEST sends back a signal to ALRSET to reset the regrowth mechanism for the subsequent cutting.

3. Three additional input values are read into ALFIN. These include:

   NDAYSC, NDAYSH: the number of days over which cutting and harvest are to take place each cutting. These variables can be ranged between 1 and 39 days. A value of 1 is recommended for comparing simulation output with test plot data. A one-day cutting and harvest period causes regrowth to be reset on the same day that the cutting is initiated.

   IQUAL: a switch for selecting an alternative set of alfalfa quality prediction equations. For a value of 1, the set of equations described in Section 4.5.2 based on data from Mowat (1966) is used to predict quality. For a value of 2, an alternative set of equations, estimated by the author using growing degree days as arguments, predicts alfalfa quality. This alternative set of equations is based on Michigan data collected by Ruppell (Ruppell et al., 1982).

4. Simulation results for each day of harvest, as well as data averaged over the duration of each cutting, is included in the program output. A function BCTEMP is activated as a counting mechanism for output control.

Coding alterations required by the above changes have been incorporated into a permanent editor file ALSIM2LPEWCOM. Execution of

this independent software program requires the weather data file ELANSWTHR5378 as the only input file other than a file containing the user-controlled inputs.

CRNPRG: Independent execution of CRNMOD. Execution of CRNPRG consists of simulating the corn planting, harvesting and storage processes described in equations 5.9-5.12 (Section 5.6.1). As in DAFOSYM, the BMATRIXLP permanent file, containing the matrix of stochastic variates generated in BTAGEN, is attached and provides CRNPRG with values for corn yield and available field working days. However, modules FORHRV, ALHARV, ALFMOD, and BIGMOD are neither attached nor executed.

All algorithms describing the production processes of planting, harvest, and storage are identical to those in CRNMOD. That which distinguishes CRNPRG from CRNMOD is the following:

1. Program CRNPRG is activated and becomes the main calling program for the independent simulation.
2. Harvesting rates for corn silage are calculated using equation 5.13. Since FORHRV is not attached, the forage harvester (chopper) for corn silage must be declared along with the planter and picker-sheller. The chopper is identified in CRNIN in input read line "WIDTH(2)...".
3. Neither fuel consumption, nor repair and maintenance costs for corn-related operations is calculated. Because tractors and blowers are not identified as inputs in CRNIN, output will show these costs as 0. However, all corn labor requirements and costs are calculated based on machine harvest rates. Annual fixed costs will reflect costs of the planter,

chopper, picker-sheller, and storage structures.

4. Two additional inputs are required in CRNIN. These are: NYRS: the number of years to be simulated (1-26); JFNAL: a hypothetical last date of third-cut alfalfa harvest (julian). For julian dates later than September 1 (244), initiation of corn silage harvest is delayed.

FORTRAN coding alterations required by the above changes have been incorporated into a permanent editor file CRNPRGLP. Execution of this independent software program requires the stochastic variate matrix data file BMATRIXLP as the only input file other than a file containing the user-controlled inputs.

APPENDIX F

RANKING SYSTEM ALTERNATIVES: STOCHASTIC EFFICIENCY CRITERIA

As described in Section 3.5.2, DAFOSYM output consists of a sample cumulative distribution function (CDF) of the system performance measure, net feed costs (NFC). An experiment whose goal is to evaluate m (i = 1,2,...m) dairy forage system alternatives (see Section 3.2.2) will consist of utilizing DAFOSYM to simulate m treatments, each resulting in CDF_i (i = 1,2,...m). Each CDF_i, generated over an n-year simulation, is a descriptive measure of how system alternative i will perform over n states of nature; it portrays a risky prospect in that the decision by a farm-firm manager to implement alternative i represents a choice or action that has a probability distribution of outcomes.

If DAFOSYM model output were to be used in the management support research role of ranking the m simulated system alternatives, or of identifying which i-th system is the "preferred" one, the question can be posed, "What is the appropriate criterion to use in ordering risky prospect i?" Stated differently, the question asks how m individual probability distributions of system outcome are to be evaluated or compared.

Under the assumption that decision makers are maximizers of expected utility[1], a convenient answer to this question presents itself in the use of stochastic efficiency criteria. In order to rank risky prospects using the expected utility hypothesis, both the probability distribution of the prospect and the decision maker's preferences for it must be known. In view of the fact that researchers generally have little or no knowledge of a decision maker's underlying utility function, stochastic efficiency criteria are convenient in that they proceed by making reasonable assumptions about the shape of the utility function, and hence eliminate the need to specify and estimate it.

Stochastic dominance occurs whenever the expected utility of one risky prospect exceeds the expected utility of another prospect. The stochastic dominance approach consists of attempting to find the efficient set of action choices--i.e., those decisions or alternatives which are undominated--for all decision makers whose utility functions possess similar behavioral characteristics. Identification of the efficient set involves pairwise comparison of CDF's associated with each of the risky outcomes. The procedure which is employed in making this comparison consists of applying sets of selection rules

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[1]The expected utility hypothesis (EUH), formalized by von Neumann and Morgenstern (1944), provides the means for defining an ordinal utility scale which can be used for ranking risky prospects. The significance of the EUH is that it differentiates the two important components of risky decision-making: preference and probability. Based on a person's acceptance of three axioms (ordering/transitivity, continuity, independence), the EUH implies the existence of: (1) a utility function that reflects his preference, and (2) a probability distribution that reflects his judgment about the chances he faces with respect to a decision's outcome. Rational individuals who accept the axioms will maximize expected utility when faced with decisions involving risk.

which are increasingly restrictive in that they assume more about the shape of the utility function. As increasingly restrictive rules are applied, the goal is to reduce the size of the admissible, efficient set. Decision makers whose preferences are consistent with the defined class of utility functions will find the "preferred" or "best" alternative in the stochastic efficient set. Two sets of selection rules are discussed below; these result in first and second degree stochastic efficiency.

First degree stochastic dominance. Selection rules for first degree stochastic dominance (FSD) are based on the weakest but most general assumption about decision makers' preferences. Under FSD (Quirk and Saposnik, 1962) the rational assumption which is applied is that more of the utility argument is preferred to less.[1] Let $U(x)$ designate the utility function for x. The FSD restriction is that the first derivative of utility is strictly positive, i.e., $U_1(x) > 0$. This implies a monotonically increasing utility function reflecting positive marginal utility for x.

The procedure for determining FSD between risky prospects F and G is to compare the respective CDF's F_1 and G_1, defined over the range $[a,b]$. In the continuous case,[2] F_1 is related to its probability

---

[1] In order to maintain consistency with the literature, the discussion assumes that the performance variable is a measure of (monetary) returns. Because the performance measure of DAFOSYM (NFC) is a measure of costs, the converse is true, i.e., less NFC is preferred to more.

[2] Both FSD and SSD (second degree stochastic dominance) are also applicable in the discrete case. The analogous criteria for discrete stochastic dominance ordering is given in Anderson et al., 1977.

density function f(x) by equation F.1:

$$\text{(F.1)} \qquad F_1(R) = \int_a^R f(x)dx$$

F dominates G by FSD if $F_1(R) \leq G_1(R)$ for all R over which the functions are defined, provided that the inequality holds for at least one value of R. Graphically, this efficiency criterion merely states that the CDF of the dominant action choice must lie nowhere to the left of the dominated distribution. If F is not dominated, it is stochastically efficient in the first degree (FSE), and would be preferred by all expected utility maximizers having positive marginal utility for x.

Second degree stochastic dominance. Selection rules for second degree stochastic dominance (SSD) are more restrictive than for FSD. Under SSD (Hanoch and Levy, 1969; Hadar and Russell, 1969) it is assumed that decision makers not only have positive marginal utility for x, but also that they are risk averse. This implies that U(x) is monotonically increasing ($U_1(x) > 0$) and that it is concave ($U_2(x) < 0$) to the origin.

Similar to FSD, ordering rules for SSD make pairwise comparisons of CDF's F_1 and G_1. F_1 dominates G_1 in the sense of SSD if it lies more to the right in terms of differences in area between the CDF curves cumulated from lower values (left to right). Mathematically, the rule is given by defining a cumulative distribution that measures the area under each CDF, i.e.,

$$\text{(F.2)} \qquad F_2(R) = \int_a^R F_1(x)dx$$

Then, F dominates G in the sense of SSD if $F_2(R) \leq G_2(R)$ for all R with at least one strong inequality. Pairwise comparison of all CDF's results in second degree stochastic efficiency (SSE), i.e., the set of risky prospects which are not dominated. Expected utility maximizers --those who prefer more to less and who are risk averse as well--would prefer this SSE set of action choices.

Properties of stochastic dominance ordering. Three noteworthy properties can be summarized for risky prospects F, G, and H ordered using stochastic efficiency criteria:

(1) Transitivity: If F dominates G by FSD and SSD, and G dominates H by FSD and SSD, then F dominates H by FSD and SSD as well.

(2) Partial ordering: If F dominates G by FSD, then F dominates G by SSD as well. However, if F dominates G by SSD, it does not hold that F dominates G by FSD.

(3) Necessary conditions: A necessary but not sufficient condition for F's dominance over G is that the lowest value in the range over which CDF F_1 is defined be not less than for the lowest value of G_1, and that the mean of F_1 be not less than the mean of G_1.

Comments. With respect to analysis of DAFOSYM outcomes, the convenience of utilizing stochastic efficiency criteria is that they permit evaluation of risk-return tradeoffs of alternative dairy forage systems without necessitating that utility functions either be specified or estimated. Likewise, restrictions (e.g., symmetry) need not be placed on the distributions of the system outcome variable. Rather, the sample cumulative distributions generated for each i-th system alternative (CDF_i) are directly compared using the ordering criteria described above.

The shortcoming of the method is that it may not necessarily reduce the size of the efficient set to a "manageable" number of alternatives. Even with SSD, selection rules may not be sufficiently restrictive, given the shapes of each CDF_i.[1] Nevertheless, as Hanoch and Levy (1969) suggest, the approach is logical in that decision-making under risk becomes a two-stage process. First, an efficient set is chosen from all possible choices; second, an alternative is selected from the efficient set based solely on individual preferences.

[1]More restrictive selection rules than those described here have been formalized. These include third degree stochastic dominance (Whitmore, 1970), and stochastic dominance with respect to a function (Meyer, 1977). Moreover, techniques have been developed for implementing Meyer's criterion using the interval approach (King, 1981).

APPENDIX G

DAIRY FORAGE FEED DISAPPEARANCE MODEL

In DAFOSYM, dairy feed disappearance is modeled in subroutine COWMOD. The purpose of this component is to account for the disposal of feedcrops and their utilization by the dairy herd in order to enable calculation of the DAFOSYM system performance measure, net feed costs (NFC). As noted in Section 1.4, this feedcrop utilization model is a temporary component of DAFOSYM in that it employs a simplified algorithm of feed disappearance which permits testing and execution of the four core modules while a permanent dairy forage feed utilization module is being developed.[1]

G.1 The Linkage between COWMOD and the System Performance Measure

Section 3.4.3 describes the four modeled system activities of DAFOSYM as crop growth/yield, crop planting/harvesting, crop storage/feeding, and feedcrop utilization (disappearance). The core modules of DAFOSYM (FORHRV, ALHARV, ALFMOD, CRNMOD) consist of algorithms which simulate the first three of these activities. Recalling the system performance measure net feed costs (NFC) of equation 3.4

3.4 $$NFC = TCPC + NCPF$$

---

[1]The feed utilization component which will replace COWMOD is being developed by the Dairy Protein Modeling Group, consisting of members of the Departments of Animal Sciences and Agricultural Economics, Michigan State University, under the direction of J. Roy Black.

(Section 3.4.6), these three simulated activities culminate in two important intermediate model output variables: (1) total annual on-farm crop production costs (TCPC), defined in equation 3.5 as being the sum of the fixed cost (FC) and variable cost vectors (VC); and, (2) the vector of feedcrops produced (DM_k) and available for consumption by the livestock enterprise for a one-year production period (equation 3.1).

Whereas TCPC figures directly into equation 3.4, the impact of vector DM on NFC can be evaluated only after the fourth modeled system activity, feedcrop utilization, has been accounted for in DAFOSYM. This is the task of COWMOD. The vector of feedcrops produced (DM) affects the system performance measure net feed costs (NFC) insofar as it influences the net cost of purchased feeds (NCPF) for the dairy herd. This relationship is summarized in equation 3.6 (Section 3.4.6) which defines NCPF as the sum of expenditures on deficit feedcrops (EDF) and feedcrop supplements (EPFS), minus cash sales of surplus feeds (SSF) grown on the farm. Equations 3.7 - 3.9 (Section 3.4.6) identify these three arguments of NCPF as being directly related to the vector DM, as well as to the milk production level M_o, and purchased feed prices (PFEED).

G.2 The Optimization Approach to Feed Utilization

Equations 3.7 - 3.9 can be described as a constrained optimization resource allocation problem. Assuming that the dairy herd is to be fed a nutritionally balanced ration consistent with a milk production output level at the herd's genetic potential, the vector of feedcrops produced annually on the farm must be allocated in a manner which minimizes the net cost of purchased feeds (NCPF).

The solution to this problem is grounded in (a) the ability of lactating animals to substitute feeds while maintaining production at a specified level, and (b) the relative price relationships between purchased feeds, feed supplements, and cash feeds sold. Theoretically, the solution to this problem is represented by the point of tangency between a milk production isoquant and the feedcrop isocost curves.[1] Operationally, this problem is solved with the use of a least cost dairy ration balancer, which employs basic linear programming techniques or an alternative version of the simplex algorithm[2] in order to determine the minimum feed cost/cow/day.

The basic ration formulation model can be described as a series of equations:[3]

$$\text{(G.1)} \qquad \text{minimize:} \qquad z = \sum_j c_j x_j \qquad (j = 1,2,\ldots l)$$

$$\text{(G.2)} \qquad \text{subject to:} \qquad \sum_j a_{ij} x_j \leq, =, \geq b_i \qquad (i = 1,2,\ldots m)$$

$$\text{(G.3)} \qquad \text{for} \qquad x_j \geq 0.$$

Equation G.1 gives the feed cost/cow/day (z) as the quantity (x_j) of the j-th ($j = 1,2,\ldots l$) feedstuff fed times its respective cost (c_j). Typically, the i-th ($i = 1,2,\ldots m$) constraint (b_i) to the model reflects daily feed requirements of nutrient i, whereas a_{ij} is the quantity of nutrient i in feedstuff j.

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[1] Isoquant and isocost curves are described in Henderson and Quandt, Chapter 3 (1971).

[2] The simplex algorithm is described in most operations research texts, e.g., Wagner (1975). Alternative formulations of ration balancers are discussed in Black and Hlubik (1980).

[3] Notation for equations G.1 - G.3 is independent of notation used in the remainder of this study.

When viewed in the whole farm context from the short-run perspective of one feeding period (one year), the least cost ration balancer approach to feedcrop allocation represents suboptimization. Once the supply of homegrown feedcrops has been placed into on-farm storage, the question of farm system design (crop mix, machinery complement, storage structures, etc.) is no longer relevant. Rather, the question is how to dispose of the fixed supply of homegrown feedcrops in the most efficient manner from both the standpoint of animal nutrition and feed price relationships.

Implications for modeling. Over an n-year ($t = 1,2,...n$) simulation, the disposal of k ($k = 1,2,3$) homegrown feedcrops--the quantity and nutrient density of which are given in the vector DM_{kt} ($k = 1,2,3$; $t = 1,2,...n$)--is ideally solved for using a least cost ration balancer. A least cost ration is balanced each simulation year t, and incorporates the vector DM_{kt} into the simplex solution matrix to reflect:

1. the quantity of feed k to use in the optimal least cost ration where the k feeds produced are a subset of the j ($j = 1,2,...l$) feeds which can enter the solution;
2. the total quantity of each of k feeds produced on the farm in year t as a subset of the i ($i = 1,2,...m$) constraints to the model; and
3. the quantity of nutrient i contained in the k-th feed produced (a_{ij}) on the farm.

Additional activities and constraints would permit sales or purchases of feedcrops to reflect feed disappearance in high and low years, respectively.

G.3 COWMOD: An Accounting Version of the Optimization Approach

The temporary feed disappearance model in DAFOSYM represents a simplified version of the optimization approach outlined in Section G.2. COWMOD is an accounting version of the optimization approach in that it calculates annual net cost of purchased feeds (NCPF, equation 3.6) based on six alternate feed budgets which were generated using a linear programming least cost ration balancer.

The COWMOD algorithm. Let R_{ij} define annual feed requirements per livestock unit (milking herd and replacements) for each of j (j = 1,2,...5) feedstuffs comprising the i-th (i = 1,2,...6) alternative ration. Furthermore, let the i rations be nutritionally balanced at milk production level M_o, and constrained to contain i alternative fractions of total forage dry weight consisting of corn silage and alfalfa. Assuming that the five feeds allocated are corn silage, high-moisture corn, alfalfa, soybean meal, and NPN (urea), and assuming that the six rations contain 0, 20, 40, 60, 80, and 100% corn silage forage, the COWMOD algorithm can be described using equations G.4 - G.7.

Given the user-inputted choice of ration NDIET ($1 \leq \text{NDIET} \leq 6$, see Appendix B), the annual quantity of the j-th feed required by the herd ($FDMD_j$) is given in equation G.4 as

$$\text{(G.4)} \qquad FDMD_j = R_{ij} * COWS \qquad (j = 1,2,\ldots 5; \quad i = NDIET)$$

where COWS is the number of mature (lactating and dry) animals in the herd. The annual quantity of feed j available to the herd ($FSUP_j$) from on-farm sources is given in equation G.5 as the vector of homegrown feedcrops.

$$\text{(G.5)} \qquad FSUP_j = DM_k \qquad (j = 1,2,\ldots 5) \quad (k = 1,2,3) \quad (\text{for all } j = k)$$

For feedcrops not produced on the farm, as well as for supplements (soybean meal, NPN), $FSUP_j$ is zero. Simple accounting in equations G.6 and G.7 provides estimates of either a positive or negative balance ($FBAL_j$) of each feed, and the net expenditure required over all j feeds (FNET):

$$\text{(G.6)} \qquad FBAL_j = FSUP_j - FDMD_j \qquad (j = 1,2,\ldots 5)$$

$$\text{(G.7)} \qquad FNET = \sum_j (FBAL_j * PFEEDS_j) \qquad \text{for } FBAL_j > 0$$

$$\sum_j (FBAL_j * PFEEDB_j) \qquad \text{for } FBAL_j \leq 0$$

In equation G.7, whenever there is a surplus of feed j ($FBAL_j > 0$), the excess crop is sold at the user-inputted sell price of the commodity ($PFEEDS_j$). By contrast, a shortage of crop j ($FBAL_j \leq 0$) requires that the deficit feed be purchased in at the user-inputted buy price ($PFEEDB_j$). Once FNET has been calculated, the total revenues from cash corn sales (sold at the user-inputted price in vector PFEEDS) are added to FNET, resulting in the net cost of purchased feeds (NCPF), which is the final component of the equation 3.4 system performance measure to be calculated.

<u>Generating the feed budgets (R_{ij})</u>. Six least cost dairy rations were balanced using a linear programming model described by Hlubik (1979). The model is an expanded version of equations G.1 - G.3 in that additional row constraints force the solution to contain a specified ratio of corn silage and alfalfa in the ration. The six balanced

rations were constrained to contain corn silage levels of 0, 20, 40, 60, 80, and 100% of forage dry matter, with the remainder being alfalfa.

Rations were balanced for each of three separate lactating groups at milk production levels of 45, 60, and 75 pounds/day. The dry matter intake limit for the three groups was 38.3, 42.9, and 47.6 lbs/day, respectively; minimum energy requirements were 24.3, 28.9, and 33.6 Mcal/day; crude protein requirements were set at 4.9, 6.1, and 7.4 lbs/day. A 305-day lactation and 3.5% fat-corrected milk was assumed. Calving interval was set at 12 months and average body weight per milker was 1350 lbs. Feeds assumed available to the milking herd, together with their respective nutrient densities, are shown in Table G.1. Nutrient densities are based on NRC (1978) recommendations with certain adjustments for alfalfa quality for use in this study.

The assumed age distribution of animals in the dairy herd is based on a study by Nott et al. (1977) and is presented in Table G.2. Dry cow rations are based on Hillman (1977) and consist of either alfalfa and corn silage, or alfalfa only when no corn silage is fed to lactating cows. Replacement rations are based on Thomas and Hlubik (1979) and provide 12% crude protein for heifers. Similar to dry cows, replacements are assumed to be fed forages containing both alfalfa and corn silage, except when no corn silage is fed to the lactating herd.

The balanced feed budget matrix R, which appears in equation G.4 above, is shown in Table G.3. For each of the six rations, elements of the matrix (R_{ij}) represent the annual quantity of each feedstuff

Table G.1 Nutrient Densities of Feedstuffs Available, Dry Matter Basis (Lbs/Lb)

	Corn Silage	High-Moisture Corn	Alfalfa	Soybean Meal	Dical	Limestone	Salt
NEL (Mcal/lb)	.7000	.9400	.5600	.8600	.000	.000	.000
Crude protein	.1100[1]	.1000	.1750	.5000	.000	.000	.000
Crude fiber	.2600	.0230	.3500	.0600	.000	.000	.000
Calcium	.0028	.0002	.0130	.0028	.231	.338	.000
Phosphorous	.0020	.0026	.0020	.0064	.186	.000	.000
Salt	.0000	.0000	.0000	.0000	.000	.000	1.000

[1]Assumes 7 lbs. NPN (urea @ 46% N) added per wet ton of corn silage.

Source: Based on National Research Council (1978).

Table G.2 Age Distribution of Animals in a Michigan Dairy Herd, Steady State Equilibrium

Animal Category	Average Number of Head in Each Age Category/Lactating Cow
Calves (0-6 weeks)	.09
Calves (6 weeks-6 months)	.17
Open heifers (6-15 months)	.47
Bred heifers (15-24 months)	.39
Lactating cows	1.00
Dry cows	.15
Total/lactating cow	2.27

Source: Nott et al., 1977.

Table G.3 Annual Feed Requirements per Dairy Livestock Unit for Six Alternative Rations

Ration	Feedstuff				
CS:A	CS[1]	HMC	A	SBM	NPN
0:100	0	2.35	7.01	.097	0
20:80	2.11	2.07	4.93	.149	.023
40:60	2.83	1.88	4.15	.262	.032
60:40	3.50	1.69	3.37	.423	.038
80:20	4.09	1.55	2.63	.581	.045
100:0	4.61	1.43	1.94	.729	.050

Each element (metric tons, dry matter basis) reflects annual feed requirements for mature cows (lactating and dry) and all replacements. Rations for lactating cows were averaged over milk production levels of 45, 60, and 75 lbs/day; rations were balanced using a least cost formulation (Hlubik, 1979).

[1] CS = corn silage; HMC = high-moisture corn (shelled); A = alfalfa; SBM = soybean meal; NPN = non-protein nitrogen (urea).

required per mature cow unit/year (metric tons, dry matter). Each matrix element is a summation of (a) the annual balanced ration requirement averaged over the three milk production levels, and (b) the annual dry cow and replacement requirement weighted to reflect the herd age distribution composition in Table G.2.

Comments. The primary advantage of the simplified accounting algorithm which describes COWMOD is that it permits simulation and evaluation of a broad spectrum of dairy farm systems based on rations whose forage compositions range from 0 to 100% corn silage. There are two disadvantages to the COWMOD approach, however.

1. Each of the six rations comprising matrix R reflects a static estimate of feedcrop utilization within a dynamic system model. Although each alternative ration is nutritionally balanced to provide a specified level of milk output, COWMOD does not provide a flexible dairy herd management response which would be characterized by altering ration formulation on an annual basis. It is likely that as simulated yields result in annually differing mixes of feedcrops available for the herd, rational management would not constrain rations to provide a fixed ratio of corn silage:alfalfa each year. Instead, ration formulation would be influenced by homegrown feedcrop availability. Incorporation of this management response into the algorithm requires that the linear program itself become a model subcomponent of an expanded COWMOD in order to permit rations to be formulated each simulation year.

2. Because the six rations of matrix R are "pre-balanced", they reflect allocation of feedstuffs based on a fixed estimate of feedcrop nutrient density. A featured aspect of DAFOSYM is the simulation of

alfalfa quality as a function of the interaction of management and crop maturity dynamics. Implicitly, the present version of COWMOD does not fully incorporate intermediate model output reflecting simulated alfalfa quality. This shortcoming would also be alleviated by incorporating a linear programming algorithm into COWMOD which permits the a_{ij}'s of the simplex matrix to reflect changing crop quality on an annual basis.

Although the present version of COWMOD satisfactorily permits evaluation of system risk due to across-year crop yield variability, it is designated as a temporary component of DAFOSYM primarily due to these two shortcomings. An anticipated feature of the permanent feed utilization component will be the alleviation of these deficiencies.

APPENDIX H

TESTING AND EVALUATION OF CORNF

CORNF is a dynamic phenological computer simulation model of corn growth developed by Stapper and Arkin (1980). Source coding for the model was obtained from the authors and a modified FORTRAN V version of CORNF, called CORNLP, was developed. Modifications in CORNLP consisted of recoding the main executive calling program of CORNF in order to facilitate multiple-year simulation,[1] and to permit greater flexibility over input and output parameters. Also, an additional subroutine was added to CORNLP which permits calculation of sample statistics of output distributions generated over the multiple-year simulations.

Model testing. The purpose of obtaining and testing CORNF was to determine whether the phenological corn growth model would serve as a suitable counterpart to ALFMOD in DAFOSYM. The goal of the testing was to resolve: (a) the appropriate genotype input parameters in CORNF (MCLASS) for the Michigan climate, and (b) whether model output for delayed corn plantings under alternative genotypes corresponded to empirical findings (see Sections 5.2.1, 5.5.1). Each is discussed in turn.

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[1] CORNLP is compatible with the 26-year weather data file ELANSWTHR5378 discussed in Appendix D.

Genotype input parameters. Genotype input parameters (MCLASS) can take integer values between 1 and 9 inclusive in CORNF. Just as a late maturing hybrid in a cooler climate may be an early maturing hybrid in a warmer climate, these inputted values reflect the sensitivity of the plant to cumulative heat units throughout the growing season. The CORNF authors report that an MCLASS of 4 was selected for comparisons of simulation output with test plots of Pioneer 3780 grown at University Park, Pennsylvania. Central Pennsylvania and lower Michigan both average 2600-2800 cumulative degree days (base 50°F.) for the May 10 - October 10 growing period. Since Pioneer 3780 is considered to be a middle season hybrid in lower Michigan, the range $3 \leq$ MCLASS ≤ 5 was selected for simulation testing under Michigan conditions, with the larger values representing later maturing hybrids.

End of year data for both grain and silage yields of Pioneer 3780 grown 1972-1978 at East Lansing, Michigan on Conover clay loam soil (Rossman, various dates) was collected. Average test plot planting date was May 1; average silage and grain harvest dates were September 4 and October 4, respectively, over the seven-year sample. CORNLP was set up to conform to these planting-harvesting dates using the East Lansing weather data file for years 1972-1978. Model input parameters were set to reflect extractable soil moisture in a 5-foot soil profile based on Vitosh and Fisher (1981).

Summary statistics for the simulation output and the historical data presented in Table H.1 imply that the maturity class 4 model parameter underestimates both grain and silage yields for Pioneer 3780. However, when the simulation period was increased to 26 years (1953-1978 weather data), the mean yield values for maturity classes

Table H.1 Corn Grain and Silage Yields, Pioneer 3780 Versus Simulated Output (CORNF), 1972-1978

	Pioneer 3780	MCLASS (CORNF)		
Grain		3	4	5
$\bar{X}$[1]	130.9	91.6	117.8	145.6
S	19.6	10.4	8.6	9.0
CV	.149	.113	.07	.06
Silage				
$\bar{X}$[1]	6.78	4.82	5.89	6.83
S	.885	.435	.237	.228
CV	.130	.09	.040	.03

Pioneer 3780 yields are taken from Rossman's (various dates) test plot trials at East Lansing, Michigan, Conover clay loam. MCLASS values reflect short, medium, and long-season corn hybrids (Stapper and Arkin, 1980). Empirical and simulated corn was planted May 1; corn silage and grain harvest dates were September 4 and October 4, respectively.

[1]Grain measurements are in bu/acre; silage in tons dry matter/acre. $\bar{X}$ = sample mean, S = standard deviation, CV = coefficient of variation.

3, 4, and 5 were 103.5, 130.5, and 152.2 bu/acre, respectively, for grain, and 5.26, 6.36, and 7.37 tons/acre (DM), respectively, for corn silage.

Although the 26-year maturity class 4 average yields of 130.5 bu/acre and 6.63 tons/acre correspond closely to the Pioneer 3780 yields of 130.9 bu/acre and 6.78 tons/acre averaged over seven years, these results demonstrate two problems which arise concerning the appropriateness of testing when validating complex models such as CORNF. First, although CORNF does not perform well against Pioneer 3780 when the restricted time series (1972-1978) is simulated, it is likely that there are other middle season hybrids whose mean yields over that same period would correspond closely with the simulated output. Or, if no individual corresponding hybrid time series could be found, it is not inconceivable that a composite time series (consisting of a "basket" of middle season hybrids) could not be developed which would show empirical yields corresponding closely with CORNF output. Use of a composite "basket" of hybrids would not necessarily be an inappropriate empirical time series against which to test the model since CORNF is not intended to be hybrid-specific. Hence, the question can be raised, "Which is the appropriate hybrid (or basket of hybrids) against which model output is to be tested?"

Second, although CORNF performs well against Pioneer 3780 when the expanded time series (1953-1978) is simulated, is the model nevertheless to be considered suitable even though performance over the restricted time series was unacceptable? This question is difficult to answer if the objective in using the model is not to simulate the years 1972-1978, but rather to simulate sample yields whose underlying parent populations are not significantly different than samples taken from test plots.

It is the author's conclusion that the CORNF MCLASS range 3-5 generates output which approximates mean corn yields at East Lansing, Michigan on Conover clay loam soils. However, in view of the discussion above, this conclusion may be somewhat inconclusive because it would appear that the process of model validation--which influences whether model output is accepted or rejected--is itself largely affected by the research objective and intended use of the model.

Date of planting. In order to test whether simulation model output would reflect decreased corn grain yields with delayed plantings, a series of 26-year runs for maturity classes 3, 4, and 5 for planting dates May 1 and May 20 were simulated using CORNF. Mean corn grain yields from these simulations are presented in Table H.2. Table H.2 demonstrates that CORNF does not accurately reflect the research findings reported in Section 5.2.1 and 5.5.1 of this study. For both maturity classes 3 and 4, average simulated yields increased when planting was delayed by three weeks. By contrast, the Rossman-Cook data (1966) showed yield decreases of 10-20% for a comparable delay in planting in mid-Michigan. Although model output for maturity class 5 showed a slight decrease (6%) in yield with delayed plantings in these simulation runs, it is nevertheless questionable that the 26-year average yield (152.2 bu/acre) for maturity class 5 is representative of any long season genotypes in Michigan.

On a subsequent set of runs, date of simulated plantings was delayed until June 1. Under these test conditions, maturity class 4 simulated yields decreased to 92% of May 1 yields. Although the

Table H.2 Simulated Corn Grain Yields for Two Dates of Planting, Three Genotypes (CORNF)

Planting Date	MCLASS (CORNF)		
	3	4	5
May 1	103.5	130.5	152.2
May 20	104.4	139.0	142.7

Results are mean yields (bu/acre) over a 26-year simulation for East Lansing, Michigan, Conover clay loam, with harvest occurring on October 4 each year.

direction of the yield change is consistent with empirical findings, this simulated yield decrease underestimates the average 28% yield drop observed by Rossman and Cook for early June plantings.

In order to test whether calibration of CORNF moisture stress parameters might generate greater yield reductions for delayed plantings, a third series of 26-year simulation runs was made. In these runs, the author alternately adjusted (1) user input variables representing extractable moisture in the soil profile, and (2) endogenous phenological model variables representing the threshold at which moisture stress begins to affect the growth rate of the grain and whole plant dry matter components. Under these subsequent runs, simulated reduction of available water and increased plant stress reduced mean yield levels across all maturity classes, but the impact of planting delays on the direction and magnitude of yield changes remained unaltered from the earlier runs reported in Table H.2.

Evaluation. One of the primary advantages of using a complex phenological crop growth model as a subcomponent of a larger farming system simulation model is that it permits study of alternative management strategies whose outcomes are closely linked to subtle technical issues of cropping systems. Models such as CORNF which address these technical issues are worthy of the increased input data requirements and simulation costs, provided that model output conforms reasonably well with empirical findings. In the present study, the author rejected using CORNF as a subcomponent of DAFOSYM primarily because of its inability to predict reduced yields with delayed corn plantings.[1] Other doubts about the model can be expressed with regard to: (1) how well any three adjacent MCLASS values reflect relative yields of short, medium, and long season hybrids for a specified region; (2) whether the model underestimates variance of yields (see Table H.1); and (3) whether the model's prediction of grain moisture content is reliable.

The developers of CORNF have not claimed that the present model is more than a first version. At present, research by the model developers is being undertaken to improve understanding of model relationships, and to expand existing algorithms. It is the author's conclusion that, given the flexible structure and design of CORNF, future improved versions will serve as useful research tools for farm system modelers.

[1]Tulu (1973) rejected use of an earlier (but unrelated) version of a phenological corn growth model for the same reason.

APPENDIX I

DAFOSYM: SAMPLE OUTPUT LISTING

```
THE MANAGEMENT INPUTS FOR AREA AND OPERATION SEQUENCE WERE READ AS FOLLOWS
    71.53 0
  22    0   42    0  153  153  173  103    0
0.00 0.00 0.00 0.00 1.50 1.50  .33 0.00 0.00
 .80 0.00  .50 0.00  .1714.00  .1714.00 0.00
1.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00 2.00  .23 0.00 6.00 6.00 1.00 0.00 0.00
    71.53 0
  22    0   42    0  153  153  173  103    0
0.00 0.00 0.00 0.00 1.50 1.50  .33 0.00 0.00
 .80 0.00  .50 0.00  .1714.00  .1714.00 0.00
1.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00 2.00  .23 0.00 6.00 6.00 1.00 0.00 0.00
    53.65 0
  22    0   42    0  153  153  173  103    0
0.00 0.00 0.00 0.00 1.50 1.50  .33 0.00 0.00
 .80 0.00  .50 0.00  .1714.00  .1714.00 0.00
1.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00 2.00  .23 0.00 6.00 6.00 1.00 0.00 0.00
     0.00 0
  357.53    357.53  32590.00  32590.00      8.00      0.00      0.00
0 0 0
```

```
INPUT VALUES FOR ALFALFA SIMULATION RUN READ INTO SUBROUTINE ALFIN

-------------------------------

FIRST AND LAST SIMULATION YEARS=  1953  1978
FIRST AND LAST SIMULATION DAY (JULIAN)=    91   285
IPRT1 (PRINT CONTROL) AND OUTPUT UNITS (0=ENGLISH 1=METRIC)=   999     1
OPTION TO DIRECT-CATALOG AFEED AND TCOST MATRICES=       1       0
SOIL MOISTURE PARAMETERS: AWFC,AWINIT,AWFS=  200.  200. .400
CUTTING DATES (JULIAN) FOR 3 CUTS/YR=  144.  186.  232.


INPUT VALUES FOR CORN SIMULATION:  SUBROUTINES CRNIN AND CORN


SIMULATION LENGTH, YEARS=  26
AREA INTENDED AS CS HMC CG AND TOTAL(HA)=    22.80   46.74   13.76   83.30
STORAGE CAPACITY OF CS AND HMC (DM TONS)=   296.02   269.26
INVESTMENT IN STORAGE STRUCTURES FOR CS AND HMC, $    34352.     19678.
WORK DAYLENGTH, PLANT PD (HRS/DAY)=    6.00
WORK DAYLENGTH, HARVEST PD (HRS/DAY)=    6.00
CS OPERATION NO. (140-149 W/SAVOIE MODEL ONLY)= 143
CORN MACHINERY INPUT DATA, COLS:  1=WIDTH (M) 2=PPM ($)  3=XMEN (MANHRS/HR)  4=NTRAC (MCODE)  5=NTBLOW (MCODE)  6=NBLOWR (MCODE)
CORN PLANTING:                3.00     6080.  2.0    13
CS HARVEST:                   1.50    13000.  2.0    14  13 241
HMC HARVEST:                  1.50    10000.  2.0    14  13 241
DISCOUNT RATES CHARGED: SHORT, MEDIUM, LONG-TERM=   .06   .06   .06
LABOR CHARGE($/HR); DIESEL, GAS CHARGE($/L)=  5.00  .299  .350
FERTILIZER/SEED/CHEMICALS ($/HA): SEEDING YEAR ALFALFA,ESTABLISHED ALFALFA, CS, HMC/CG=  261.69  130.42  253.91  182.60
DRYING CHARGE, CG-SOLD ($/PT/BU); CUSTOM HARVEST CHARGE, CG ($/HA)=   .03    67.22
CUSTOM CHARGE FOR PRE-PLANT TILLAGE, CORN; PRE-HARVEST TILLAGE/SEEDING, ALFALFA ($/HA)= 80.11  118.67
STORAGE STRUCTURE LIFE (YRS); SV/INVEST=  25.0 0.00
MACHINERY LIFE (YRS); SV/INVEST=   7.0  .10
```

```
 INPUT VALUES FOR ALFALFA SIMULATION RUN READ INTO SUBROUTINE ALFIN

-------------------------------

FIRST AND LAST SIMULATION YEARS=  1953  1978
FIRST AND LAST SIMULATION DAY (JULIAN)=    91   285
IPRT1 (PRINT CONTROL) AND OUTPUT UNITS (0=ENGLISH 1=METRIC)=   999      1
OPTION TO DIRECT-CATALOG AFEED AND TCOST MATRICES=        1       0
SOIL MOISTURE PARAMETERS: AWFC,AWINIT,AWFS=  200.  200.  .400
CUTTING DATES (JULIAN) FOR 3 CUTS/YR=  144.   186.   232.


INPUT VALUES FOR CORN SIMULATION:  SUBROUTINES CRNIN AND CORN


SIMULATION LENGTH, YEARS=  26
AREA INTENDED AS CS HMC CG AND TOTAL(HA)=    22.80   46.74   13.76   83.30
STORAGE CAPACITY OF CS AND HMC (DM TONS)=   296.02   269.26
INVESTMENT IN STORAGE STRUCTURES FOR CS AND HMC, $    34352.    19678.
WORK DAYLENGTH, PLANT PD (HRS/DAY)=   6.00
WORK DAYLENGTH, HARVEST PD (HRS/DAY)=   6.00
CS OPERATION NO. (140-149 W/SAVOIE MODEL ONLY)= 143
CORN MACHINERY INPUT DATA, COLS:  1=WIDTH (M) 2=PPM ($)  3=XMEN (MANHRS/HR)  4=NTRAC (MCODE)  5=NTBLOW (MCODE)  6=NBLOWR (MCODE)
CORN PLANTING:               3.00     6080.  2.0    13
CS HARVEST:                  1.50    13000.  2.0    14   13 241
HMC HARVEST:                 1.50    10000.  2.0    14   13 241
DISCOUNT RATES CHARGED: SHORT, MEDIUM, LONG-TERM=   .06    .06    .06
LABOR CHARGE($/HR); DIESEL, GAS CHARGE($/L)=  5.00  .299   .350
FERTILIZER/SEED/CHEMICALS ($/HA): SEEDING YEAR ALFALFA,ESTABLISHED ALFALFA, CS, HMC/CG=  261.69   130.42   253.91   182.60
DRYING CHARGE, CG-SOLD ($/PT/BU); CUSTOM HARVEST CHARGE, CG ($/HA)=    .03     67.22
CUSTOM CHARGE FOR PRE-PLANT TILLAGE, CORN; PRE-HARVEST TILLAGE/SEEDING, ALFALFA ($/HA)= 80.11  118.67
STORAGE STRUCTURE LIFE (YRS); SV/INVEST=  25.0 0.00
MACHINERY LIFE (YRS); SV/INVEST=   7.0  .10
```

MATRIX GENERATED IN BTAGEN, READ FROM CORN: ROWS=SAMPLE OBSERVATIONS (YRS)
COLS: (1-5)=AVAIL DAYS PLANTING (6-11)=AVAIL DAYS HARVEST (12-16)=HMC AND CG YLD, T/HA (17)=CS YLD, T/HA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	9.38	7.92	9.98	7.60	9.90	14.96	14.69	11.41	15.00	14.68	7.70	6.84	6.95	6.29	6.01	5.30	15.68
2	2.52	9.40	9.25	7.94	9.05	13.48	10.25	7.79	10.47	11.85	3.46	5.78	5.92	5.65	5.00	4.08	12.57
3	9.67	8.09	9.93	11.00	8.79	14.89	7.46	8.59	14.17	11.26	5.12	6.17	5.98	5.40	4.90	3.57	12.59
4	6.98	9.99	9.42	6.17	13.59	14.95	14.24	14.76	12.29	8.76	3.86	5.71	6.01	5.93	5.54	5.01	15.34
5	7.37	7.53	9.72	8.48	9.88	14.86	12.15	14.51	15.00	14.16	2.40	5.18	5.40	4.63	4.27	4.23	12.52
6	1.53	5.82	5.83	4.15	9.09	14.95	7.76	7.07	10.70	9.85	5.39	6.94	6.85	5.93	5.61	4.50	12.81
7	7.76	8.67	2.93	3.52	10.14	13.93	11.84	14.99	12.61	10.19	10.67	6.10	6.58	6.35	5.42	4.91	15.23
8	2.78	9.99	9.98	9.67	11.66	15.00	14.85	13.59	14.98	14.47	6.04	5.24	5.50	4.30	3.67	3.57	12.68
9	5.71	9.87	9.42	5.96	11.03	10.01	7.44	9.28	6.88	4.71	2.57	6.78	7.19	6.53	5.74	5.37	14.81
10	8.27	3.10	9.93	10.97	13.90	14.99	13.23	14.36	14.86	7.18	4.92	5.83	6.38	6.33	6.02	5.90	13.78
11	9.95	9.02	8.30	3.50	11.83	15.00	11.19	12.40	14.85	14.67	4.88	5.61	5.98	5.63	4.84	4.38	13.02
12	1.89	3.17	9.97	10.88	12.67	10.00	8.96	12.93	9.14	5.32	.13	6.58	6.86	5.86	5.19	4.75	15.82
13	6.36	9.86	3.22	10.97	8.89	12.57	10.12	7.28	11.60	8.83	.36	6.16	6.02	5.47	5.14	3.95	14.25
14	7.76	8.35	9.93	6.99	12.40	14.71	12.42	8.37	10.69	8.44	.13	5.80	5.84	4.79	4.50	3.90	14.85
15	3.97	4.39	9.66	5.88	11.38	12.82	14.47	14.94	14.84	13.16	13.69	5.74	5.77	5.20	4.82	3.96	12.63
16	8.88	8.36	9.87	10.42	13.85	10.02	8.22	14.62	7.22	4.30	1.67	5.26	5.35	4.33	4.09	3.83	12.50
17	8.84	7.44	7.78	10.45	8.79	13.64	11.14	11.25	14.21	13.98	3.23	6.03	6.24	5.66	5.16	4.56	13.46
18	1.22	3.05	6.59	11.00	13.86	15.00	14.82	14.93	15.00	14.59	1.33	5.70	5.77	5.81	5.48	4.47	12.68
19	4.99	9.35	2.77	10.58	13.44	14.93	14.37	13.84	14.57	11.02	11.90	6.16	6.11	5.77	4.73	3.34	14.81
20	8.67	5.11	7.22	7.04	12.40	10.90	9.08	6.78	5.99	14.15	8.60	6.00	6.24	5.39	4.70	4.17	13.31
21	1.33	4.83	10.00	3.86	10.01	10.01	6.58	9.20	7.26	4.24	1.94	5.45	5.51	4.65	4.62	4.20	13.89
22	3.49	9.97	8.85	10.88	11.98	10.81	6.67	8.69	13.88	14.17	2.86	5.36	5.45	4.78	3.96	3.22	12.88
23	8.74	9.88	9.93	8.03	11.75	14.89	14.93	14.99	14.99	13.09	2.93	7.10	7.15	6.54	6.05	4.99	15.39
24	9.39	6.70	9.31	10.93	13.18	15.00	10.26	10.29	14.79	14.95	13.25	6.43	6.82	6.63	5.73	5.01	13.89
25	4.64	9.77	9.03	6.55	13.58	13.16	6.66	6.81	11.44	6.23	4.36	7.01	7.15	6.76	6.36	5.55	16.15
26	4.51	4.35	10.00	6.24	13.90	15.00	13.52	12.53	13.24	14.67	13.69	5.36	5.38	4.45	4.34	3.87	12.81

SUMMARY OUTPUT FOR 26 SIMULATION YEARS, 1953-1978: MATRIX YALF, PRE-HARVEST ALFALFA YIELD, QUALITY.

SUMMARY OUTPUT COLUMNS: EVERY 5 COLS=1 CUTTING. INDIVIDUAL COLS ARE: 1=DMYLD 2=CP 3=DIG 4=CF 5=GDD85.
COLS 1-20 SUMMARIZE CUTTINGS 1-4; COLS 21-25 SUMMARIZE TOTAL ANNUAL PRODUCTION.
EACH ROW IS ONE SIMULATION YEAR. ALL MEASURES ARE TAKEN ON FIRST DAY OF CUTTING.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	3.75	.23	.70	.24	269.	3.13	.23	.70	.31	512.	2.98	.23	.70	.31	525.	0.00	0.00	0.00	0.00	0.	9.86	.23	.70	.28	1306.
2	3.88	.23	.70	.24	278.	3.23	.23	.70	.31	516.	2.90	.23	.70	.29	461.	0.00	0.00	0.00	0.00	0.	10.01	.23	.70	.28	1254.
3	5.69	.17	.64	.28	438.	3.46	.23	.70	.30	474.	1.63	.23	.70	.33	598.	0.00	0.00	0.00	0.00	0.	10.78	.20	.67	.29	1510.
4	3.24	.23	.70	.22	210.	3.09	.23	.70	.30	492.	3.15	.23	.70	.31	518.	0.00	0.00	0.00	0.00	0.	9.48	.23	.70	.27	1219.
5	3.65	.23	.70	.25	318.	3.31	.23	.70	.29	473.	3.54	.22	.70	.31	541.	0.00	0.00	0.00	0.00	0.	10.49	.23	.70	.29	1331.
6	5.12	.18	.65	.24	298.	1.30	.23	.70	.24	273.	1.87	.23	.70	.30	489.	0.00	0.00	0.00	0.00	0.	8.29	.20	.67	.26	1060.
7	4.78	.20	.67	.25	333.	3.97	.23	.70	.31	521.	3.29	.23	.70	.35	659.	0.00	0.00	0.00	0.00	0.	12.04	.22	.69	.30	1513.
8	4.16	.23	.70	.25	323.	3.84	.23	.70	.28	434.	4.02	.19	.66	.34	619.	0.00	0.00	0.00	0.00	0.	12.03	.21	.69	.29	1376.
9	4.14	.22	.69	.23	254.	3.36	.23	.70	.30	486.	.98	.23	.70	.31	519.	0.00	0.00	0.00	0.00	0.	8.47	.23	.70	.27	1259.
10	4.51	.21	.68	.28	426.	3.92	.23	.70	.31	524.	1.84	.23	.70	.34	631.	0.00	0.00	0.00	0.00	0.	10.26	.22	.70	.30	1581.
11	5.09	.19	.66	.25	321.	3.80	.23	.70	.31	514.	2.81	.23	.70	.32	556.	0.00	0.00	0.00	0.00	0.	11.70	.21	.68	.29	1391.
12	5.22	.18	.65	.29	463.	3.47	.23	.70	.31	529.	1.01	.23	.70	.30	503.	0.00	0.00	0.00	0.00	0.	9.70	.20	.67	.30	1495.
13	5.02	.18	.66	.27	402.	2.84	.23	.70	.29	461.	.61	.23	.70	.31	526.	0.00	0.00	0.00	0.00	0.	8.47	.20	.68	.28	1390.
14	3.82	.23	.70	.23	233.	3.85	.23	.70	.32	555.	2.57	.23	.70	.34	621.	0.00	0.00	0.00	0.00	0.	10.24	.23	.70	.29	1408.
15	4.35	.22	.69	.23	254.	3.60	.23	.70	.31	541.	2.71	.23	.70	.32	577.	0.00	0.00	0.00	0.00	0.	10.66	.23	.70	.28	1372.
16	5.31	.18	.65	.25	332.	3.31	.23	.70	.29	461.	3.49	.23	.70	.33	601.	0.00	0.00	0.00	0.00	0.	12.10	.21	.68	.29	1394.
17	4.79	.20	.67	.25	327.	3.56	.23	.70	.28	419.	3.55	.22	.70	.34	643.	0.00	0.00	0.00	0.00	0.	11.91	.22	.69	.29	1389.
18	4.94	.19	.66	.28	406.	3.11	.23	.70	.29	442.	3.26	.23	.70	.31	542.	0.00	0.00	0.00	0.00	0.	11.31	.21	.69	.29	1391.
19	4.76	.19	.66	.25	308.	2.98	.23	.70	.32	565.	1.20	.23	.70	.30	475.	0.00	0.00	0.00	0.00	0.	8.94	.21	.68	.28	1348.
20	4.33	.21	.69	.26	341.	3.39	.23	.70	.29	464.	2.23	.23	.70	.30	486.	0.00	0.00	0.00	0.00	0.	9.95	.22	.70	.28	1290.
21	4.51	.22	.69	.25	313.	2.76	.23	.70	.29	463.	2.80	.23	.70	.31	532.	0.00	0.00	0.00	0.00	0.	10.07	.22	.70	.28	1308.
22	4.27	.23	.70	.25	322.	3.53	.23	.70	.30	489.	2.38	.23	.70	.33	596.	0.00	0.00	0.00	0.00	0.	10.18	.23	.70	.29	1407.
23	3.93	.23	.70	.26	344.	3.08	.23	.70	.31	520.	2.62	.23	.70	.31	522.	0.00	0.00	0.00	0.00	0.	9.63	.23	.70	.29	1386.
24	4.03	.23	.70	.24	281.	3.47	.23	.70	.31	511.	3.63	.22	.69	.32	554.	0.00	0.00	0.00	0.00	0.	11.13	.23	.70	.29	1346.
25	4.73	.20	.67	.29	463.	3.15	.23	.70	.29	461.	2.31	.23	.70	.30	497.	0.00	0.00	0.00	0.00	0.	10.19	.22	.69	.29	1421.
26	3.65	.23	.70	.23	248.	2.90	.23	.70	.28	427.	2.00	.23	.70	.30	493.	0.00	0.00	0.00	0.00	0.	8.55	.23	.70	.26	1167.

SAMPLE STATISTICS FOR SIMULATION OUTPUT. ROWS: 1=MEAN 2=STANDARD DEVIATION 3=COEF. OF VARIATION

1	4.45	.21	.68	.25	327.	3.28	.23	.70	.30	482.	2.51	.23	.70	.32	549.	0.00	0.00	0.00	0.00	0.	10.25	.22	.69	.28	1358.
2	.61	.02	.02	.02	69.	.53	.00	.00	.02	58.	.91	.01	.01	.02	56.	0.00	0.00	0.00	0.00	0.	1.16	.01	.01	.01	111.
3	.14	.10	.03	.08	.21	.16	.00	.00	.06	.12	.36	.04	.01	.05	.10	0.00	0.00	0.00	0.00	0.00	.11	.05	.02	.04	.08

SUMMARY OUTPUT FOR 26 SIMULATION YEARS, 1953-1978: MATRIX YALF, PRE-HARVEST ALFALFA YIELD, QUALITY.

SUMMARY OUTPUT COLUMNS: EVERY 5 COLS=1 CUTTING. INDIVIDUAL COLS ARE: 1=DMYLD 2=CP 3=DIG 4=CF 5=GDDB5.
COLS 1-20 SUMMARIZE CUTTINGS 1-4; COLS 21-25 SUMMARIZE TOTAL ANNUAL PRODUCTION.
EACH ROW IS ONE SIMULATION YEAR. ALL MEASURES ARE TAKEN ON FIRST DAY OF CUTTING.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	3.75	.23	.70	.24	269.	3.13	.23	.70	.31	512.	2.98	.23	.70	.31	525.	0.00	0.00	0.00	0.00	0.	9.86	.23	.70	.28	1306.
2	3.88	.23	.70	.24	278.	3.23	.23	.70	.31	516.	2.90	.23	.70	.29	461.	0.00	0.00	0.00	0.00	0.	10.01	.23	.70	.28	1254.
3	5.69	.17	.64	.28	438.	3.46	.23	.70	.30	474.	1.63	.23	.70	.33	598.	0.00	0.00	0.00	0.00	0.	10.78	.20	.67	.29	1510.
4	3.24	.23	.70	.22	210.	3.09	.23	.70	.30	492.	3.15	.23	.70	.31	518.	0.00	0.00	0.00	0.00	0.	9.48	.23	.70	.27	1219.
5	3.65	.23	.70	.25	318.	3.31	.23	.70	.29	473.	3.54	.22	.70	.31	541.	0.00	0.00	0.00	0.00	0.	10.49	.23	.70	.29	1331.
6	5.12	.18	.65	.24	298.	1.30	.23	.70	.24	273.	1.87	.23	.70	.30	489.	0.00	0.00	0.00	0.00	0.	8.29	.20	.67	.26	1060.
7	4.78	.20	.67	.25	333.	3.97	.23	.70	.31	521.	3.29	.23	.70	.35	659.	0.00	0.00	0.00	0.00	0.	12.04	.22	.69	.30	1513.
8	4.16	.23	.70	.25	323.	3.84	.23	.70	.28	434.	4.02	.19	.66	.34	619.	0.00	0.00	0.00	0.00	0.	12.03	.21	.69	.29	1376.
9	4.14	.22	.69	.23	254.	3.36	.23	.70	.30	486.	.98	.23	.70	.31	519.	0.00	0.00	0.00	0.00	0.	8.47	.23	.70	.27	1259.
10	4.51	.21	.68	.28	426.	3.92	.23	.70	.31	524.	1.84	.23	.70	.34	631.	0.00	0.00	0.00	0.00	0.	10.26	.22	.70	.30	1581.
11	5.09	.19	.66	.25	321.	3.80	.23	.70	.31	514.	2.81	.23	.70	.32	556.	0.00	0.00	0.00	0.00	0.	11.70	.21	.68	.29	1391.
12	5.22	.18	.65	.29	463.	3.47	.23	.70	.31	529.	1.01	.23	.70	.30	503.	0.00	0.00	0.00	0.00	0.	9.70	.20	.67	.30	1495.
13	5.02	.18	.66	.27	402.	2.84	.23	.70	.29	461.	.61	.23	.70	.31	526.	0.00	0.00	0.00	0.00	0.	8.47	.20	.68	.28	1390.
14	3.82	.23	.70	.23	233.	3.85	.23	.70	.32	555.	2.57	.23	.70	.34	621.	0.00	0.00	0.00	0.00	0.	10.24	.23	.70	.29	1408.
15	4.35	.22	.69	.23	254.	3.60	.23	.70	.31	541.	2.71	.23	.70	.32	577.	0.00	0.00	0.00	0.00	0.	10.66	.23	.70	.28	1372.
16	5.31	.18	.65	.25	332.	3.31	.23	.70	.29	461.	3.49	.23	.70	.33	601.	0.00	0.00	0.00	0.00	0.	12.10	.21	.68	.29	1394.
17	4.79	.20	.67	.25	327.	3.56	.23	.70	.28	419.	3.55	.22	.70	.34	643.	0.00	0.00	0.00	0.00	0.	11.91	.22	.69	.29	1389.
18	4.94	.19	.66	.28	406.	3.11	.23	.70	.29	442.	3.26	.23	.70	.31	542.	0.00	0.00	0.00	0.00	0.	11.31	.21	.69	.29	1391.
19	4.76	.19	.66	.25	308.	2.98	.23	.70	.32	565.	1.20	.23	.70	.30	475.	0.00	0.00	0.00	0.00	0.	8.94	.21	.68	.28	1348.
20	4.33	.21	.69	.26	341.	3.39	.23	.70	.29	464.	2.23	.23	.70	.30	486.	0.00	0.00	0.00	0.00	0.	9.95	.22	.70	.28	1290.
21	4.51	.22	.69	.25	313.	2.76	.23	.70	.29	463.	2.80	.23	.70	.31	532.	0.00	0.00	0.00	0.00	0.	10.07	.22	.70	.28	1308.
22	4.27	.23	.70	.25	322.	3.53	.23	.70	.30	489.	2.38	.23	.70	.33	596.	0.00	0.00	0.00	0.00	0.	10.18	.23	.70	.29	1407.
23	3.93	.23	.70	.26	344.	3.08	.23	.70	.31	520.	2.62	.23	.70	.31	522.	0.00	0.00	0.00	0.00	0.	9.63	.23	.70	.29	1386.
24	4.03	.23	.70	.24	281.	3.47	.23	.70	.31	511.	3.63	.22	.69	.32	554.	0.00	0.00	0.00	0.00	0.	11.13	.23	.70	.29	1346.
25	4.73	.20	.67	.29	463.	3.15	.23	.70	.29	461.	2.31	.23	.70	.30	497.	0.00	0.00	0.00	0.00	0.	10.19	.22	.69	.29	1421.
26	3.65	.23	.70	.23	248.	2.90	.23	.70	.28	427.	2.00	.23	.70	.30	493.	0.00	0.00	0.00	0.00	0.	8.55	.23	.70	.26	1167.

SAMPLE STATISTICS FOR SIMULATION OUTPUT. ROWS: 1=MEAN 2=STANDARD DEVIATION 3=COEF. OF VARIATION

1	4.45	.21	.68	.25	327.	3.28	.23	.70	.30	482.	2.51	.23	.70	.32	549.	0.00	0.00	0.00	0.00	0.	10.25	.22	.69	.28	1358.
2	.61	.02	.02	.02	69.	.53	.00	.00	.02	58.	.91	.01	.01	.02	56.	0.00	0.00	0.00	0.00	0.	1.16	.01	.01	.01	111.
3	.14	.10	.03	.08	.21	.16	.00	.00	.06	.12	.36	.04	.01	.05	.10	0.00	0.00	0.00	0.00	0.00	.11	.05	.02	.04	.08

AVERAGE ALFALFA DM YIELD AVAILABLE AS FEED (T/HA), AVERAGE CRUDE PROTEIN (DEC) AND AVERAGE DIGESTIBILITY (DEC) FOR UP TO 4 HARVESTS AND THE ANNUAL TOTAL

YR	HARVEST 1			HARVEST 2			HARVEST 3			HARVEST 4			TOTAL YEARLY		
	DM	CP	DIG	DM	CP	DIG	DM	CP	DIG	DM	CP	DIG	DM	CP	DIG
1	3.51	.172	.647	3.16	.186	.661	2.39	.184	.662	0.00	0.000	0.000	9.05	.180	.655
2	3.45	.170	.647	3.43	.178	.651	2.42	.174	.654	0.00	0.000	0.000	9.30	.174	.650
3	4.52	.141	.593	3.10	.197	.677	1.40	.215	.696	0.00	0.000	0.000	9.02	.170	.635
4	3.23	.180	.659	3.12	.186	.667	2.53	.176	.653	0.00	0.000	0.000	8.87	.181	.661
5	3.49	.175	.650	3.32	.174	.641	2.63	.176	.653	0.00	0.000	0.000	9.44	.175	.647
6	4.50	.142	.598	2.11	.215	.695	1.91	.212	.692	0.00	0.000	0.000	8.51	.173	.640
7	3.88	.156	.625	3.01	.202	.682	2.57	.174	.646	0.00	0.000	0.000	9.46	.176	.649
8	3.51	.170	.645	3.15	.182	.658	3.18	.140	.587	0.00	0.000	0.000	9.85	.166	.634
9	3.56	.160	.628	2.61	.214	.689	1.46	.219	.696	0.00	0.000	0.000	7.63	.188	.660
10	3.73	.163	.634	3.09	.195	.673	1.29	.218	.696	0.00	0.000	0.000	8.12	.182	.657
11	4.13	.155	.614	3.21	.186	.659	2.06	.185	.664	0.00	0.000	0.000	9.40	.171	.639
12	4.26	.146	.607	3.16	.198	.676	1.52	.215	.696	0.00	0.000	0.000	8.94	.175	.644
13	4.13	.149	.607	2.27	.216	.695	1.21	.212	.692	0.00	0.000	0.000	7.60	.178	.645
14	3.18	.175	.653	3.21	.186	.651	2.00	.207	.684	0.00	0.000	0.000	8.39	.185	.658
15	3.56	.162	.632	3.15	.179	.653	2.19	.190	.667	0.00	0.000	0.000	8.89	.174	.647
16	4.34	.143	.590	3.20	.183	.660	2.64	.177	.659	0.00	0.000	0.000	10.19	.163	.628
17	4.06	.153	.614	3.17	.179	.635	2.72	.171	.644	0.00	0.000	0.000	9.96	.166	.628
18	4.36	.151	.606	3.28	.183	.659	2.59	.162	.637	0.00	0.000	0.000	10.23	.164	.631
19	3.86	.152	.620	2.60	.214	.694	.99	.217	.694	0.00	0.000	0.000	7.45	.181	.654
20	3.64	.158	.626	3.14	.195	.673	1.91	.208	.685	0.00	0.000	0.000	8.68	.181	.654
21	4.13	.159	.625	3.08	.194	.671	2.24	.194	.673	0.00	0.000	0.000	9.45	.178	.650
22	3.54	.173	.649	3.09	.190	.668	1.88	.210	.690	0.00	0.000	0.000	8.51	.186	.663
23	3.50	.163	.630	3.16	.191	.670	2.31	.173	.642	0.00	0.000	0.000	8.97	.175	.648
24	3.44	.171	.647	3.20	.183	.662	2.68	.171	.645	0.00	0.000	0.000	9.32	.176	.652
25	3.85	.159	.631	2.95	.206	.680	1.82	.209	.686	0.00	0.000	0.000	8.62	.184	.658
26	3.42	.178	.655	3.06	.197	.674	1.66	.216	.696	0.00	0.000	0.000	8.14	.192	.669

SAMPLE STATISTICS FOR SIMULATION OUTPUT. ROW 1=MEAN, ROW 2=STANDARD DEVIATION, ROW 3=COEF. OF VARIATION

1	3.80	.161	.628	3.04	.193	.668	2.08	.193	.669	0.00	0.000	0.000	8.92	.177	.648
2	.40	.012	.020	.31	.012	.016	.55	.022	.026	0.00	0.000	0.000	.75	.007	.011
3	.10	.073	.032	.10	.064	.024	.27	.113	.040	0.00	0.000	0.000	.08	.042	.017

TOTAL ALFALFA FEED AVAILABLE FROM FOUR STORAGE LOCATIONS
THE INFORMATION INCLUDES TOTAL DM (T), AVERAGE CP, BIASED STANDARD DEVIATION OF CP
AVERAGE DIG AND BIASED STANDARD DEVIATION OF DIG

YR	ALFALFA IN FIRST SILO					ALFALFA IN SECOND SILO					HIGH QUALITY HAY					LOW QUALITY HAY				
	DM	CP	S(CP)	DIG	S(DIG)	DM	CP	S(CP)	DIG	S(DIG)	DM	CP	S(CP)	DIG	S(DIG)	DM	CP	S(CP)	DIG	S(DIG)
1	304.8	.189	.014	.667	.016	300.1	.173	.018	.648	.021	0.0	.000	.000	.000	.000	0.0	.000	.000	.000	.000
2	299.4	.184	.013	.662	.020	304.6	.169	.016	.645	.020	0.0	.000	.000	.000	.000	17.8	.148	.000	.629	.000
3	300.3	.200	.019	.677	.025	297.3	.141	.010	.594	.021	22.4	.212	.000	.696	.000	0.0	.000	.000	.000	.000
4	299.3	.191	.015	.673	.016	290.3	.173	.013	.650	.018	0.0	.000	.000	.000	.000	0.0	.000	.000	.000	.000
5	318.7	.184	.015	.661	.019	309.8	.168	.015	.638	.027	0.0	.000	.000	.000	.000	0.0	.000	.000	.000	.000
6	277.3	.209	.019	.688	.026	297.2	.142	.007	.600	.009	0.0	.000	.000	.000	.000	0.0	.000	.000	.000	.000
7	303.7	.197	.011	.674	.015	308.6	.157	.010	.626	.013	0.0	.000	.000	.000	.000	18.5	.151	.000	.627	.000
8	304.9	.187	.015	.666	.016	318.3	.150	.011	.609	.022	0.0	.000	.000	.000	.000	24.4	.127	.000	.559	.000
9	299.6	.210	.014	.686	.014	220.3	.165	.027	.634	.031	0.0	.000	.000	.000	.000	0.0	.000	.000	.000	.000
10	301.2	.190	.014	.668	.014	256.1	.185	.031	.659	.035	0.0	.000	.000	.000	.000	0.0	.000	.000	.000	.000
11	300.7	.190	.015	.665	.020	317.5	.155	.007	.616	.027	0.0	.000	.000	.000	.000	17.2	.160	.000	.627	.000
12	307.5	.205	.011	.683	.011	305.0	.146	.007	.608	.010	0.0	.000	.000	.000	.000	0.0	.000	.000	.000	.000
13	227.1	.214	.007	.693	.005	295.2	.149	.008	.608	.018	0.0	.000	.000	.000	.000	0.0	.000	.000	.000	.000
14	297.7	.191	.017	.662	.027	266.8	.185	.024	.660	.025	0.0	.000	.000	.000	.000	0.0	.000	.000	.000	.000
15	306.6	.191	.014	.672	.014	290.6	.158	.013	.623	.022	0.0	.000	.000	.000	.000	0.0	.000	.000	.000	.000
16	296.3	.188	.015	.666	.017	310.6	.142	.009	.588	.034	0.0	.000	.000	.000	.000	74.7	.158	.007	.641	.003
17	309.7	.184	.015	.660	.018	314.3	.151	.010	.599	.029	0.0	.000	.000	.000	.000	39.4	.148	.002	.619	.000
18	297.4	.186	.018	.665	.019	311.9	.151	.007	.607	.025	0.0	.000	.000	.000	.000	76.2	.140	.008	.606	.002
19	239.5	.215	.006	.694	.004	275.9	.152	.008	.621	.013	0.0	.000	.000	.000	.000	0.0	.000	.000	.000	.000
20	299.7	.193	.014	.672	.011	287.1	.174	.028	.644	.036	0.0	.000	.000	.000	.000	0.0	.000	.000	.000	.000
21	305.5	.191	.015	.667	.019	299.2	.171	.021	.641	.030	31.1	.174	.002	.656	.000	0.0	.000	.000	.000	.000
22	314.8	.188	.015	.667	.018	260.2	.190	.023	.667	.025	0.0	.000	.000	.000	.000	0.0	.000	.000	.000	.000
23	305.0	.191	.010	.671	.011	295.6	.161	.018	.627	.023	0.0	.000	.000	.000	.000	0.0	.000	.000	.000	.000
24	312.5	.187	.014	.666	.020	306.3	.166	.013	.641	.015	0.0	.000	.000	.000	.000	0.0	.000	.000	.000	.000
25	307.8	.203	.014	.677	.016	276.4	.168	.021	.641	.026	0.0	.000	.000	.000	.000	0.0	.000	.000	.000	.000
26	299.2	.195	.013	.673	.014	253.5	.195	.023	.672	.026	0.0	.000	.000	.000	.000	0.0	.000	.000	.000	.000

SAMPLE STATISTICS FOR SIMULATION OUTPUT. ROW 1=MEAN, ROW 2=STANDARD DEVIATION, ROW 3=COEF. OF VARIATION

1	297.6	.194	.014	.672	.016	291.1	.163	.015	.630	.023	2.1	.015	.000	.052	.000	10.3	.040	.001	.166	.000
2	20.5	.009	.003	.010	.005	23.7	.015	.007	.023	.007	7.4	.053	.000	.184	.000	21.6	.067	.002	.279	.001
3	.07	.049	.218	.014	.335	.08	.093	.488	.037	.318	3.58	****	****	****	.000	2.10	****	****	****	****

STARTING AND ENDING HARVEST DATES OF ALFALFA FOR THE WHOLE SIMULATION

YR	HARVEST 1 STARTING DATE	HARVEST 1 ENDING DATE	HARVEST 1 SPAN	HARVEST 2 STARTING DATE	HARVEST 2 ENDING DATE	HARVEST 2 SPAN	HARVEST 3 STARTING DATE	HARVEST 3 ENDING DATE	HARVEST 3 SPAN	HARVEST 4 STARTING DATE	HARVEST 4 ENDING DATE	HARVEST 4 SPAN
1	148.	164.	16.	194.	206.	12.	237.	244.	7.	0.	0.	0.
2	146.	163.	17.	195.	207.	12.	239.	248.	9.	0.	0.	0.
3	145.	166.	21.	196.	207.	11.	242.	252.	10.	0.	0.	0.
4	151.	163.	12.	194.	206.	12.	235.	244.	9.	0.	0.	0.
5	149.	163.	14.	192.	205.	13.	233.	241.	8.	0.	0.	0.
6	155.	179.	24.	196.	207.	11.	242.	249.	7.	0.	0.	0.
7	145.	160.	15.	189.	199.	10.	235.	244.	9.	0.	0.	0.
8	145.	160.	15.	187.	198.	11.	233.	243.	10.	0.	0.	0.
9	145.	163.	18.	196.	207.	11.	242.	250.	8.	0.	0.	0.
10	145.	160.	15.	187.	197.	10.	242.	249.	7.	0.	0.	0.
11	145.	163.	18.	192.	206.	14.	242.	252.	10.	0.	0.	0.
12	146.	164.	18.	196.	207.	11.	242.	250.	8.	0.	0.	0.
13	145.	164.	19.	196.	205.	9.	242.	254.	12.	0.	0.	0.
14	145.	157.	12.	188.	200.	12.	242.	249.	7.	0.	0.	0.
15	145.	162.	17.	190.	204.	14.	242.	250.	8.	0.	0.	0.
16	145.	166.	21.	192.	202.	10.	233.	242.	9.	0.	0.	0.
17	145.	165.	20.	190.	203.	13.	233.	240.	7.	0.	0.	0.
18	150.	167.	17.	195.	208.	13.	235.	248.	13.	0.	0.	0.
19	145.	163.	18.	196.	207.	11.	242.	250.	8.	0.	0.	0.
20	145.	162.	17.	196.	207.	11.	242.	252.	10.	0.	0.	0.
21	147.	168.	21.	196.	206.	10.	239.	246.	7.	0.	0.	0.
22	145.	161.	16.	191.	201.	10.	242.	251.	9.	0.	0.	0.
23	146.	165.	19.	196.	208.	12.	242.	255.	13.	0.	0.	0.
24	146.	161.	15.	191.	202.	11.	233.	240.	7.	0.	0.	0.
25	145.	161.	16.	196.	208.	12.	242.	251.	9.	0.	0.	0.
26	149.	163.	14.	196.	208.	12.	242.	249.	7.	0.	0.	0.

SAMPLE STATISTICS FOR SIMULATION OUTPUT. ROW 1=MEAN, ROW 2=STANDARD DEVIATION, ROW 3=COEF. OF VARIATION

1	146.46	163.58	17.12	193.19	204.65	11.46	239.04	247.81	8.77	0.00	0.00	0.00
2	2.49	3.97	2.86	3.16	3.33	1.27	3.83	4.29	1.80	0.00	0.00	0.00
3	.02	.02	.17	.02	.02	.11	.02	.02	.20	0.00	0.00	0.00

THE AVERAGE NUMBER OF DAYS ALFALFA WAS FIELD CURING BEFORE GOING INTO STORAGE

YR	FIRST SILO			SECOND SILO			HIGH QUALITY HAY			LOW QUALITY HAY		
	PLOTS	DAYS	S(DAY)	PLOTS	DAYS	S(DAY)	PLOTS	DAYS	S(DAY)	PLOTS	DAYS	S(DAY)
1	15.	2.80	1.265	15.	2.73	1.033	0.	0.00	0.000	0.	0.00	0.000
2	14.	2.71	1.590	15.	3.13	1.060	0.	0.00	0.000	1.	5.00	0.000
3	17.	2.29	1.105	13.	3.85	1.864	2.	3.00	0.000	0.	0.00	0.000
4	15.	2.93	1.280	15.	3.13	1.187	0.	0.00	0.000	0.	0.00	0.000
5	15.	2.40	1.121	15.	3.13	1.060	0.	0.00	0.000	0.	0.00	0.000
6	18.	2.61	1.243	13.	3.15	.987	0.	0.00	0.000	0.	0.00	0.000
7	16.	2.63	1.204	14.	2.86	.949	0.	0.00	0.000	1.	4.00	0.000
8	15.	2.60	1.121	14.	2.57	1.089	0.	0.00	0.000	1.	3.00	0.000
9	18.	2.61	1.378	10.	3.50	1.434	0.	0.00	0.000	0.	0.00	0.000
10	15.	2.40	1.121	15.	2.47	.915	0.	0.00	0.000	0.	0.00	0.000
11	16.	3.00	1.155	14.	2.64	1.082	0.	0.00	0.000	1.	2.00	0.000
12	18.	2.11	.900	13.	2.92	.862	0.	0.00	0.000	0.	0.00	0.000
13	17.	2.65	1.272	12.	3.17	1.030	0.	0.00	0.000	0.	0.00	0.000
14	15.	3.20	1.474	14.	2.43	1.158	0.	0.00	0.000	0.	0.00	0.000
15	16.	2.81	1.167	13.	3.69	1.548	0.	0.00	0.000	0.	0.00	0.000
16	15.	2.40	1.121	13.	4.15	2.794	0.	0.00	0.000	4.	4.50	1.291
17	16.	2.25	1.125	13.	4.31	1.843	0.	0.00	0.000	2.	3.50	.707
18	15.	2.93	1.280	13.	2.46	1.127	0.	0.00	0.000	4.	6.00	2.160
19	17.	2.35	.996	12.	3.33	1.497	0.	0.00	0.000	0.	0.00	0.000
20	15.	2.40	1.121	14.	3.29	1.204	0.	0.00	0.000	0.	0.00	0.000
21	14.	2.07	.997	14.	2.64	1.082	2.	3.50	.707	0.	0.00	0.000
22	15.	2.47	1.060	14.	2.50	1.092	0.	0.00	0.000	0.	0.00	0.000
23	15.	3.00	1.414	14.	3.86	1.562	0.	0.00	0.000	0.	0.00	0.000
24	15.	2.80	1.373	15.	3.13	1.685	0.	0.00	0.000	0.	0.00	0.000
25	17.	2.82	1.286	13.	3.00	1.000	0.	0.00	0.000	0.	0.00	0.000
26	15.	3.07	1.438	14.	2.43	1.016	0.	0.00	0.000	0.	0.00	0.000

SAMPLE STATISTICS FOR SIMULATION OUTPUT. ROW 1=MEAN, ROW 2=STANDARD DEVIATION, ROW 3=COEF. OF VARIATION

1	15.73	2.628	1.216	13.62	3.096	1.275	.15	.250	.027	.54	1.077	.160
2	1.19	.301	.162	1.17	.541	.420	.54	.886	.139	1.14	1.922	.497
3	.08	.115	.133	.09	.175	.329	3.53	3.544	5.099	2.12	1.785	3.106

CORN SIMULATION OUTPUT: SECTION (1).
SUMMARY OUTPUT FOR 26 SIMULATION YEARS. MATRIX YCORN.
EACH ROW REPRESENTS ONE SIMULATION YEAR. COLUMNS REPRESENT:
1=JFNPLT 2=JFNALF 3=JBGHRV 4=JFNHRV 5=HAPLTD 6=HACS 7=HAHMC 8=HACG 9=HACORN 10=DMCS 11=DMHMC 12=DMCG 13=CSYLD 14=HMCYLD 15=CGYLD 16=WTR

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	132.00	244.00	245.00	288.00	83.30	20.08	40.05	23.17	83.30	296.02	269.26	148.20	14.74	6.72	6.40	25.12
2	138.00	248.00	249.00	313.00	83.30	25.26	49.01	9.02	83.30	296.02	269.26	44.03	11.72	5.49	4.88	6.60
3	131.00	252.00	253.00	302.00	83.30	25.01	46.23	12.06	83.30	296.02	269.26	65.41	11.83	5.82	5.42	10.98
4	132.00	244.00	245.00	294.00	83.30	20.52	46.83	15.94	83.30	296.02	269.26	86.69	14.42	5.75	5.44	14.82
5	134.00	241.00	244.00	296.00	83.30	25.15	53.19	4.96	83.30	296.02	269.26	20.76	11.77	5.06	4.19	3.87
6	153.00	249.00	250.00	314.00	83.30	24.87	46.87	11.56	83.30	296.02	269.26	56.24	11.90	5.74	4.86	11.63
7	135.00	244.00	245.00	290.00	83.30	20.67	43.26	19.37	83.30	296.02	269.26	116.61	14.32	6.22	6.02	20.53
8	136.00	243.00	244.00	303.00	83.30	25.07	55.57	2.65	83.30	296.02	269.26	10.31	11.81	4.85	3.89	1.92
9	134.00	250.00	251.00	314.00	83.30	21.27	39.30	22.73	83.30	296.02	269.26	135.28	13.92	6.85	5.95	18.96
10	138.00	249.00	250.00	291.00	83.30	22.86	44.95	15.49	83.30	296.02	269.26	89.82	12.95	5.99	5.80	17.67
11	130.00	252.00	253.00	294.00	83.30	24.20	47.91	11.19	83.30	296.02	269.26	60.68	12.23	5.62	5.42	10.19
12	144.00	250.00	251.00	311.00	83.30	19.94	47.35	16.01	83.30	296.02	269.26	75.41	14.84	5.69	4.71	14.52
13	136.00	254.00	255.00	308.00	83.30	22.10	46.46	14.73	83.30	296.02	269.26	74.33	13.39	5.80	5.04	11.05
14	133.00	249.00	250.00	302.00	83.30	21.20	47.87	14.23	83.30	296.02	269.26	68.79	13.96	5.62	4.84	12.09
15	141.00	250.00	251.00	300.00	83.30	24.93	52.48	5.90	83.30	296.02	269.26	27.74	11.88	5.13	4.71	5.17
16	132.00	242.00	244.00	295.00	83.30	25.19	52.17	5.93	83.30	296.02	269.26	27.49	11.75	5.16	4.63	4.72
17	133.00	240.00	244.00	293.00	83.30	23.39	44.99	14.92	83.30	296.02	269.26	81.23	12.66	5.99	5.44	14.20
18	148.00	248.00	249.00	299.00	83.30	25.23	49.77	8.30	83.30	296.02	269.26	41.06	11.73	5.41	4.94	10.06
19	142.00	250.00	251.00	299.00	83.30	21.27	45.89	16.14	83.30	296.02	269.26	82.69	13.92	5.87	5.12	15.81
20	137.00	252.00	253.00	313.00	83.30	23.67	47.28	12.35	83.30	296.02	269.26	57.49	12.51	5.69	4.65	8.62
21	145.00	246.00	247.00	335.00	83.30	22.91	48.90	0.00	71.81	296.02	218.68	0.00	12.92	4.47	0.00	0.00
22	136.00	251.00	252.00	309.00	83.30	24.45	53.82	5.04	83.30	296.02	269.26	20.80	12.11	5.00	4.13	3.12
23	130.00	255.00	256.00	288.00	83.30	20.46	38.84	23.99	83.30	296.02	269.26	158.59	14.47	6.93	6.61	26.63
24	133.00	240.00	244.00	291.00	83.30	22.67	41.74	18.88	83.30	296.02	269.26	116.55	13.06	6.45	6.17	20.33
25	135.00	251.00	252.00	311.00	83.30	19.50	39.48	24.32	83.30	296.02	269.26	147.45	15.18	6.82	6.06	22.80
26	140.00	249.00	250.00	307.00	83.30	24.58	58.72	0.00	83.30	296.02	264.20	0.00	12.04	4.50	0.00	0.00

SAMPLE STATISTICS FOR SIMULATION RUN: ROWS 1=MEAN 2=STANDARD DEVIATION 3=COEF OF VARIATION

1	136.85	247.81	249.15	302.31	83.30	22.94	47.27	12.65	82.86	296.02	267.12	69.76	13.00	5.72	4.82	11.98
2	5.75	4.29	3.73	10.92	.00	2.00	5.10	7.15	2.25	.00	9.93	46.19	1.17	.68	1.58	7.60
3	.04	.02	.01	.04	.00	.09	.11	.57	.03	.00	.04	.66	.09	.12	.33	.63

MATRIX YCORN (CONTINUED):
17=CSFEED 18=HMCFEED 19=CGSELL

	17	18	19
1	253.10	248.12	148.20
2	253.10	248.12	44.03
3	253.10	248.12	65.41
4	253.10	248.12	86.69
5	253.10	248.12	20.76
6	253.10	248.12	56.24
7	253.10	248.12	116.61
8	253.10	248.12	10.31
9	253.10	248.12	135.28
10	253.10	248.12	89.82
11	253.10	248.12	60.68
12	253.10	248.12	75.41
13	253.10	248.12	74.33
14	253.10	248.12	68.79
15	253.10	248.12	27.74
16	253.10	248.12	27.49
17	253.10	248.12	81.23
18	253.10	248.12	41.06
19	253.10	248.12	82.69
20	253.10	248.12	57.49
21	253.10	201.52	0.00
22	253.10	248.12	20.80
23	253.10	248.12	158.59
24	253.10	248.12	116.55
25	253.10	248.12	147.45
26	253.10	243.46	0.00

SAMPLE STATISTICS FOR SIMULATION RUN: ROWS 1=MEAN 2=STANDARD DEVIATION 3=COEF OF VARIATION

1	253.10	246.15	69.76
2	.00	9.15	46.19
3	.00	.04	.66

CORN SIMULATION OUTPUT: SECTION (2).
SUMMARY OUTPUT FOR 26 SIMULATION YEARS. MATRIX CCOST.
EACH ROW REPRESENTS ONE SIMULATION YEAR. COLUMNS REPRESENT:
1=RM$ 2=FUEL$ 3=LABR1$ 4=LABR2$ 5=FUEL(L) 6=LABR1 7=LABR2 8=CUSTOM$ 9=CGDRY$ 10=CRNFSC$ 11=MCHINV$ 12=STGINV$ 13=FCM$ 14=FCSTG$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1561.	1043.	2164.	414.	3489.	433.	83.	8231.	2478.	16836.	16080.	54030.	2729.	4227.
2	1736.	1176.	2413.	414.	3933.	483.	83.	7280.	651.	16836.	16080.	54030.	2729.	4227.
3	1682.	1135.	2336.	414.	3795.	467.	83.	7484.	1083.	16836.	16080.	54030.	2729.	4227.
4	1694.	1144.	2353.	414.	3825.	471.	83.	7745.	1462.	16836.	16080.	54030.	2729.	4227.
5	1818.	1238.	2529.	414.	4140.	506.	83.	7007.	382.	16836.	16080.	54030.	2729.	4227.
6	1695.	1144.	2354.	414.	3827.	471.	83.	7450.	1147.	16836.	16080.	54030.	2729.	4227.
7	1624.	1091.	2253.	414.	3648.	451.	83.	7975.	2025.	16836.	16080.	54030.	2729.	4227.
8	1865.	1273.	2595.	414.	4257.	519.	83.	6851.	190.	16836.	16080.	54030.	2729.	4227.
9	1546.	1032.	2143.	414.	3452.	429.	83.	8201.	1870.	16836.	16080.	54030.	2729.	4227.
10	1657.	1116.	2300.	414.	3732.	460.	83.	7714.	1743.	16836.	16080.	54030.	2729.	4227.
11	1715.	1160.	2383.	414.	3878.	477.	83.	7426.	1005.	16836.	16080.	54030.	2729.	4227.
12	1704.	1151.	2367.	414.	3851.	473.	83.	7749.	1432.	16836.	16080.	54030.	2729.	4227.
13	1686.	1138.	2342.	414.	3807.	468.	83.	7664.	1090.	16836.	16080.	54030.	2729.	4227.
14	1714.	1159.	2382.	414.	3876.	476.	83.	7629.	1193.	16836.	16080.	54030.	2729.	4227.
15	1804.	1227.	2510.	414.	4104.	502.	83.	7069.	510.	16836.	16080.	54030.	2729.	4227.
16	1798.	1223.	2501.	414.	4089.	500.	83.	7072.	465.	16836.	16080.	54030.	2729.	4227.
17	1658.	1116.	2301.	414.	3734.	460.	83.	7676.	1401.	16836.	16080.	54030.	2729.	4227.
18	1751.	1187.	2434.	414.	3970.	487.	83.	7231.	993.	16836.	16080.	54030.	2729.	4227.
19	1675.	1130.	2326.	414.	3778.	465.	83.	7758.	1560.	16836.	16080.	54030.	2729.	4227.
20	1703.	1150.	2365.	414.	3847.	473.	83.	7503.	850.	16836.	16080.	54030.	2729.	4227.
21	1729.	1169.	2410.	337.	3908.	482.	67.	6673.	0.	16836.	16080.	54030.	2729.	4227.
22	1830.	1247.	2547.	414.	4171.	509.	83.	7012.	308.	16836.	16080.	54030.	2729.	4227.
23	1538.	1025.	2131.	414.	3430.	426.	83.	8286.	2627.	16836.	16080.	54030.	2729.	4227.
24	1594.	1068.	2211.	414.	3573.	442.	83.	7943.	2005.	16836.	16080.	54030.	2729.	4227.
25	1550.	1035.	2148.	414.	3461.	430.	83.	8308.	2249.	16836.	16080.	54030.	2729.	4227.
26	1926.	1319.	2683.	407.	4411.	537.	81.	6673.	0.	16836.	16080.	54030.	2729.	4227.

SAMPLE STATISTICS FOR SIMULATION RUN: ROWS 1=MEAN 2=STANDARD DEVIATION 3=COEF OF VARIATION

1	1702.	1150.	2365.	411.	3846.	473.	82.	7524.	1181.	16836.	16080.	54030.	2729.	4227.
2	100.	75.	142.	15.	252.	28.	3.	481.	749.	0.	0.	0.	0.	0.
3	.06	.07	.06	.04	.07	.06	.04	.06	.63	.00	0.00	0.00	.00	.00

SUMMARY OUTPUT FOR 26 SIMULATION YEARS: FEED UTILIZATION SUBCOMPONENT.

INPUT VALUES READ INTO SUBROUTINE COWMOD:
NUMBER OF MILKING COWS (LACTATING + DRY)= 120.0
AVERAGE MILK/COW/YR, CWT= 180.0
RATION FED TO LACTATING COWS= 2
MILK PRICE RECEIVED, $/CWT= 13.00

PRICES OF FEEDS:	1=CS($/DMT)	2=HMC($/DMT)	3=ALF($/DMT)	4=CPALF($/DMT)	5=SBM($/DMT)	6=NPN($/DMT)	7=CGSELL($/DMT)
FEEDS SOLD=	61.07	111.84	60.00	671.50	335.65	308.70	132.80
FEEDS PURCHASED=	76.34	139.80	75.00	671.50	335.65	308.70	139.80

(1) ANNUAL FEED REQUIREMENTS (DMT) FOR 120.0 COWS.

1=CS	2=HMC	3=ALF	4=CPALF	5=SBM	6=NPN
253.10	248.12	591.86	89.98	17.83	2.77

(1) ANNUAL FEED REQUIREMENTS PER COW,DMT.

1=CS	2=HMC	3=ALF	4=CPALF	5=SBM	6=NPN
2.11	2.07	4.93	.75	.15	.02

(2) ANNUAL FEED PRODUCED (DMT) FOR 120.0 COWS.

1	253.10	248.12	604.95	109.70	0.00	0.00
2	253.10	248.12	621.80	109.05	0.00	0.00
3	253.10	248.12	620.02	106.54	0.00	0.00
4	253.10	248.12	589.54	107.30	0.00	0.00
5	253.10	248.12	628.47	110.62	0.00	0.00
6	253.10	248.12	574.53	100.24	0.00	0.00
7	253.10	248.12	630.79	110.89	0.00	0.00
8	253.10	248.12	647.62	107.81	0.00	0.00
9	253.10	248.12	519.89	99.42	0.00	0.00
10	253.10	248.12	557.38	104.77	0.00	0.00
11	253.10	248.12	635.43	109.17	0.00	0.00
12	253.10	248.12	612.53	107.67	0.00	0.00
13	253.10	248.12	522.27	92.66	0.00	0.00
14	253.10	248.12	564.42	106.02	0.00	0.00
15	253.10	248.12	597.14	104.37	0.00	0.00
16	253.10	248.12	681.56	111.63	0.00	0.00
17	253.10	248.12	663.44	110.14	0.00	0.00
18	253.10	248.12	685.51	112.82	0.00	0.00
19	253.10	248.12	515.43	93.45	0.00	0.00
20	253.10	248.12	586.81	108.02	0.00	0.00
21	253.10	201.52	635.78	114.76	0.00	0.00
22	253.10	248.12	575.01	108.70	0.00	0.00
23	253.10	248.12	600.61	105.91	0.00	0.00
24	253.10	248.12	618.80	109.26	0.00	0.00
25	253.10	248.12	584.21	109.01	0.00	0.00
26	253.10	243.46	552.69	107.85	0.00	0.00

(2) ANNUAL FEED PRODUCED PER COW,DMT.

1	2.11	2.07	5.04	.91	0.00	0.00
2	2.11	2.07	5.18	.91	0.00	0.00
3	2.11	2.07	5.17	.89	0.00	0.00
4	2.11	2.07	4.91	.89	0.00	0.00
5	2.11	2.07	5.24	.92	0.00	0.00
6	2.11	2.07	4.79	.84	0.00	0.00
7	2.11	2.07	5.26	.92	0.00	0.00
8	2.11	2.07	5.40	.90	0.00	0.00
9	2.11	2.07	4.33	.83	0.00	0.00
10	2.11	2.07	4.64	.87	0.00	0.00
11	2.11	2.07	5.30	.91	0.00	0.00
12	2.11	2.07	5.10	.90	0.00	0.00
13	2.11	2.07	4.35	.77	0.00	0.00
14	2.11	2.07	4.70	.88	0.00	0.00
15	2.11	2.07	4.98	.87	0.00	0.00
16	2.11	2.07	5.68	.93	0.00	0.00
17	2.11	2.07	5.53	.92	0.00	0.00
18	2.11	2.07	5.71	.94	0.00	0.00
19	2.11	2.07	4.30	.78	0.00	0.00
20	2.11	2.07	4.89	.90	0.00	0.00
21	2.11	1.68	5.30	.96	0.00	0.00
22	2.11	2.07	4.79	.91	0.00	0.00
23	2.11	2.07	5.01	.88	0.00	0.00
24	2.11	2.07	5.16	.91	0.00	0.00
25	2.11	2.07	4.87	.91	0.00	0.00
26	2.11	2.03	4.61	.90	0.00	0.00

SUMMARY OUTPUT FOR 26 SIMULATION YEARS: FEED UTILIZATION SUBCOMPONENT.

(3) ANNUAL FEED SURPLUS/DEFECIT PER 120.0 COWS.DMT.

	1=CS	2=HMC	3=ALF	4=CPALF	5=SBM	6=NPN
1	-.01	-.00	13.08	19.72	-17.83	-2.77
2	-.01	-.00	29.94	19.08	-17.83	-2.77
3	-.01	-.00	28.15	16.57	-17.83	-2.77
4	-.01	-.00	-2.32	17.32	-17.83	-2.77
5	-.01	-.00	36.61	20.65	-17.83	-2.77
6	-.01	-.00	-17.34	10.26	-17.83	-2.77
7	-.01	-.00	38.92	20.91	-17.83	-2.77
8	-.01	-.00	55.75	17.83	-17.83	-2.77
9	-.01	-.00	-71.98	9.45	-17.83	-2.77
10	-.01	-.00	-34.48	14.80	-17.83	-2.77
11	-.01	-.00	43.57	19.19	-17.83	-2.77
12	-.01	-.00	20.67	17.70	-17.83	-2.77
13	-.01	-.00	-69.59	2.68	-17.83	-2.77
14	-.01	-.00	-27.45	16.04	-17.83	-2.77
15	-.01	-.00	5.28	14.39	-17.83	-2.77
16	-.01	-.00	89.70	21.65	-17.83	-2.77
17	-.01	-.00	71.58	20.16	-17.83	-2.77
18	-.01	-.00	93.65	22.84	-17.83	-2.77
19	-.01	-.00	-76.43	3.48	-17.83	-2.77
20	-.01	-.00	-5.05	18.05	-17.83	-2.77
21	-.01	-46.61	43.92	24.79	-17.83	-2.77
22	-.01	-.00	-16.86	18.72	-17.83	-2.77
23	-.01	-.00	8.74	15.93	-17.83	-2.77
24	-.01	-.00	26.94	19.29	-17.83	-2.77
25	-.01	-.00	-7.65	19.03	-17.83	-2.77
26	-.01	-4.67	-39.17	17.87	-17.83	-2.77

(3) ANNUAL SURPLUS/DEFECIT PER COW.DMT.

	1=CS	2=HMC	3=ALF	4=CPALF	5=SBM	6=NPN
1	-.00	-.00	.11	.16	-.15	-.02
2	-.00	-.00	.25	.16	-.15	-.02
3	-.00	-.00	.23	.14	-.15	-.02
4	-.00	-.00	-.02	.14	-.15	-.02
5	-.00	-.00	.31	.17	-.15	-.02
6	-.00	-.00	-.14	.09	-.15	-.02
7	-.00	-.00	.32	.17	-.15	-.02
8	-.00	-.00	.46	.15	-.15	-.02
9	-.00	-.00	-.60	.08	-.15	-.02
10	-.00	-.00	-.29	.12	-.15	-.02
11	-.00	-.00	.36	.16	-.15	-.02
12	-.00	-.00	.17	.15	-.15	-.02
13	-.00	-.00	-.58	.02	-.15	-.02
14	-.00	-.00	-.23	.13	-.15	-.02
15	-.00	-.00	.04	.12	-.15	-.02
16	-.00	-.00	.75	.18	-.15	-.02
17	-.00	-.00	.60	.17	-.15	-.02
18	-.00	-.00	.78	.19	-.15	-.02
19	-.00	-.00	-.64	.03	-.15	-.02
20	-.00	-.00	-.04	.15	-.15	-.02
21	-.00	-.39	.37	.21	-.15	-.02
22	-.00	-.00	-.14	.16	-.15	-.02
23	-.00	-.00	.07	.13	-.15	-.02
24	-.00	-.00	.22	.16	-.15	-.02
25	-.00	-.00	-.06	.16	-.15	-.02
26	-.00	-.04	-.33	.15	-.15	-.02

SUMMARY OUTPUT FOR 26 SIMULATION YEARS: FEED UTILIZATION SUBCOMPONENT.

(4) GROSS AND NET COSTS/RETURNS FOR FEED FOR 120.0 COWS,$/YR.

	1=CS	2=HMC	3=ALF	4=CPALF	5=SBM	6=NPN	7=SUM(1-6)
1	-1.	-0.	785.	0.	-5985.	-856.	-6057.
2	-1.	-0.	1796.	0.	-5985.	-856.	-5045.
3	-1.	-0.	1689.	0.	-5985.	-856.	-5153.
4	-1.	-0.	-174.	0.	-5985.	-856.	-7016.
5	-1.	-0.	2196.	0.	-5985.	-856.	-4645.
6	-1.	-0.	-1300.	0.	-5985.	-855.	-8142.
7	-1.	-0.	2335.	0.	-5985.	-856.	-4506.
8	-1.	-0.	3345.	0.	-5985.	-856.	-3496.
9	-1.	-0.	-5398.	0.	-5985.	-856.	-12240.
10	-1.	-0.	-2586.	0.	-5985.	-856.	-9428.
11	-1.	-0.	2614.	0.	-5985.	-856.	-4228.
12	-1.	-0.	1240.	0.	-5985.	-856.	-5602.
13	-1.	-0.	-5219.	0.	-5985.	-856.	-12061.
14	-1.	-0.	-2059.	0.	-5985.	-856.	-8900.
15	-1.	-0.	317.	0.	-5985.	-856.	-6525.
16	-1.	-0.	5382.	0.	-5985.	-856.	-1460.
17	-1.	-0.	4295.	0.	-5985.	-856.	-2547.
18	-1.	-0.	5619.	0.	-5985.	-856.	-1223.
19	-1.	-0.	-5733.	0.	-5985.	-856.	-12574.
20	-1.	-0.	-379.	0.	-5985.	-856.	-7220.
21	-1.	-6516.	2635.	0.	-5985.	-856.	-10722.
22	-1.	-0.	-1264.	0.	-5985.	-856.	-8106.
23	-1.	-0.	525.	0.	-5985.	-856.	-6317.
24	-1.	-0.	1616.	0.	-5985.	-856.	-5225.
25	-1.	-0.	-574.	0.	-5985.	-856.	-7416.
26	-1.	-652.	-2938.	0.	-5985.	-856.	-10431.

(4) GROSS AND NET COSTS/RETURNS PER COW.$/YR.

	1=CS	2=HMC	3=ALF	4=CPALF	5=SBM	6=NPN	7=SUM(1-6)
1	-0.	-0.	7.	0.	-50.	-7.	-50.
2	-0.	-0.	15.	0.	-50.	-7.	-42.
3	-0.	-0.	14.	0.	-50.	-7.	-43.
4	-0.	-0.	-1.	0.	-50.	-7.	-58.
5	-0.	-0.	18.	0.	-50.	-7.	-39.
6	-0.	-0.	-11.	0.	-50.	-7.	-68.
7	-0.	-0.	19.	0.	-50.	-7.	-38.
8	-0.	-0.	28.	0.	-50.	-7.	-29.
9	-0.	-0.	-45.	0.	-50.	-7.	-102.
10	-0.	-0.	-22.	0.	-50.	-7.	-79.
11	-0.	-0.	22.	0.	-50.	-7.	-35.
12	-0.	-0.	10.	0.	-50.	-7.	-47.
13	-0.	-0.	-43.	0.	-50.	-7.	-101.
14	-0.	-0.	-17.	0.	-50.	-7.	-74.
15	-0.	-0.	3.	0.	-50.	-7.	-54.
16	-0.	-0.	45.	0.	-50.	-7.	-12.
17	-0.	-0.	36.	0.	-50.	-7.	-21.
18	-0.	-0.	47.	0.	-50.	-7.	-10.
19	-0.	-0.	-48.	0.	-50.	-7.	-105.
20	-0.	-0.	-3.	0.	-50.	-7.	-60.
21	-0.	-54.	22.	0.	-50.	-7.	-89.
22	-0.	-0.	-11.	0.	-50.	-7.	-68.
23	-0.	-0.	4.	0.	-50.	-7.	-53.
24	-0.	-0.	13.	0.	-50.	-7.	-44.
25	-0.	-0.	-5.	0.	-50.	-7.	-62.
26	-0.	-5.	-24.	0.	-50.	-7.	-87.

SUMMARY OUTPUT FOR 26 SIMULATION YEARS: FEED UTILIZATION SUBCOMPONENT.

(4) GROSS AND NET COSTS/RETURNS FOR FEED FOR 120.0 COWS,$/YR.

	1=CS	2=HMC	3=ALF	4=CPALF	5=SBM	6=NPN	7=SUM(1-6)
1	-1.	-0.	785.	0.	-5985.	-856.	-6057.
2	-1.	-0.	1796.	0.	-5985.	-856.	-5045.
3	-1.	-0.	1689.	0.	-5985.	-856.	-5153.
4	-1.	-0.	-174.	0.	-5985.	-856.	-7016.
5	-1.	-0.	2196.	0.	-5985.	-856.	-4645.
6	-1.	-0.	-1300.	0.	-5985.	-855.	-8142.
7	-1.	-0.	2335.	0.	-5985.	-856.	-4506.
8	-1.	-0.	3345.	0.	-5985.	-856.	-3496.
9	-1.	-0.	-5398.	0.	-5985.	-856.	-12240.
10	-1.	-0.	-2586.	0.	-5985.	-856.	-9428.
11	-1.	-0.	2614.	0.	-5985.	-856.	-4228.
12	-1.	-0.	1240.	0.	-5985.	-856.	-5602.
13	-1.	-0.	-5219.	0.	-5985.	-856.	-12061.
14	-1.	-0.	-2059.	0.	-5985.	-856.	-8900.
15	-1.	-0.	317.	0.	-5985.	-856.	-6525.
16	-1.	-0.	5382.	0.	-5985.	-856.	-1460.
17	-1.	-0.	4295.	0.	-5985.	-856.	-2547.
18	-1.	-0.	5619.	0.	-5985.	-856.	-1223.
19	-1.	-0.	-5733.	0.	-5985.	-856.	-12574.
20	-1.	-0.	-379.	0.	-5985.	-856.	-7220.
21	-1.	-6516.	2635.	0.	-5985.	-856.	-10722.
22	-1.	-0.	-1264.	0.	-5985.	-856.	-8106.
23	-1.	-0.	525.	0.	-5985.	-856.	-6317.
24	-1.	-0.	1616.	0.	-5985.	-856.	-5225.
25	-1.	-0.	-574.	0.	-5985.	-856.	-7416.
26	-1.	-652.	-2938.	0.	-5985.	-856.	-10431.

(4) GROSS AND NET COSTS/RETURNS PER COW,$/YR.

	1=CS	2=HMC	3=ALF	4=CPALF	5=SBM	6=NPN	7=SUM(1-6)
1	-0.	-0.	7.	0.	-50.	-7.	-50.
2	-0.	-0.	15.	0.	-50.	-7.	-42.
3	-0.	-0.	14.	0.	-50.	-7.	-43.
4	-0.	-0.	-1.	0.	-50.	-7.	-58.
5	-0.	-0.	18.	0.	-50.	-7.	-39.
6	-0.	-0.	-11.	0.	-50.	-7.	-68.
7	-0.	-0.	19.	0.	-50.	-7.	-38.
8	-0.	-0.	28.	0.	-50.	-7.	-29.
9	-0.	-0.	-45.	0.	-50.	-7.	-102.
10	-0.	-0.	-22.	0.	-50.	-7.	-79.
11	-0.	-0.	22.	0.	-50.	-7.	-35.
12	-0.	-0.	10.	0.	-50.	-7.	-47.
13	-0.	-0.	-43.	0.	-50.	-7.	-101.
14	-0.	-0.	-17.	0.	-50.	-7.	-74.
15	-0.	-0.	3.	0.	-50.	-7.	-54.
16	-0.	-0.	45.	0.	-50.	-7.	-12.
17	-0.	-0.	36.	0.	-50.	-7.	-21.
18	-0.	-0.	47.	0.	-50.	-7.	-10.
19	-0.	-0.	-48.	0.	-50.	-7.	-105.
20	-0.	-0.	-3.	0.	-50.	-7.	-60.
21	-0.	-54.	22.	0.	-50.	-7.	-89.
22	-0.	-0.	-11.	0.	-50.	-7.	-68.
23	-0.	-0.	4.	0.	-50.	-7.	-53.
24	-0.	-0.	13.	0.	-50.	-7.	-44.
25	-0.	-0.	-5.	0.	-50.	-7.	-62.
26	-0.	-5.	-24.	0.	-50.	-7.	-87.

SUMMARY OUTPUT FOR 26 SIMULATION YEARS: FEED UTILIZATION SUBCOMPONENT.

(4) GROSS AND NET COSTS/RETURNS FOR FEED FOR 120.0 COWS,$/YR.

	1=CS	2=HMC	3=ALF	4=CPALF	5=SBM	6=NPN	7=SUM(1-6)
1	-1.	-0.	785.	0.	-5985.	-856.	-6057.
2	-1.	-0.	1796.	0.	-5985.	-856.	-5045.
3	-1.	-0.	1689.	0.	-5985.	-856.	-5153.
4	-1.	-0.	-174.	0.	-5985.	-856.	-7016.
5	-1.	-0.	2196.	0.	-5985.	-856.	-4645.
6	-1.	-0.	-1300.	0.	-5985.	-856.	-8142.
7	-1.	-0.	2335.	0.	-5985.	-856.	-4506.
8	-1.	-0.	3345.	0.	-5985.	-856.	-3496.
9	-1.	-0.	-5398.	0.	-5985.	-856.	-12240.
10	-1.	-0.	-2586.	0.	-5985.	-856.	-9428.
11	-1.	-0.	2614.	0.	-5985.	-856.	-4228.
12	-1.	-0.	1240.	0.	-5985.	-856.	-5602.
13	-1.	-0.	-5219.	0.	-5985.	-856.	-12061.
14	-1.	-0.	-2059.	0.	-5985.	-856.	-8900.
15	-1.	-0.	317.	0.	-5985.	-856.	-6525.
16	-1.	-0.	5382.	0.	-5985.	-856.	-1460.
17	-1.	-0.	4295.	0.	-5985.	-856.	-2547.
18	-1.	-0.	5619.	0.	-5985.	-856.	-1223.
19	-1.	-0.	-5733.	0.	-5985.	-856.	-12574.
20	-1.	-0.	-379.	0.	-5985.	-856.	-7220.
21	-1.	-6516.	2635.	0.	-5985.	-856.	-10722.
22	-1.	-0.	-1264.	0.	-5985.	-856.	-8106.
23	-1.	-0.	525.	0.	-5985.	-856.	-6317.
24	-1.	-0.	1616.	0.	-5985.	-856.	-5225.
25	-1.	-0.	-574.	0.	-5985.	-856.	-7416.
26	-1.	-652.	-2938.	0.	-5985.	-856.	-10431.

(4) GROSS AND NET COSTS/RETURNS PER COW,$/YR.

	1=CS	2=HMC	3=ALF	4=CPALF	5=SBM	6=NPN	7=SUM(1-6)
1	-0.	-0.	7.	0.	-50.	-7.	-50.
2	-0.	-0.	15.	0.	-50.	-7.	-42.
3	-0.	-0.	14.	0.	-50.	-7.	-43.
4	-0.	-0.	-1.	0.	-50.	-7.	-58.
5	-0.	-0.	18.	0.	-50.	-7.	-39.
6	-0.	-0.	-11.	0.	-50.	-7.	-68.
7	-0.	-0.	19.	0.	-50.	-7.	-38.
8	-0.	-0.	28.	0.	-50.	-7.	-29.
9	-0.	-0.	-45.	0.	-50.	-7.	-102.
10	-0.	-0.	-22.	0.	-50.	-7.	-79.
11	-0.	-0.	22.	0.	-50.	-7.	-35.
12	-0.	-0.	10.	0.	-50.	-7.	-47.
13	-0.	-0.	-43.	0.	-50.	-7.	-101.
14	-0.	-0.	-17.	0.	-50.	-7.	-74.
15	-0.	-0.	3.	0.	-50.	-7.	-54.
16	-0.	-0.	45.	0.	-50.	-7.	-12.
17	-0.	-0.	36.	0.	-50.	-7.	-21.
18	-0.	-0.	47.	0.	-50.	-7.	-10.
19	-0.	-0.	-48.	0.	-50.	-7.	-105.
20	-0.	-0.	-3.	0.	-50.	-7.	-60.
21	-0.	-54.	22.	0.	-50.	-7.	-89.
22	-0.	-0.	-11.	0.	-50.	-7.	-68.
23	-0.	-0.	4.	0.	-50.	-7.	-53.
24	-0.	-0.	13.	0.	-50.	-7.	-44.
25	-0.	-0.	-5.	0.	-50.	-7.	-62.
26	-0.	-5.	-24.	0.	-50.	-7.	-87.

SUMMARY OUTPUT FOR 26 SIMULATION YEARS: FEED UTILIZATION SUBCOMPONENT.

(4) GROSS AND NET COSTS/RETURNS FOR FEED FOR 120.0 COWS,$/YR.

	1=CS	2=HMC	3=ALF	4=CPALF	5=SBM	6=NPN	7=SUM(1-6)
1	-1.	-0.	785.	0.	-5985.	-856.	-6057.
2	-1.	-0.	1796.	0.	-5985.	-856.	-5045.
3	-1.	-0.	1689.	0.	-5985.	-856.	-5153.
4	-1.	-0.	-174.	0.	-5985.	-856.	-7016.
5	-1.	-0.	2196.	0.	-5985.	-856.	-4645.
6	-1.	-0.	-1300.	0.	-5985.	-855.	-8142.
7	-1.	-0.	2335.	0.	-5985.	-856.	-4506.
8	-1.	-0.	3345.	0.	-5985.	-856.	-3496.
9	-1.	-0.	-5398.	0.	-5985.	-856.	-12240.
10	-1.	-0.	-2586.	0.	-5985.	-856.	-9428.
11	-1.	-0.	2614.	0.	-5985.	-856.	-4228.
12	-1.	-0.	1240.	0.	-5985.	-856.	-5602.
13	-1.	-0.	-5219.	0.	-5985.	-856.	-12061.
14	-1.	-0.	-2059.	0.	-5985.	-856.	-8900.
15	-1.	-0.	317.	0.	-5985.	-856.	-6525.
16	-1.	-0.	5382.	0.	-5985.	-856.	-1460.
17	-1.	-0.	4295.	0.	-5985.	-856.	-2547.
18	-1.	-0.	5619.	0.	-5985.	-856.	-1223.
19	-1.	-0.	-5733.	0.	-5985.	-856.	-12574.
20	-1.	-0.	-379.	0.	-5985.	-856.	-7220.
21	-1.	-6516.	2635.	0.	-5985.	-856.	-10722.
22	-1.	-0.	-1264.	0.	-5985.	-856.	-8106.
23	-1.	-0.	525.	0.	-5985.	-856.	-6317.
24	-1.	-0.	1616.	0.	-5985.	-856.	-5225.
25	-1.	-0.	-574.	0.	-5985.	-856.	-7416.
26	-1.	-652.	-2938.	0.	-5985.	-856.	-10431.

(4) GROSS AND NET COSTS/RETURNS PER COW,$/YR.

	1=CS	2=HMC	3=ALF	4=CPALF	5=SBM	6=NPN	7=SUM(1-6)
1	-0.	-0.	7.	0.	-50.	-7.	-50.
2	-0.	-0.	15.	0.	-50.	-7.	-42.
3	-0.	-0.	14.	0.	-50.	-7.	-43.
4	-0.	-0.	-1.	0.	-50.	-7.	-58.
5	-0.	-0.	18.	0.	-50.	-7.	-39.
6	-0.	-0.	-11.	0.	-50.	-7.	-68.
7	-0.	-0.	19.	0.	-50.	-7.	-38.
8	-0.	-0.	28.	0.	-50.	-7.	-29.
9	-0.	-0.	-45.	0.	-50.	-7.	-102.
10	-0.	-0.	-22.	0.	-50.	-7.	-79.
11	-0.	-0.	22.	0.	-50.	-7.	-35.
12	-0.	-0.	10.	0.	-50.	-7.	-47.
13	-0.	-0.	-43.	0.	-50.	-7.	-101.
14	-0.	-0.	-17.	0.	-50.	-7.	-74.
15	-0.	-0.	3.	0.	-50.	-7.	-54.
16	-0.	-0.	45.	0.	-50.	-7.	-12.
17	-0.	-0.	36.	0.	-50.	-7.	-21.
18	-0.	-0.	47.	0.	-50.	-7.	-10.
19	-0.	-0.	-48.	0.	-50.	-7.	-105.
20	-0.	-0.	-3.	0.	-50.	-7.	-60.
21	-0.	-54.	22.	0.	-50.	-7.	-89.
22	-0.	-0.	-11.	0.	-50.	-7.	-68.
23	-0.	-0.	4.	0.	-50.	-7.	-53.
24	-0.	-0.	13.	0.	-50.	-7.	-44.
25	-0.	-0.	-5.	0.	-50.	-7.	-62.
26	-0.	-5.	-24.	0.	-50.	-7.	-87.

(5) SUMMARY: FEED UTILIZATION SUBCOMPONENT

1=NET FEED(CS,HMC,ALF,SBM,NPN) COSTS/RETURNS,$/YR.
2=CASH CORN(CG) SALES,$/YR.
3=NET PURCHASES/SALES FROM FEEDS/CORN,$/YR.

1	-6057.	19681.	13624.
2	-5045.	5848.	802.
3	-5153.	8686.	3533.
4	-7016.	11512.	4497.
5	-4645.	2757.	-1888.
6	-8142.	7469.	-673.
7	-4506.	15485.	10979.
8	-3496.	1369.	-2127.
9	-12240.	17966.	5726.
10	-9428.	11928.	2500.
11	-4228.	8058.	3831.
12	-5602.	10014.	4412.
13	-12061.	9871.	-2190.
14	-8900.	9136.	236.
15	-6525.	3684.	-2841.
16	-1460.	3650.	2190.
17	-2547.	10788.	8241.
18	-1223.	5452.	4229.
19	-12574.	10981.	-1593.
20	-7220.	7635.	415.
21	-10722.	0.	-10722.
22	-8106.	2763.	-5343.
23	-6317.	21061.	14743.
24	-5225.	15478.	10253.
25	-7416.	19581.	12165.
26	-10431.	0.	-10431.

(5) SUMMARY: FEED UTILIZATION SUBCOMPONENT

1=NET FEED(CS,HMC,ALF,SBM,NPN) COSTS/RETURNS,$/YR.
2=CASH CORN(CG) SALES,$/YR.
3=NET PURCHASES/SALES FROM FEEDS/CORN,$/YR.

1	-6057.	19681.	13624.
2	-5045.	5848.	802.
3	-5153.	8686.	3533.
4	-7016.	11512.	4497.
5	-4645.	2757.	-1888.
6	-8142.	7469.	-673.
7	-4506.	15485.	10979.
8	-3496.	1369.	-2127.
9	-12240.	17966.	5726.
10	-9428.	11928.	2500.
11	-4228.	8058.	3831.
12	-5602.	10014.	4412.
13	-12061.	9871.	-2190.
14	-8900.	9136.	236.
15	-6525.	3684.	-2841.
16	-1460.	3650.	2190.
17	-2547.	10788.	8241.
18	-1223.	5452.	4229.
19	-12574.	10981.	-1593.
20	-7220.	7635.	415.
21	-10722.	0.	-10722.
22	-8106.	2763.	-5343.
23	-6317.	21061.	14743.
24	-5225.	15478.	10253.
25	-7416.	19581.	12165.
26	-10431.	0.	-10431.

END OF SIMULATION RUN RESULTS FOR COMBINED DAIRY-FORAGE SYSTEMS MODEL (DAFOSYM).

MATRIX TRES=TOTAL RESOURCE USE AND INVESTMENT.
EACH ROW EQUALS ONE SIMULATION YEAR.
COLUMNS REPRESENT:
1=M/INV$ 2=STG/INV$ 3=FUEL(L) 4=M/RM$ 5=LABFLD(HRS) 6=LABFEED(HRS) 7=CROPS(HA) 8=CG(HA) 9=CG(DMT)

	1	2	3	4	5	6	7	8	9
1	141680.	119210.	11847.	7049.	1190.	878.	155.	23.	148.
2	141680.	119210.	12281.	7173.	1239.	907.	155.	9.	44.
3	141680.	119210.	12431.	7425.	1263.	906.	155.	12.	65.
4	141680.	119210.	12113.	7138.	1223.	839.	155.	16.	87.
5	141680.	119210.	12627.	7301.	1263.	908.	155.	5.	21.
6	141680.	119210.	12365.	7473.	1263.	872.	155.	12.	56.
7	141680.	119210.	12229.	7250.	1230.	883.	155.	19.	117.
8	141680.	119210.	12778.	7387.	1288.	925.	155.	3.	10.
9	141680.	119210.	11346.	6890.	1168.	768.	155.	23.	135.
10	141680.	119210.	11956.	7199.	1223.	819.	155.	15.	90.
11	141680.	119210.	12513.	7378.	1260.	922.	155.	11.	61.
12	141680.	119210.	12496.	7511.	1268.	885.	155.	16.	75.
13	141680.	119210.	11836.	7234.	1232.	798.	155.	15.	74.
14	141680.	119210.	12026.	7115.	1223.	827.	155.	14.	69.
15	141680.	119210.	12547.	7341.	1265.	891.	155.	6.	28.
16	141680.	119210.	12690.	7410.	1295.	964.	155.	6.	27.
17	141680.	119210.	12304.	7235.	1240.	944.	155.	15.	81.
18	141680.	119210.	12632.	7410.	1287.	973.	155.	8.	41.
19	141680.	119210.	11786.	7158.	1221.	793.	155.	16.	83.
20	141680.	119210.	12218.	7229.	1235.	862.	155.	12.	57.
21	141680.	119210.	12245.	7200.	1247.	897.	155.	0.	0.
22	141680.	119210.	12485.	7327.	1267.	852.	155.	5.	21.
23	141680.	119210.	11694.	6997.	1180.	870.	155.	24.	159.
24	141680.	119210.	12051.	7094.	1201.	896.	155.	19.	117.
25	141680.	119210.	11804.	7132.	1198.	859.	155.	24.	147.
26	141680.	119210.	12587.	7364.	1288.	823.	155.	0.	0.

SAMPLE STATISTICS FOR SIMULATION RUN: ROWS 1=MEAN 2=STANDARD DEVIATION 3=COEF OF VARIATION

1	141680.	119210.	12226.	7247.	1241.	876.	155.	13.	70.
2	0.	0.	361.	153.	35.	51.	0.	7.	46.
3	0.00	0.00	.03	.02	.03	.06	.00	.57	.66

SAMPLE MEAN VALUES FOR ABOVE SIMULATION RUN REPORTED ON ALTERNATIVE UNIT BASES.
MEANS REPORTED ARE BASED ON: HA= 154.8 ACRES= 382.4 COWS= 120.0 CWT/YR= 21600.
ROWS REPRESENT MEANS: 1=PER HECTARE 2=PER ACRE 3=PER COW-UNIT 4=PER CWT MILK

1	915.07	769.94	78.97	46.80	8.01	5.65	1.00	.08	.45
2	370.47	311.72	31.97	18.95	3.24	2.29	.40	.03	.18
3	1180.67	993.42	101.89	60.39	10.34	7.30	1.29	.11	.58
4	6.56	5.52	.57	.34	.06	.04	.01	.00	.00

END OF SIMULATION RUN RESULTS FOR COMBINED DAIRY-FORAGE SYSTEMS MODEL (DAFOSYM).

SUMMARY OUTPUT FOR 26 SIMULATION YEARS.
MATRIX TCOST=TOTAL COST OF PRODUCTION, GROSS AND NET RETURNS ($).
EACH ROW EQUALS ONE SIMULATION YEAR.
COLUMNS 11, 12, 14 AND 15 ARE RETURNS. ALL OTHER COLUMNS ARE COSTS.
COLUMNS REPRESENT:
1=FCM 2=FCSTG 3=FUEL 4=RMM 5=LABFLD 6=LABFEED 7=FSC 8=CUSTOM 9=DRYCG 10=SUM(1-9) 11=FNET 12=CGNET 13=NCOST 14=MILK 15=NRET

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	23732.	9325.	3542.	7049.	5952.	4392.	30845.	10353.	2478.	97668.	-6057.	19681.	84044.	280800.	196756.
2	23732.	9482.	3672.	7173.	6196.	4536.	30845.	9402.	651.	95689.	-5045.	5848.	94887.	280800.	185913.
3	23732.	9522.	3717.	7425.	6315.	4532.	30845.	9606.	1083.	96777.	-5153.	8686.	93244.	280800.	187556.
4	23732.	9325.	3622.	7138.	6114.	4195.	30845.	9867.	1462.	96301.	-7016.	11512.	91804.	280800.	188996.
5	23732.	9325.	3776.	7301.	6315.	4541.	30845.	9129.	382.	95345.	-4645.	2757.	97233.	280800.	183567.
6	23732.	9325.	3697.	7473.	6315.	4361.	30845.	9572.	1147.	96468.	-8142.	7469.	97141.	280800.	183659.
7	23732.	9487.	3657.	7250.	6151.	4417.	30845.	10097.	2025.	97661.	-4506.	15485.	86682.	280800.	194118.
8	23732.	9539.	3821.	7387.	6440.	4624.	30845.	8974.	190.	95550.	-3496.	1369.	97678.	280800.	183122.
9	23732.	9325.	3392.	6890.	5840.	3840.	30845.	10323.	1870.	96057.	-12240.	17966.	90332.	280800.	190468.
10	23732.	9325.	3575.	7199.	6117.	4095.	30845.	9836.	1743.	96467.	-9428.	11928.	93967.	280800.	186833.
11	23732.	9477.	3741.	7378.	6298.	4610.	30845.	9548.	1005.	96635.	-4228.	8058.	92804.	280800.	187996.
12	23732.	9325.	3736.	7511.	6342.	4425.	30845.	9871.	1432.	97221.	-5602.	10014.	92809.	280800.	187991.
13	23732.	9325.	3539.	7234.	6158.	3988.	30845.	9786.	1090.	95697.	-12061.	9871.	97886.	280800.	182914.
14	23732.	9325.	3596.	7115.	6114.	4137.	30845.	9752.	1193.	95809.	-8900.	9136.	95573.	280800.	185227.
15	23732.	9325.	3751.	7341.	6325.	4456.	30845.	9192.	510.	95478.	-6525.	3684.	98318.	280800.	182482.
16	23732.	9980.	3794.	7410.	6474.	4822.	30845.	9194.	465.	96717.	-1460.	3650.	94527.	280800.	186273.
17	23732.	9671.	3679.	7235.	6202.	4718.	30845.	9798.	1401.	97281.	-2547.	10788.	89040.	280800.	191760.
18	23732.	9994.	3777.	7410.	6433.	4866.	30845.	9354.	993.	97403.	-1223.	5452.	93173.	280800.	187627.
19	23732.	9325.	3524.	7158.	6105.	3966.	30845.	9881.	1560.	96096.	-12574.	10981.	97689.	280800.	183111.
20	23732.	9325.	3653.	7229.	6174.	4308.	30845.	9625.	850.	95741.	-7220.	7635.	95327.	280800.	185473.
21	23732.	9598.	3661.	7200.	6235.	4483.	30845.	8795.	0.	94549.	-10722.	0.	105272.	280800.	175528.
22	23732.	9325.	3733.	7327.	6337.	4262.	30845.	9134.	308.	95003.	-8106.	2763.	100346.	280800.	180454.
23	23732.	9325.	3497.	6997.	5900.	4352.	30845.	10408.	2627.	97683.	-6317.	21061.	82939.	280800.	197861.
24	23732.	9325.	3603.	7094.	6007.	4481.	30845.	10065.	2005.	97157.	-5225.	15478.	86904.	280800.	193896.
25	23732.	9325.	3529.	7132.	5990.	4295.	30845.	10430.	2249.	97528.	-7416.	19581.	85363.	280800.	195437.
26	23732.	9325.	3763.	7364.	6438.	4114.	30845.	8795.	0.	94377.	-10431.	0.	104808.	280800.	175992.

SAMPLE STATISTICS FOR SIMULATION RUN: ROWS 1=MEAN 2=STANDARD DEVIATION 3=COEF OF VARIATION

1	23732.	9434.	3656.	7247.	6203.	4378.	30845.	9646.	1181.	96321.	-6780.	9264.	93838.	280800.	186962.
2	0.	192.	108.	153.	173.	257.	0.	481.	749.	969.	3164.	6134.	5716.	0.	5716.
3	0.00	.02	.03	.02	.03	.06	.00	.05	.63	.01	-.47	.66	.06	0.00	.03

SAMPLE MEAN VALUES FOR ABOVE SIMULATION RUN REPORTED ON ALTERNATIVE UNIT BASES.
MEANS REPORTED ARE BASED ON: HA= 154.8 ACRES= 382.4 COWS= 120.0 CWT/YR= 21600.
ROWS REPRESENT MEANS: 1=PER HECTARE 2=PER ACRE 3=PER COW-UNIT 4=PER CWT MILK

1	153.28	60.93	23.61	46.80	40.07	28.27	199.22	62.30	7.63	622.11	-43.79	59.83	606.07	1813.60	1207.53
2	62.06	24.67	9.56	18.95	16.22	11.45	80.66	25.22	3.09	251.87	-17.73	24.22	245.37	734.25	488.88
3	197.77	78.62	30.46	60.39	51.69	36.48	257.04	80.38	9.85	802.68	-56.50	77.20	781.98	2340.00	1558.02
4	1.10	.44	.17	.34	.29	.20	1.43	.45	.05	4.46	-.31	.43	4.34	13.00	8.66

END OF SIMULATION RUN RESULTS FOR COMBINED DAIRY-FORAGE SYSTEMS MODEL (DAFOSYM).

SUMMARY OUTPUT FOR 26 SIMULATION YEARS.
MATRIX TCOST=TOTAL COST OF PRODUCTION, GROSS AND NET RETURNS ($).
EACH ROW EQUALS ONE SIMULATION YEAR.
COLUMNS 11, 12, 14 AND 15 ARE RETURNS. ALL OTHER COLUMNS ARE COSTS.
COLUMNS REPRESENT:
1=FCM 2=FCSTG 3=FUEL 4=RMM 5=LABFLD 6=LABFEED 7=FSC 8=CUSTOM 9=DRYCG 10=SUM(1-9) 11=FNET 12=CGNET 13=NCOST 14=MILK 15=NRET

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	23732.	9325.	3542.	7049.	5952.	4392.	30845.	10353.	2478.	97668.	-6057.	19681.	84044.	280800.	196756.
2	23732.	9482.	3672.	7173.	6196.	4536.	30845.	9402.	651.	95689.	-5045.	5848.	94887.	280800.	185913.
3	23732.	9522.	3717.	7425.	6315.	4532.	30845.	9606.	1083.	96777.	-5153.	8686.	93244.	280800.	187556.
4	23732.	9325.	3622.	7138.	6114.	4195.	30845.	9867.	1462.	96301.	-7016.	11512.	91804.	280800.	188996.
5	23732.	9325.	3776.	7301.	6315.	4541.	30845.	9129.	382.	95345.	-4645.	2757.	97233.	280800.	183567.
6	23732.	9325.	3697.	7473.	6315.	4361.	30845.	9572.	1147.	96468.	-8142.	7469.	97141.	280800.	183659.
7	23732.	9487.	3657.	7250.	6151.	4417.	30845.	10097.	2025.	97661.	-4506.	15485.	86682.	280800.	194118.
8	23732.	9539.	3821.	7387.	6440.	4624.	30845.	8974.	190.	95550.	-3496.	1369.	97678.	280800.	183122.
9	23732.	9325.	3392.	6890.	5840.	3840.	30845.	10323.	1870.	96057.	-12240.	17966.	90332.	280800.	190468.
10	23732.	9325.	3575.	7199.	6117.	4095.	30845.	9836.	1743.	96467.	-9428.	11928.	93967.	280800.	186833.
11	23732.	9477.	3741.	7378.	6298.	4610.	30845.	9548.	1005.	96635.	-4228.	8058.	92804.	280800.	187996.
12	23732.	9325.	3736.	7511.	6342.	4425.	30845.	9871.	1432.	97221.	-5602.	10014.	92809.	280800.	187991.
13	23732.	9325.	3539.	7234.	6158.	3988.	30845.	9786.	1090.	95697.	-12061.	9871.	97886.	280800.	182914.
14	23732.	9325.	3596.	7115.	6114.	4137.	30845.	9752.	1193.	95809.	-8900.	9136.	95573.	280800.	185227.
15	23732.	9325.	3751.	7341.	6325.	4456.	30845.	9192.	510.	95478.	-6525.	3684.	98318.	280800.	182482.
16	23732.	9980.	3794.	7410.	6474.	4822.	30845.	9194.	465.	96717.	-1460.	3650.	94527.	280800.	186273.
17	23732.	9671.	3679.	7235.	6202.	4718.	30845.	9798.	1401.	97281.	-2547.	10788.	89040.	280800.	191760.
18	23732.	9994.	3777.	7410.	6433.	4866.	30845.	9354.	993.	97403.	-1223.	5452.	93173.	280800.	187627.
19	23732.	9325.	3524.	7158.	6105.	3966.	30845.	9881.	1560.	96096.	-12574.	10981.	97689.	280800.	183111.
20	23732.	9325.	3653.	7229.	6174.	4308.	30845.	9625.	850.	95741.	-7220.	7635.	95327.	280800.	185473.
21	23732.	9598.	3661.	7200.	6235.	4483.	30845.	8795.	0.	94549.	-10722.	0.	105272.	280800.	175528.
22	23732.	9325.	3733.	7327.	6337.	4262.	30845.	9134.	308.	95003.	-8106.	2763.	100346.	280800.	180454.
23	23732.	9325.	3497.	6997.	5900.	4352.	30845.	10408.	2627.	97683.	-6317.	21061.	82939.	280800.	197861.
24	23732.	9325.	3603.	7094.	6007.	4481.	30845.	10065.	2005.	97157.	-5225.	15478.	86904.	280800.	193896.
25	23732.	9325.	3529.	7132.	5990.	4295.	30845.	10430.	2249.	97528.	-7416.	19581.	85363.	280800.	195437.
26	23732.	9325.	3763.	7364.	6438.	4114.	30845.	8795.	0.	94377.	-10431.	0.	104808.	280800.	175992.

SAMPLE STATISTICS FOR SIMULATION RUN: ROWS 1=MEAN 2=STANDARD DEVIATION 3=COEF OF VARIATION

1	23732.	9434.	3656.	7247.	6203.	4378.	30845.	9646.	1181.	96321.	-6780.	9264.	93838.	280800.	186962.
2	0.	192.	108.	153.	173.	257.	0.	481.	749.	969.	3164.	6134.	5716.	0.	5716.
3	0.00	.02	.03	.02	.03	.06	.00	.05	.63	.01	-.47	.66	.06	0.00	.03

SAMPLE MEAN VALUES FOR ABOVE SIMULATION RUN REPORTED ON ALTERNATIVE UNIT BASES.
MEANS REPORTED ARE BASED ON: HA= 154.8 ACRES= 382.4 COWS= 120.0 CWT/YR= 21600.
ROWS REPRESENT MEANS: 1=PER HECTARE 2=PER ACRE 3=PER COW-UNIT 4=PER CWT MILK

1	153.28	60.93	23.61	46.80	40.07	28.27	199.22	62.30	7.63	622.11	-43.79	59.83	606.07	1813.60	1207.53
2	62.06	24.67	9.56	18.95	16.22	11.45	80.66	25.22	3.09	251.87	-17.73	24.22	245.37	734.25	488.88
3	197.77	78.62	30.46	60.39	51.69	36.48	257.04	80.38	9.85	802.68	-56.50	77.20	781.98	2340.00	1558.02
4	1.10	.44	.17	.34	.29	.20	1.43	.45	.05	4.46	-.31	.43	4.34	13.00	8.66

END OF SIMULATION-RUN RESULTS FOR DAIRY-FORAGE SYSTEMS MODEL (DAFOSYM).

CUMULATIVE DISTRIBUTIONS.
COLUMNS 10, 13, AND 15 OF TCOST MATRIX ORDERED FROM LOWEST TO TO HIGHEST VALUE.
COLS REPRESENT: 1=CUMULATIVE PROB 2=TCOST(10) 3=TCOST(13) 4=TCOST(15)
COLS 3 AND 4 BASED ON SUBROUTINE COWMOD.

	1	2	3	4
1	.038	-97683.	-105272.	175528.
2	.077	-97668.	-104808.	175992.
3	.115	-97661.	-100346.	180454.
4	.154	-97528.	-98318.	182482.
5	.192	-97403.	-97886.	182914.
6	.231	-97281.	-97689.	183111.
7	.269	-97221.	-97678.	183122.
8	.308	-97157.	-97233.	183567.
9	.346	-96777.	-97141.	183659.
10	.385	-96717.	-95573.	185227.
11	.423	-96635.	-95327.	185473.
12	.462	-96468.	-94887.	185913.
13	.500	-96467.	-94527.	186273.
14	.538	-96301.	-93967.	186833.
15	.577	-96096.	-93244.	187556.
16	.615	-96057.	-93173.	187627.
17	.654	-95809.	-92809.	187991.
18	.692	-95741.	-92804.	187996.
19	.731	-95697.	-91804.	188996.
20	.769	-95689.	-90332.	190468.
21	.808	-95550.	-89040.	191760.
22	.846	-95478.	-86904.	193896.
23	.885	-95345.	-86682.	194118.
24	.923	-95003.	-85363.	195437.
25	.962	-94549.	-84044.	196756.
26	1.000	-94377.	-82939.	197861.

RUN SUCCESFULLY CATALOGUED ON DISC AS PERMANENT FILE=DAFOSYMCOWTB79370

END OF SIMULATION RUN RESULTS FOR COMBINED DAIRY-FORAGE SYSTEMS MODEL (DAFOSYM).

SUMMARY OUTPUT FOR 26 SIMULATION YEARS.
MATRIX TCOST=TOTAL COST OF PRODUCTION, GROSS AND NET RETURNS ($).
EACH ROW EQUALS ONE SIMULATION YEAR.
COLUMNS 11, 12, 14 AND 15 ARE RETURNS. ALL OTHER COLUMNS ARE COSTS.
COLUMNS REPRESENT:
1=FCM 2=FCSTG 3=FUEL 4=RMM 5=LABFLD 6=LABFEED 7=FSC 8=CUSTOM 9=DRYCG 10=SUM(1-9) 11=FNET 12=CGNET 13=NCOST 14=MILK 15=NRET

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	23732.	9325.	3542.	7049.	5952.	4392.	30845.	10353.	2478.	97668.	-6057.	19681.	84044.	280800.	196756.
2	23732.	9482.	3672.	7173.	6196.	4536.	30845.	9402.	651.	95689.	-5045.	5848.	94887.	280800.	185913.
3	23732.	9522.	3717.	7425.	6315.	4532.	30845.	9606.	1083.	96777.	-5153.	8686.	93244.	280800.	187556.
4	23732.	9325.	3622.	7138.	6114.	4195.	30845.	9867.	1462.	96301.	-7016.	11512.	91804.	280800.	188996.
5	23732.	9325.	3776.	7301.	6315.	4541.	30845.	9129.	382.	95345.	-4645.	2757.	97233.	280800.	183567.
6	23732.	9325.	3697.	7473.	6315.	4361.	30845.	9572.	1147.	96468.	-8142.	7469.	97141.	280800.	183659.
7	23732.	9487.	3657.	7250.	6151.	4417.	30845.	10097.	2025.	97661.	-4506.	15485.	86682.	280800.	194118.
8	23732.	9539.	3821.	7387.	6440.	4624.	30845.	8974.	190.	95550.	-3496.	1369.	97678.	280800.	183122.
9	23732.	9325.	3392.	6890.	5840.	3840.	30845.	10323.	1870.	96057.	-12240.	17966.	90332.	280800.	190468.
10	23732.	9325.	3575.	7199.	6117.	4095.	30845.	9836.	1743.	96467.	-9428.	11928.	93967.	280800.	186833.
11	23732.	9477.	3741.	7378.	6298.	4610.	30845.	9548.	1005.	96635.	-4228.	8058.	92804.	280800.	187996.
12	23732.	9325.	3736.	7511.	6342.	4425.	30845.	9871.	1432.	97221.	-5602.	10014.	92809.	280800.	187991.
13	23732.	9325.	3539.	7234.	6158.	3988.	30845.	9786.	1090.	95697.	-12061.	9871.	97886.	280800.	182914.
14	23732.	9325.	3596.	7115.	6114.	4137.	30845.	9752.	1193.	95809.	-8900.	9136.	95573.	280800.	185227.
15	23732.	9325.	3751.	7341.	6325.	4456.	30845.	9192.	510.	95478.	-6525.	3684.	98318.	280800.	182482.
16	23732.	9980.	3794.	7410.	6474.	4822.	30845.	9194.	465.	96717.	-1460.	3650.	94527.	280800.	186273.
17	23732.	9671.	3679.	7235.	6202.	4718.	30845.	9798.	1401.	97281.	-2547.	10788.	89040.	280800.	191760.
18	23732.	9994.	3777.	7410.	6433.	4866.	30845.	9354.	993.	97403.	-1223.	5452.	93173.	280800.	187627.
19	23732.	9325.	3524.	7158.	6105.	3966.	30845.	9881.	1560.	96096.	-12574.	10981.	97689.	280800.	183111.
20	23732.	9325.	3653.	7229.	6174.	4308.	30845.	9625.	850.	95741.	-7220.	7635.	95327.	280800.	185473.
21	23732.	9598.	3661.	7200.	6235.	4483.	30845.	8795.	0.	94549.	-10722.	0.	105272.	280800.	175528.
22	23732.	9325.	3733.	7327.	6337.	4262.	30845.	9134.	308.	95003.	-8106.	2763.	100346.	280800.	180454.
23	23732.	9325.	3497.	6997.	5900.	4352.	30845.	10408.	2627.	97683.	-6317.	21061.	82939.	280800.	197861.
24	23732.	9325.	3603.	7094.	6007.	4481.	30845.	10065.	2005.	97157.	-5225.	15478.	86904.	280800.	193896.
25	23732.	9325.	3529.	7132.	5990.	4295.	30845.	10430.	2249.	97528.	-7416.	19581.	85363.	280800.	195437.
26	23732.	9325.	3763.	7364.	6438.	4114.	30845.	8795.	0.	94377.	-10431.	0.	104808.	280800.	175992.

SAMPLE STATISTICS FOR SIMULATION RUN: ROWS 1=MEAN 2=STANDARD DEVIATION 3=COEF OF VARIATION

1	23732.	9434.	3656.	7247.	6203.	4378.	30845.	9646.	1181.	96321.	-6780.	9264.	93838.	280800.	186962.
2	0.	192.	108.	153.	173.	257.	0.	481.	749.	969.	3164.	6134.	5716.	0.	5716.
3	0.00	.02	.03	.02	.03	.06	.00	.05	.63	.01	-.47	.66	.06	0.00	.03

SAMPLE MEAN VALUES FOR ABOVE SIMULATION RUN REPORTED ON ALTERNATIVE UNIT BASES.
MEANS REPORTED ARE BASED ON: HA= 154.8 ACRES= 382.4 COWS= 120.0 CWT/YR= 21600.
ROWS REPRESENT MEANS: 1=PER HECTARE 2=PER ACRE 3=PER COW-UNIT 4=PER CWT MILK

1	153.28	60.93	23.61	46.80	40.07	28.27	199.22	62.30	7.63	622.11	-43.79	59.83	606.07	1813.60	1207.53
2	62.06	24.67	9.56	18.95	16.22	11.45	80.66	25.22	3.09	251.87	-17.73	24.22	245.37	734.25	488.88
3	197.77	78.62	30.46	60.39	51.69	36.48	257.04	80.38	9.85	802.68	-56.50	77.20	781.98	2340.00	1558.02
4	1.10	.44	.17	.34	.29	.20	1.43	.45	.05	4.46	-.31	.43	4.34	13.00	8.66

END OF SIMULATION-RUN RESULTS FOR DAIRY-FORAGE SYSTEMS MODEL (DAFOSYM).

CUMULATIVE DISTRIBUTIONS.
COLUMNS 10, 13, AND 15 OF TCOST MATRIX ORDERED FROM LOWEST TO TO HIGHEST VALUE.
COLS REPRESENT: 1=CUMULATIVE PROB 2=TCOST(10) 3=TCOST(13) 4=TCOST(15)
COLS 3 AND 4 BASED ON SUBROUTINE COWMOD.

	1	2	3	4
1	.038	-97683.	-105272.	175528.
2	.077	-97668.	-104808.	175992.
3	.115	-97661.	-100346.	180454.
4	.154	-97528.	-98318.	182482.
5	.192	-97403.	-97886.	182914.
6	.231	-97281.	-97689.	183111.
7	.269	-97221.	-97678.	183122.
8	.308	-97157.	-97233.	183567.
9	.346	-96777.	-97141.	183659.
10	.385	-96717.	-95573.	185227.
11	.423	-96635.	-95327.	185473.
12	.462	-96468.	-94887.	185913.
13	.500	-96467.	-94527.	186273.
14	.538	-96301.	-93967.	186833.
15	.577	-96096.	-93244.	187556.
16	.615	-96057.	-93173.	187627.
17	.654	-95809.	-92809.	187991.
18	.692	-95741.	-92804.	187996.
19	.731	-95697.	-91804.	188996.
20	.769	-95689.	-90332.	190468.
21	.808	-95550.	-89040.	191760.
22	.846	-95478.	-86904.	193896.
23	.885	-95345.	-86682.	194118.
24	.923	-95003.	-85363.	195437.
25	.962	-94549.	-84044.	196756.
26	1.000	-94377.	-82939.	197861.

RUN SUCCESFULLY CATALOGUED ON DISC AS PERMANENT FILE=DAFOSYMCOWTB79370

APPENDIX J

FORTRAN SOFTWARE LISTING

J.1 Software Listing, BIGMOD

```
      PROGRAM BIGMOD
C
C  BIGMOD IS THE MAIN CALLING PROGRAM FOR THE DAIRY FORAGE SYSTEMS
C  MODEL DEVELOPED BY:
C
C       LUCAS PARSCH, DEPT OF AG ECON, MSU.
C       PHILIPPE SAVOIE, DEPT OF AG ENGR, MSU.
C
C  EXECUTION OF THE MODEL REQUIRES ATTACHING:
C    -3 USER INPUT FILES (MACH,MGTALF,ALFCRN)
C    -2 DATA FILES (BMATRX,WEATHR)
C    -5 BINARY SOURCE CODE (FTN5) FILES:
C          FORHRV-MACHINERY USE/FLOWS (SAVOIE)
C          ALHARV-ALFALFA HARVEST/STORAGE (SAVOIE)
C          ALFMOD-ALFALFA GROWTH MODEL (PARSCH)
C          CRNMOD-CORN GROWTH, HARVEST/STORAGE (PARSCH)
C          BIGMOD-MAIN CALLING, OUTPUT CONTROL (PARSCH)
C
C  THE PRESENT VERSION OF BIGMOD REQUIRES THREE SUBPROGRAMS:
C  REPORT,COWMOD,CATJOB, AND RORDER.
C  (L. PARSCH, DEPT OF AG ECON, MSU, 4/82)
C
      COMMON/ALF123/SLA,DTL,SDCLAI,XLDLAI,CSF,DTS,XMLOSC,RCTNC,RGR,
     +       XMLBUD,XMLTNC,XFROST,ALCROP,ALSOIL,U,ALPHA,XL,PTF,XLAT,
     +       XIRRIG,AWFC,AWFS,AWINIT,WTHR(365,5),DAY1(39),DEC(39),
     +       DAY2(14),SRAD(14)
      COMMON/CTRL24/BGNCUT(5),NTHYR,NTHCUT,NDAYSC,NDAYSH,YLD(4),
     +       QUAL(3,4),GDDCUM,METRIC,JYEARF,JYEARL,IPRT1,IPRT2,
     +       JDAYF,JDAYL,JPRT,NYRS,IPRT4,NCUTS,JYEAR,JLALHR,CPLANT
      COMMON/Y3/NMDATA,NOPER,IN,IO
C
C
      OPEN(1,FILE='MACH')
      OPEN(2,FILE='MGTALF')
      OPEN(3,FILE='BMATRX')
      OPEN(4,FILE='WEATHR')
      OPEN(5,FILE='ALFCRN')
      OPEN(6,FILE='OUTPUT')
C
C  READ IN ALL USER-INPUTTED DATA FROM FILES.
C
      IN=1
      CALL FORHRV
      IN=2
      CALL MGTINF
      CALL ALFIN(IFEED,ICDF)
      CALL CRNIN(NYRS,IPRT4)
C
C  BEGIN SIMULATION CYCLE.  LOOP 10=YEARS, LOOP 20=DAYS.
C
      DO 10 JYEAR=JYEARF,JYEARL
      NTHYR=JYEAR-JYEARF+1
C
C  READ IN CLIMATOLOGICAL DATA FOR JYEAR.  INITIALIZE
C  RELEVANT VARIABLES.  PLANT CORN CROP FOR JYEAR.
C
      READ(4,200)((WTHR(JDAY,ITYPE),ITYPE=1,5),JDAY=1,365)
      CALL YRINIT
      CALL CRNPLT(NTHYR,CPLANT)
C
C  OUTPUT CONTROL OPTION (DAILY) FOR PHENOLOGICAL ALFALFA
C  CROP GROWTH MODEL.
C
      IF(IPRT1.NE.999)CALL ALFOUT(1)
C
      DO 20 JDAY=JDAYF,JDAYL
C
C  GROW ALFALFA CROP FOR JDAY.  DETERMINE YIELD, QUALITY
C  ON DAILY BASIS.  IF APPROPRIATE, HARVEST AND STORE
C  ALFALFA CROP.  SAVE FIRST-DAY STANDING YIELD, QUALITY
C  VALUES (ALFOUT).
C
      CALL ALMAIN(JDAY)
      IF(JDAY.EQ.BGNCUT(NTHCUT))CALL ALFOUT(2)
C
20    CONTINUE
C
```

```
C  SUMMARIZE AND STORE END-OF-YEAR STANDING ALFALFA YIELD
C  AND QUALITY MEASURED ON FIRST DAY OF EACH CUTTING.
C  HARVEST CORN CROP FOR JYEAR ONCE 3RD CUT ALFALFA HARVEST
C  HAS FINISHED.  WRITE OUT END-OF-YEAR CORN RESULTS IF
C  APPROPRIATE.
C
      CALL ALFOUT(3)
      CALL CRNHRV(NTHYR,JLALHR)
      CALL WRITAL(2)
      IF(IPRT4.EQ.1)CALL CRNOUT(NTHYR,NYRS,1)
C
10    CONTINUE
C
C  SUMMARIZE AND PRINT STANDING YIELD/QUALITY ESTIMATES
C  OF ALFALFA AT END OF SIMULATION.  SUMMARIZE AND PRINT
C  OUT RESULTS OF CORN SIMULATION.
C
      CALL REPORT(NTHYR,NYRS,IFEED,ICDF)
C
200   FORMAT(F7.0,1X,F4.0,1X,F4.0,1X,F5.0,1X,F4.0,1X)
      STOP
      END
```

```
C
C  ****************************************************
      SUBROUTINE RORDER(SMPL,NDIST,NOBS)
C  ****************************************************
C
C  RORDER ORDERS A SAMPLE GENERATED DISTRIBUTION INTO AN EMPIRICAL
C  CUMULATIVE DISTRIBUTION. ORDERING IS FROM LOWEST VALUE TO HIGHEST
C  VALUE FOR A MATRIX (SMPL) CONTAINING NDIST DISTRIBUTIONS EACH
C  CONTAINING NOBS OBSERVATIONS.
C  (L. PARSCH, DEPT OF AG ECON, MSU, 4/82)
C
      DIMENSION SMPL(26,20)
C
      DO 10 JCOL=1,NDIST
      DO 20 IROW=1,NOBS-1
C
      SMALL=SMPL(IROW,JCOL)
      N=IROW
C
      DO 30 IROW1=IROW+1,NOBS
      IF(SMALL.LE.SMPL(IROW1,JCOL))GO TO 30
      N=IROW1
      SMALL=SMPL(IROW1,JCOL)
30    CONTINUE
C
      SMPL(N,JCOL)=SMPL(IROW,JCOL)
      SMPL(IROW,JCOL)=SMALL
C
20    CONTINUE
10    CONTINUE
C
      RETURN
      END
```

```
C     ************************************************************
         SUBROUTINE REPORT(NTHYR,NYRS,IFEED,ICDF)
C     ************************************************************
C
C     THIS SUBROUTINE SERVES TWO PURPOSES: (1) IT ORGANISES ALL SUMMARY
C     OUTPUT DATA FROM THE DAFOSYM MODEL INTO THREE SUMMARY MATRICES CALLED
C     TRES (TOTAL RESOURCE USE), TCOST (TOTAL COST/RETURNS), AND AFEED
C     (TOTAL FEED PRODUCED AVAILABLE TO THE HERD ON AN ANNUAL BASIS).
C     PART OF THIS PROCESS ENTAILS THE EVALUATION OF USE OF FEEDCROPS
C     PRODUCED ON THE FARM.  SUBROUTINE COWMOD IS CALLED FOR THIS PURPOSE.
C     (2) ALL SUMMARY END OF SIMULATION-RUN RESULTS ARE OUTPUTTED.
C     (L. PARSCH, DEPT OF AG ECON, MSU, 4/82)
C
         COMMON/Z1/AREA(6),NBO(6),NOPSO(5,9),CRTR(5,4,9),SILO(2)
         COMMON/Z7/ALHRFD(26,15),AFEED(26,23)
         COMMON/Z10/TCOSTS(26,20),TRESS(26,20)
         COMMON/SUMRY1/YCORN(26,19),SCORN(4,19),CCOST(26,16),SCOST(4,16)
         COMMON/COWDTA/RATION(7,7),FSUP(26,7),FDMD(7),FBAL(26,7),PFEEDB(7),
     +         PFEEDS(7),FGROSS(26,7),FNET(26,3),COWS,AVGMLK,PMILK,NDIET
         COMMON/PRICE/PLABOR,PFUELD,PFUELG,RATEIM,PDRYCG,PHRVCG,COEFSV(3),
     +         PFSCA1,PFSCA2,PFSCCS,PFSCHM,ALFYRS,RATEIS,RATEIL,XLIFE(3)
         COMMON/TILL/PTILLC,PTILLA
         COMMON/SUMRY2/TRESP(26,20),TCOSTP(26,20),TCOST(26,20),
     +         STCOST(4,20),TRES(26,20),SRES(4,20)
         COMMON/CUMDTA/CUMPRB(27),SORDER(26,20)
         DATA TRESP,TCOSTP,TCOST,STCOST,TRES,SRES,SORDER,CUMPRB/520*0.,
     +         520*0.,520*0.,80*0.,520*0.,80*0.,520*0.,27*0./
C
C
C     WRITE OUT SIMULATION-END RESULTS GENERATED IN THE INDIVIDUAL
C     SUB-MODELS.
C
         CALL ALFOUT(4)
         CALL WRITAL(3)
         CALL CRNOUT(NTHYR,NYRS,2)
C
C     ORGANIZE TOTAL FEED PRODUCTION OVER THE ENTIRE SIMULATION INTO A
C     SINGLE MATRIX AFEED.  CALL THE SIMPLIFIED COW MODEL TO ESTIMATE
C     DISAPPEARANCE OF FEEDS OVER THE NYRS PERIOD.
C
         DO 5 N=1,NYRS
         DO 5 JCOL=21,23
         AFEED(N,JCOL)=YCORN(N,JCOL-4)
 5       CONTINUE
         CALL COWMOD(NYRS)
C
C     GENERATE THE RESOURCE AND COST MATRICES (TRES,TCOST).  COLUMNS
C     IN THE RESOURCE MATRIX (TRES) REPRESENT:
C     1=MACHINE INVESTMENT $   2=FEED STORAGE INVESTMENT $   3=FUEL USE (L)
C     4=REPAIR-MAINTENANCE $   5=FIELD LABOR (MAN-HRS)   6=FEED LAB (MAN-HRS)
C     7=AREA IN CROPS (HA)   8=AREA AS CG SOLD (HA)   9=CG PRODUCED (DMT)
C
C     COLUMNS IN THE COST/RETURN MATRIX (TCOST) REPRESENT:
C     1=MACHINE FIXED COST $/YR   2=STORAGE FIXED COST $/YR   3=FUEL $/YR
C     4=REPAIR-MAINT, MACHINES $/YR   5=FIELD LABOR $/YR   6=FEED LAB $/YR
C     7=FERT/SEED/CHEMS $/YR   8=CUSTOM HARVEST CG $/YR 9=DRYDOWN CG $/YR
C     10=TOTAL ON-FARM PRODUCTION COSTS $/YR (SUM COLS 1-9)
C     11=NET PURCHASES OR SALES OF FEEDS (CS,HMC,ALF,SBM,NPN) $/YR
C     12=CG SALES $/YR   13=TOTAL COSTS $/YR (SUM 10-12)
C     14=GROSS MILK SALES $/YR   15=NET RETURNS $/YR (14-13)
C
         DO 10 N=1,NYRS
         TRESP(N,1)=CCOST(N,11)
         TRESP(N,2)=CCOST(N,12)
         TRESP(N,3)=CCOST(N,5)
         TRESP(N,4)=CCOST(N,1)
         TRESP(N,5)=CCOST(N,6)
         TRESP(N,6)=CCOST(N,7)
         TRESP(N,7)=YCORN(N,5)
         TRESP(N,8)=YCORN(N,8)
         TRESP(N,9)=YCORN(N,19)
C
         TRESS(N,7)=AREA(1)
         TCOSTS(N,7)=AREA(1)*(PFSCA2+(PFSCA1/ALFYRS))
         TCOSTS(N,8)=(AREA(1)/ALFYRS)*PTILLA
C
         TCOSTP(N,1)=CCOST(N,13)
```

```
C     ******************************************************
      SUBROUTINE REPORT(NTHYR,NYRS,IFEED,ICDF)
C     ******************************************************
C
C     THIS SUBROUTINE SERVES TWO PURPOSES: (1) IT ORGANISES ALL SUMMARY
C     OUTPUT DATA FROM THE DAFOSYM MODEL INTO THREE SUMMARY MATRICES CALLED
C     TRES (TOTAL RESOURCE USE), TCOST (TOTAL COST/RETURNS), AND AFEED
C     (TOTAL FEED PRODUCED AVAILABLE TO THE HERD ON AN ANNUAL BASIS).
C     PART OF THIS PROCESS ENTAILS THE EVALUATION OF USE OF FEEDCROPS
C     PRODUCED ON THE FARM.  SUBROUTINE COWMOD IS CALLED FOR THIS PURPOSE.
C     (2) ALL SUMMARY END OF SIMULATION-RUN RESULTS ARE OUTPUTTED.
C     (L. PARSCH, DEPT OF AG ECON, MSU, 4/82)
C
      COMMON/Z1/AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
      COMMON/Z7/ALHRFD(26,15),AFEED(26,23)
      COMMON/Z10/TCOSTS(26,20),TRESS(26,20)
      COMMON/SUMRY1/YCORN(26,19),SCORN(4,19),CCOST(26,16),SCOST(4,16)
      COMMON/COWDTA/RATION(7,7),FSUP(26,7),FDMD(7),FBAL(26,7),PFEEDB(7),
     +        PFEEDS(7),FGROSS(26,7),FNET(26,3),COWS,AVGMLK,PMILK,NDIET
      COMMON/PRICE/PLABOR,PFUELD,PFUELG,RATEIM,PDRYCG,PHRVCG,COEFSV(3),
     +        PFSCA1,PFSCA2,PFSCCS,PFSCHM,ALFYRS,RATEIS,RATEIL,XLIFE(3)
      COMMON/TILL/PTILLC,PTILLA
      COMMON/SUMRY2/TRESP(26,20),TCOSTP(26,20),TCOST(26,20),
     +        STCOST(4,20),TRES(26,20),SRES(4,20)
      COMMON/CUMDTA/CUMPRB(27),SORDER(26,20)
      DATA TRESP,TCOSTP,TCOST,STCOST,TRES,SRES,SORDER,CUMPRB/520*0.,
     +        520*0.,520*0.,80*0.,520*0.,80*0.,520*0.,27*0./
C
C
C     WRITE OUT SIMULATION-END RESULTS GENERATED IN THE INDIVIDUAL
C     SUB-MODELS.
C
      CALL ALFOUT(4)
      CALL WRITAL(3)
      CALL CRNOUT(NTHYR,NYRS,2)
C
C     ORGANIZE TOTAL FEED PRODUCTION OVER THE ENTIRE SIMULATION INTO A
C     SINGLE MATRIX AFEED.  CALL THE SIMPLIFIED COW MODEL TO ESTIMATE
C     DISAPPEARANCE OF FEEDS OVER THE NYRS PERIOD.
C
      DO 5 N=1,NYRS
      DO 5 JCOL=21,23
      AFEED(N,JCOL)=YCORN(N,JCOL-4)
    5 CONTINUE
      CALL COWMOD(NYRS)
C
C     GENERATE THE RESOURCE AND COST MATRICES (TRES,TCOST).  COLUMNS
C     IN THE RESOURCE MATRIX (TRES) REPRESENT:
C     1=MACHINE INVESTMENT $  2=FEED STORAGE INVESTMENT $  3=FUEL USE (L)
C     4=REPAIR-MAINTENANCE $  5=FIELD LABOR (MAN-HRS)  6=FEED LAB (MAN-HRS)
C     7=AREA IN CROPS (HA)  8=AREA AS CG SOLD (HA)  9=CG PRODUCED (DMT)
C
C     COLUMNS IN THE COST/RETURN MATRIX (TCOST) REPRESENT:
C     1=MACHINE FIXED COST $/YR  2=STORAGE FIXED COST $/YR  3=FUEL $/YR
C     4=REPAIR-MAINT. MACHINES $/YR  5=FIELD LABOR $/YR  6=FEED LAB $/YR
C     7=FERT/SEED/CHEMS $/YR  8=CUSTOM HARVEST CG $/YR 9=DRYDOWN CG $/YR
C     10=TOTAL ON-FARM PRODUCTION COSTS $/YR (SUM COLS 1-9)
C     11=NET PURCHASES OR SALES OF FEEDS (CS,HMC,ALF,SBM,NPN) $/YR
C     12=CG SALES $/YR  13=TOTAL COSTS $/YR (SUM 10-12)
C     14=GROSS MILK SALES $/YR  15=NET RETURNS $/YR (14-13)
C
      DO 10 N=1,NYRS
      TRESP(N,1)=CCOST(N,11)
      TRESP(N,2)=CCOST(N,12)
      TRESP(N,3)=CCOST(N,5)
      TRESP(N,4)=CCOST(N,1)
      TRESP(N,5)=CCOST(N,6)
      TRESP(N,6)=CCOST(N,7)
      TRESP(N,7)=YCORN(N,5)
      TRESP(N,8)=YCORN(N,8)
      TRESP(N,9)=YCORN(N,19)
C
      TRESS(N,7)=AREA(1)
      TCOSTS(N,7)=AREA(1)*(PFSCA2+(PFSCA1/ALFYRS))
      TCOSTS(N,8)=(AREA(1)/ALFYRS)*PTILLA
C
      TCOSTP(N,1)=CCOST(N,13)
```

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      TCOSTP(N,2)=CCOST(N,14)
      TCOSTP(N,3)=CCOST(N,2)
      TCOSTP(N,4)=CCOST(N,1)
      TCOSTP(N,5)=CCOST(N,3)
      TCOSTP(N,6)=CCOST(N,4)
      TCOSTP(N,7)=CCOST(N,10)
      TCOSTP(N,8)=CCOST(N,8)
      TCOSTP(N,9)=CCOST(N,9)
C
10    CONTINUE
C
C  TRESP AND TCOSTP ARE SUB-RESOURCE AND COST MATRICES DEVELOPED IN
C  THE PARSCH SUB-COMPONENTS OF THE DAFOSYM MODEL.  PARALLEL MATRICES
C  DEVELOPED BY SAVOIE ARE TRESS AND TCOSTS.  THESE SUB-MATRICES ARE
C  NOW ADDED TO GENERATE THE TOTAL RESOURCE USE (TRES) AND TOTAL
C  COST/RETURNS (TCOST) MATRICES.
C
      DO 20 N=1,NYRS
      DO 24 I=1,9
      TRES(N,I)=TRESP(N,I)+TRESS(N,I)
      TCOST(N,I)=TCOSTP(N,I)+TCOSTS(N,I)
      TCOST(N,10)=TCOST(N,10)+TCOST(N,I)
24    CONTINUE
C
      TCOST(N,13)=TCOST(N,10)-TCOST(N,11)-TCOST(N,12)
      TCOST(N,15)=TCOST(N,14)-TCOST(N,13)
20    CONTINUE
C
C  WRITE OUT THE RESOURCE AND COST/PROFIT MATRICES.
C
      WRITE(6,200)
      WRITE(6,211)((JCOL),JCOL=1,9)
      DO 30 N=1,NYRS
30    WRITE(6,210)N,(TRES(N,I),I=1,9)
C
      CALL SSTAT(9,TRES,NYRS,SRES)
      WRITE(6,118)
      WRITE(6,120)
      DO 35 I=1,2
35    WRITE(6,210)I,(SRES(I,J),J=1,9)
      WRITE(6,225)I,((SRES(I,J),J=1,9),I=3,3)
C
      WRITE(6,250)
      IF(COWS.GT.0.)THEN
         WRITE(6,255)SRES(1,7),(SRES(1,7)*2.47),COWS,(COWS*AVGMLK)
         WRITE(6,225)((I),I=1,1),((SRES(1,J)/SRES(1,7)),J=1,9)
         WRITE(5,225)((I),I=2,2),((SRES(1,J)/(SRES(1,7)*2.47)),J=1,9)
         WRITE(6,225)((I),I=3,3),((SRES(1,J)/COWS),J=1,9)
         WRITE(6,225)((I),I=4,4),((SRES(1,J)/(COWS*AVGMLK)),J=1,9)
      ELSE
         WRITE(6,260)SRES(1,7),(SRES(1,7)*2.47)
         WRITE(6,225)((I),I=1,1),((SRES(1,J)/SRES(1,7)),J=1,9)
         WRITE(6,225)((I),I=2,2),((SRES(1,J)/(SRES(1,7)*2.47)),J=1,9)
      ENDIF
C
      WRITE(6,100)NYRS
      WRITE(6,111)((JCOL),JCOL=1,15)
      DO 40 N=1,NYRS
40    WRITE(6,110)N,(TCOST(N,I),I=1,15)
C
      CALL SSTAT(15,TCOST,NYRS,STCOST)
      WRITE(6,118)
      WRITE(6,120)
      DO 45 I=1,2
45    WRITE(6,110)I,(STCOST(I,J),J=1,15)
      WRITE(6,125)I,((STCOST(I,J),J=1,15),I=3,3)
C
      WRITE(6,250)
      IF(COWS.GT.0.)THEN
         WRITE(6,255)SRES(1,7),(SRES(1,7)*2.47),COWS,(COWS*AVGMLK)
         WRITE(6,125)((I),I=1,1),((STCOST(1,J)/SRES(1,7)),J=1,15)
         WRITE(6,125)((I),I=2,2),((STCOST(1,J)/(SRES(1,7)*2.47)),J=1,15)
         WRITE(6,125)((I),I=3,3),((STCOST(1,J)/COWS),J=1,15)
         WRITE(6,125)((I),I=4,4),((STCOST(1,J)/(COWS*AVGMLK)),J=1,15)
      ELSE
         WRITE(6,260)SRES(1,7),(SRES(1,7)*2.47)
         WRITE(6,125)((I),I=1,1),((STCOST(1,J)/SRES(1,7)),J=1,15)
```

```
            WRITE(6,125)((I),I=2,2),((STCOST(1,J)/(SRES(1,7)*2.47)),J=1,15)
         ENDIF
C
C  CALCULATE CUMULATIVE PROBABILITIES.  CATALOG ONTO DISC THE AFEED,
C  TCOST, AND CUMBPRB MATRICES FOR FURTHER ANALYSES IF APPROPRIATE.
C  ORDER PRODUCTION COSTS, NET COSTS, AND NET RETURNS FROM LOWEST
C  TO HIGHEST (CUMULATIVE DISTRIBUTIONS OF GENERATED SAMPLES).
C
      DIFF=(1./FLOAT(NYRS))
      CUMPRB(1)=DIFF
      DO 50 N=2,NYRS
      CUMPRB(N)=CUMPRB(N-1)+DIFF
50    CONTINUE
C
      CALL CATJOB(NYRS,COWS,IFEED,ICDF)
C
      DO 55 N=1,NYRS
      SORDER(N,1)=TCOST(N,10)*(-1.)
      SORDER(N,2)=TCOST(N,13)*(-1.)
      SORDER(N,3)=TCOST(N,15)
55    CONTINUE
C
      CALL RORDER(SORDER,3,NYRS)
C
      WRITE(6,300)
      WRITE(6,311)((JCOL),JCOL=1,4)
      DO 60 N=1,NYRS
      WRITE(6,310)N,CUMPRB(N),(SORDER(N,J),J=1,3)
60    CONTINUE
C
100   FORMAT('1','END OF SIMULATION RUN RESULTS FOR COMBINED',
     +      ' DAIRY-FORAGE SYSTEMS MODEL (DAFOSYM).',//,
     +      ' SUMMARY OUTPUT FOR ',I2,' SIMULATION YEARS.',/,
     +      ' MATRIX TCOST=TOTAL COST OF PRODUCTION, GROSS AND NET',
     +      ' RETURNS ($).',/,
     +      ' EACH ROW EQUALS ONE SIMULATION YEAR.',/,
     +      ' COLUMNS 11, 12, 14 AND 15 ARE RETURNS. ALL OTHER COLUMNS',
     +      ' ARE COSTS.',/,' COLUMNS REPRESENT:',/,
     +      ' 1=FCM  2=FCSTG  3=FUEL  4=RMM  5=LABFLD ',
     +      ' 6=LABFEED 7=FSC 8=CUSTOM 9=DRYCG 10=SUM(1-9)',
     +      ' 11=FNET 12=CGNET 13=NCOST 14=MILK',
     +      ' 15=NRET',///)
C
110   FORMAT(I3,2(1X,F7.0),1X,F6.0,12(1X,F8.0))
111   FORMAT(1X,2(1X,I7),1X,I6,12(1X,I8)/)
125   FORMAT(I3,2(1X,F7.2),1X,F6.2,12(1X,F8.2))
C
118   FORMAT(//)
120   FORMAT(' SAMPLE STATISTICS FOR SIMULATION RUN:',
     +   ' ROWS 1=MEAN  2=STANDARD DEVIATION  3=COEF OF VARIATION',/)
C
200   FORMAT('1','END OF SIMULATION RUN RESULTS FOR COMBINED',
     +      ' DAIRY-FORAGE SYSTEMS MODEL (DAFOSYM).',//,
     +      ' MATRIX TRES=TOTAL RESOURCE USE AND INVESTMENT.',/,
     +      ' EACH ROW EQUALS ONE SIMULATION YEAR.',/,
     +      ' COLUMNS REPRESENT:',/,
     +      ' 1=M/INV$  2=STG/INV$  3=FUEL(L)  4=M/RM$ ',
     +      ' 5=LABFLD(HRS)  6=LABFEED(HRS)  7=CROPS(HA) ',
     +      ' 8=CG(HA)  9=CG(DMT)',///)
C
210   FORMAT(I3,2(1X,F8.0),2(1X,F7.0),5(1X,F6.0))
211   FORMAT(1X,2(1X,I8),2(1X,I7),5(1X,I6)/)
225   FORMAT(I3,2(1X,F8.2),2(1X,F7.2),5(1X,F6.2))
C
250   FORMAT(////' SAMPLE MEAN VALUES FOR ABOVE SIMULATION RUN',
     +      ' REPORTED ON ALTERNATIVE UNIT BASES.')
255   FORMAT(' MEANS REPORTED ARE BASED ON:  HA=',F6.1,'    ACRES=',
     +     F6.1,'     COWS=',F6.1,'     CWT/YR=',F8.0,/,
     +      ' ROWS REPRESENT MEANS:  1=PER HECTARE  2=PER ACRE',
     +      '  3=PER COW-UNIT  4=PER CWT MILK',/)
260   FORMAT(' MEANS REPORTED ARE BASED ON:  HA=',F6.1,'    ACRES=',
     +     F6.1,/,' ROWS REPRESENT MEANS:  1=PER HECTARE  2=PER ACRE',/)
300   FORMAT('1','END OF SIMULATION-RUN RESULTS FOR DAIRY-FORAGE',
     + ' SYSTEMS MODEL (DAFOSYM).',//,' CUMULATIVE DISTRIBUTIONS.',/,
     + ' COLUMNS 10, 13, AND 15 OF TCOST MATRIX ORDERED FROM LOWEST TO',
     + ' TO HIGHEST VALUE.',/,' COLS REPRESENT: 1=CUMULATIVE PROB',
     + '  2=TCOST(10)',

     + '  3=TCOST(13)  4=TCOST(15)',
     + /,' COLS 3 AND 4 BASED ON SUBROUTINE COWMOD.'//)
310   FORMAT(I3,1X,F5.3,3(2X,F9.0))
311   FORMAT(3X,I5,3(2X,I9),/)
C
      RETURN
      END
```

```
C     ****************************************************
      SUBROUTINE COWMOD(NYRS)
C     ****************************************************
C
C   COWMOD IS A SIMPLIFIED DAIRY FEED-USE MODEL. IT PLACES A VALUE ON
C   FEEDS PRODUCED BY DETERMINING THE SURPLUS OR DEFECIT OF FEEDS
C   REQUIRED TO PRODUCE A SPECIFED MILK PRODUCTION, GIVEN A SPECIFIED
C   BALANCED RATION.  FOR A GIVEN BALANCED RATION, SURPLUSES OR DEFECITS
C   ARE ACCOUNTED FOR BY SELLING OR PURCHASING IN EACH FEED-STUFF AT
C   A USER-INPUTTED PRICE.
C   (L. PARSCH, DEPT OF AG ECON, MSU, 4/82)
C
      COMMON/Z7/ALHRFD(26,15),AFEED(26,23)
      COMMON/COWDTA/RATION(7,7),FSUP(26,7),FDMD(7),FBAL(26,7),PFEEDB(7),
     +      PFEEDS(7),FGROSS(26,7),FNET(26,3),COWS,AVGMLK,PMILK,NDIET
      COMMON/SUMRY2/TRESP(26,20),TCOSTP(26,20),TCOST(26,20),
     +      STCOST(4,20),TRES(26,20),SRES(4,20)
      DIMENSION DUMMY4(6)
C
      DATA RATION/ 0.0000, 2.1092, 2.8928, 3.5011, 4.0949, 4.6091, 0.0,
     +             2.3498, 2.0677, 1.8767, 1.6913, 1.5466, 1.4346, 0.0,
     +             7.0114, 4.9322, 4.1466, 3.3724, 2.6301, 1.9473, 0.0,
     +             1.0272,  .7498,  .6124,  .4769,  .3469,  .2275, 0.0,
     +              .0974,  .1486,  .2624,  .4230,  .5806,  .7286, 0.0,
     +              .0   ,  .0231,  .0317,  .0383,  .0448,  .0504, 0.0,
     +              .0   ,  .0   ,  .0   ,  .0   ,  .0   ,  .0   , 0.0/
      DATA FSUP,FNET,FGROSS/182*0.,78*0.,182*0./
C
C   READ IN DATA PERTAINING TO THE SIMPLIFIED COW MODEL.  EXPLANATION
C   OF INPUT VARIABLES:
C    -DUMMY4=DUMMY VARIABLE USED AS COLUMN INDICATOR IN INPUT FILE.
C    -COWS=NUMBER OF COW UNITS IN HERD (MILKING+LACTATING).
C    -AVGMLK=MILK/COW/YR PRODUCED,CWT.
C    -PMILK=$/CWT OF MILK.
C    -NDIET=RATION DEFINED BY CS/FORAGE RATIO FED TO LACTATING HERD;
C          (1-6):  1=0CS 2=20CS 3=40CS...6=100CS.
C    -PFEEDB,-S=PRICES PAID FOR FEEDS BOUGHT OR SOLD; 1=CS 2=HMC
C          3=ALF 4=CP(ALF) 5=SBM 6=NPN 7=CG(DRY), $/DMT,METRIC.
C
      READ(5,100)(DUMMY4(I),I=1,6)
      READ(5,110)COWS,AVGMLK,PMILK,NDIET
      READ(5,100)(PFEEDB(J),J=1,7)
      READ(5,100)(PFEEDS(J),J=1,7)
C
      WRITE(6,115)NYRS
      WRITE(6,120)COWS
      WRITE(6,125)AVGMLK
      WRITE(6,130)NDIET
      WRITE(6,135)PMILK
      WRITE(6,140)(PFEEDS(J),J=1,7)
      WRITE(6,145)(PFEEDB(J),J=1,7)
C
C   CALCULATE FEEDS AVAILABLE TO THE HERD OVER THE NYRS PERIOD.
C
      DO 10 N=1,NYRS
      FSUP(N,1)=AFEED(N,21)
      FSUP(N,2)=AFEED(N,22)
      DO 20 JCOL=1,16,5
      FSUP(N,3)=FSUP(N,3)+AFEED(N,JCOL)
20    FSUP(N,4)=FSUP(N,4)+(AFEED(N,JCOL)*AFEED(N,JCOL+1))
      FSUP(N,7)=AFEED(N,23)
      DO 30 JFEED=1,6
      FDMD(JFEED)=COWS*RATION(NDIET,JFEED)
      FBAL(N,JFEED)=FSUP(N,JFEED)-FDMD(JFEED)
      IF(JFEED.EQ.4)GO TO 30
      FGROSS(N,JFEED)=FBAL(N,JFEED)*PFEEDS(JFEED)
      IF(FBAL(N,JFEED).LE.O.)FGROSS(N,JFEED)=
     +          FBAL(N,JFEED)*PFEEDB(JFEED)
      FNET(N,1)=FNET(N,1)+FGROSS(N,JFEED)
30    CONTINUE
      FNET(N,2)=AFEED(N,23)*PFEEDS(7)
      FNET(N,3)=FNET(N,1)+FNET(N,2)
      TCOST(N,11)=FNET(N,1)
      TCOST(N,12)=FNET(N,2)
      TCOST(N,14)=AVGMLK*PMILK*COWS
10    CONTINUE
C
```

```
      WRITE(6,150)COWS
      WRITE(6,155)
      WRITE(6,161)(FDMD(J),J=1,6),((FDMD(J)/COWS),J=1,6)
C
      WRITE(6,158)COWS
      DO 50 N=1,NYRS
50    WRITE(6,160)N,(FSUP(N,J),J=1,6),N,((FSUP(N,J)/COWS),J=1,6)
C
      WRITE(6,165)NYRS,COWS
      WRITE(6,155)
      DO 60 N=1,NYRS
60    WRITE(6,160)N,(FBAL(N,J),J=1,6),N,((FBAL(N,J)/COWS),J=1,6)
C
      WRITE(6,170)NYRS,COWS
      WRITE(6,175)
      DO 70 N=1,NYRS
70    WRITE(6,180)N,(FGROSS(N,J),J=1,6),FNET(N,1),
     +       N,((FGROSS(N,J)/COWS),J=1,6),(FNET(N,1)/COWS)
C
      WRITE(6,185)
      DO 80 N=1,NYRS
80    WRITE(6,182)N,(FNET(N,J),J=1,3)
C
100   FORMAT(7F10.0)
110   FORMAT(3F10.0,I10)
115   FORMAT('1','SUMMARY OUTPUT FOR',I3,' SIMULATION YEARS:',
     +        ' FEED UTILIZATION SUBCOMPONENT.',//,
     +        ' INPUT VALUES READ INTO SUBROUTINE COWMOD:')
120   FORMAT(' NUMBER OF MILKING COWS (LACTATING + DRY)=',F6.1)
125   FORMAT(' AVERAGE MILK/COW/YR, CWT=',1X,F6.1)
130   FORMAT(' RATION FED TO LACTATING COWS=',I3)
135   FORMAT(' MILK PRICE RECEIVED, $/CWT=',F6.2)
C
140   FORMAT(' PRICES OF FEEDS:          1=CS($/DMT)  2=HMC($/DMT)',
     +        ' 3=ALF($/DMT) 4=CPALF($/DMT)  5=SBM($/DMT)  6=NPN($/DMT)',
     +        ' 7=CGSELL($/DMT)',/,'    FEEDS SOLD=',T25,7(4X,F9.2))
145   FORMAT('    FEEDS PURCHASED=',T25,7(4X,F9.2))
C
150   FORMAT(///' (1) ANNUAL FEED REQUIREMENTS (DMT) FOR',F6.1,
     +        ' COWS.',T68,' (1) ANNUAL FEED REQUIREMENTS PER COW,DMT.',/)
155    FORMAT('       1=CS    2=HMC    3=ALF    4=CPALF     5=SBM    6=NPN   ',
     +       T68,'      1=CS 2=HMC 3=ALF 4=CPALF 5=SBM',
     +        ' 6=NPN   ',/)
158   FORMAT(///' (2) ANNUAL FEED PRODUCED (DMT) FOR ',F6.1,
     +        ' COWS.',T68,' (2) ANNUAL FEED PRODUCED PER COW,DMT.',/)
160   FORMAT(I3,6(1X,F7.2),T68,I3,6(1X,F5.2))
161   FORMAT(3X,6(1X,F7.2),T68,3X,6(1X,F5.2))
C
165   FORMAT('1','SUMMARY OUTPUT FOR',I3,' SIMULATION YEARS:',
     +        ' FEED UTILIZATION SUBCOMPONENT.',//,
     +        ' (3) ANNUAL FEED SURPLUS/DEFECIT PER',F6.1,' COWS,DMT.',
     +       T68,' (3) ANNUAL SURPLUS/DEFECIT PER COW,DMT.',/)
C
170   FORMAT('1','SUMMARY OUTPUT FOR',I3,' SIMULATION YEARS:',
     +        ' FEED UTILIZATION SUBCOMPONENT.',//,
     +        ' (4) GROSS AND NET COSTS/RETURNS FOR FEED',
     +' FOR',F6.1,' COWS,$/YR.',T68,' (4) GROSS AND NET COSTS/RETURNS',
     +        ' PER COW,$/YR.',/)
175   FORMAT('       1=CS    2=HMC    3=ALF   4=CPALF   5=SBM',
     +        '    6=NPN   7=SUM(1-6)',
     +T68,3X, ' 1=CS 2=HMC 3=ALF 4=CPALF 5=SBM 6=NPN 7=SUM(1-6)',/)
180   FORMAT(I3,6(1X,F7.0),3X,F8.0,T68,I3,6(1X,F5.0),3X,F6.0)
182   FORMAT(I3,3(1X,F9.0))
185   FORMAT(///' (5) SUMMARY: FEED UTILIZATION SUBCOMPONENT',//,
     +  ' 1=NET FEED(CS,HMC,ALF,SBM,NPN) COSTS/RETURNS,$/YR.',/,
     +        ' 2=CASH CORN(CG) SALES,$/YR.',/,
     +    ' 3=NET PURCHASES/SALES FROM FEEDS/CORN,$/YR.',/)
C
      RETURN
      END
```

```
C
C    ************************************************
         SUBROUTINE CATJOB(NYRS,COWS,IFEED,ICDF)
C    ************************************************
C
C    CATJOB CATALOGS SELECTED SUMMARY OUTPUT VARIABLES ONTO DISC
C    FOR USE IN LATER ANALYSIS (E.G., AFEED MATRIX IS PASSED TO
C    BLACKS'S SEPARABLE PROGRAM FOR EVALUATING FEED DISAPPEARANCE;
C    CUMULATIVE DISTRIBUTION FUNCTIONS OF TOTAL COSTS OR NET
C    RETURNS ARE SAVED FOR STOCHASTIC DOMINANCE ANALYSIS, OR
C    FOR PLOTTING.  INFORMATION IS CATALOGED AS PERMANENT FILE
C    WHOSE NAME CONTAINS THE SEQUENCE RUN NUMBER FOR IDENTIFICATION
C    PURPOSES.
C    (L. PARSCH, DEPT OF AG ECON, MSU, 4/82)
C
         COMMON/SUMRY2/TRESP(26,20),TCOSTP(26,20),TCOST(26,20),
     +         STCOST(4,20),TRES(26,20),SRES(4,20)
         COMMON/CUMDTA/CUMPRB(27),SORDER(26,20)
         COMMON/Z7/ALHRFD(26,15),AFEED(26,23)
C
         DIMENSION CPBLK(16)
         CHARACTER CATCMD*80,SEQNO*7
         DATA CATCMD/'CATALOG,FEEDS,DAFOSYMCOWXXXXXXX,ID=PARSCH,RP=999.'/
C
C    GET JOB STATUS VARIABLES FROM CYBER SYSTEM.
C
         CALL CPSTAT(CPBLK)
C
         WRITE(SEQNO,'(A7)')CPBLK(2)
C
         IF(IFEED.EQ.1)THEN
            OPEN(7,FILE='FEEDS')
            WRITE(7,300)SEQNO,COWS,NYRS
C
            DO 20 N=1,NYRS
            WRITE(7,310)(AFEED(N,J),J=1,23)
20          CONTINUE
C
            DO 25 N=1,NYRS
            WRITE(7,320)(TCOST(N,I),I=1,10)
25          CONTINUE
C
            DO 30 N=1,NYRS
            WRITE(7,325)TCOST(N,13),CUMPRB(N)
30          CONTINUE
C
            WRITE(7,330)(CUMPRB(N),N=1,NYRS)
            WRITE(7,335)(TCOST(N,10),N=1,NYRS)
            WRITE(7,335)(TCOST(N,13),N=1,NYRS)
            WRITE(7,335)(TCOST(N,15),N=1,NYRS)
C
            CLOSE (7)
            CATCMD(25:31)=SEQNO
            ERR=PF(CATCMD)
            IF(ERR.NE.0.)THEN
               PRINT*,' PF ERROR CODE FOR AFEED MATRIX= ',ERR
            ELSE
               WRITE(6,350)SEQNO
            ENDIF
         ENDIF
C
300      FORMAT(1X,A7,1X,F10.1,1X,I3)
310      FORMAT(1X,4(F7.2,4(F5.3)),3(F7.2))
320      FORMAT(1X,10(1X,F8.0))
325      FORMAT(1X,F8.0,1X,F5.3)
350      FORMAT(/////,' RUN SUCCESFULLY CATALOGUED ON DISC AS ',
     +        ' PERMANENT FILE=DAFOSYMCOW',A7)
330      FORMAT(3(9(F8.3)/),/)
335      FORMAT(3(9(F8.0)/),/)
C
         RETURN
         END
```

```
      C
      C     ***************************************************
            SUBROUTINE CATJOB(NYRS,COWS,IFEED,ICDF)
      C     ***************************************************
      C
      C     CATJOB CATALOGS SELECTED SUMMARY OUTPUT VARIABLES ONTO DISC
      C     FOR USE IN LATER ANALYSIS (E.G., AFEED MATRIX IS PASSED TO
      C     BLACKS'S SEPARABLE PROGRAM FOR EVALUATING FEED DISAPPEARANCE;
      C     CUMULATIVE DISTRIBUTION FUNCTIONS OF TOTAL COSTS OR NET
      C     RETURNS ARE SAVED FOR STOCHASTIC DOMINANCE ANALYSIS, OR
      C     FOR PLOTTING.  INFORMATION IS CATALOGED AS PERMANENT FILE
      C     WHOSE NAME CONTAINS THE SEQUENCE RUN NUMBER FOR IDENTIFICATION
      C     PURPOSES.
      C     (L. PARSCH, DEPT OF AG ECON, MSU, 4/82)
      C
            COMMON/SUMRY2/TRESP(26,20),TCOSTP(26,20),TCOST(26,20),
           +       STCOST(4,20),TRES(26,20),SRES(4,20)
            COMMON/CUMDTA/CUMPRB(27),SORDER(26,20)
            COMMON/Z7/ALHRFD(26,15),AFEED(26,23)
      C
            DIMENSION CPBLK(16)
            CHARACTER CATCMD*80,SEQNO*7
            DATA CATCMD/'CATALOG,FEEDS,DAFOSYMCOWXXXXXXX,ID=PARSCH,RP=999.'/
      C
      C     GET JOB STATUS VARIABLES FROM CYBER SYSTEM.
      C
            CALL CPSTAT(CPBLK)
      C
            WRITE(SEQNO,'(A7)')CPBLK(2)
      C
            IF(IFEED.EQ.1)THEN
               OPEN(7,FILE='FEEDS')
               WRITE(7,300)SEQNO,COWS,NYRS
      C
               DO 20 N=1,NYRS
               WRITE(7,310)(AFEED(N,J),J=1,23)
      20       CONTINUE
      C
               DO 25 N=1,NYRS
               WRITE(7,320)(TCOST(N,I),I=1,10)
      25       CONTINUE
      C
               DO 30 N=1,NYRS
               WRITE(7,325)TCOST(N,13),CUMPRB(N)
      30       CONTINUE
      C
               WRITE(7,330)(CUMPRB(N),N=1,NYRS)
               WRITE(7,335)(TCOST(N,10),N=1,NYRS)
               WRITE(7,335)(TCOST(N,13),N=1,NYRS)
               WRITE(7,335)(TCOST(N,15),N=1,NYRS)
      C
               CLOSE (7)
               CATCMD(25:31)=SEQNO
               ERR=PF(CATCMD)
               IF(ERR.NE.0.)THEN
                  PRINT*,' PF ERROR CODE FOR AFEED MATRIX= ',ERR
               ELSE
                  WRITE(6,350)SEQNO
               ENDIF
            ENDIF
      C
      300   FORMAT(1X,A7,1X,F10.1,1X,I3)
      310   FORMAT(1X,4(F7.2,4(F5.3)),3(F7.2))
      320   FORMAT(1X,10(1X,F8.0))
      325   FORMAT(1X,F8.0,1X,F5.3)
      350   FORMAT(////,' RUN SUCCESFULLY CATALOGUED ON DISC AS ',
           +       ' PERMANENT FILE=DAFOSYMCOW',A7)
      330   FORMAT(3(9(F8.3)/),/)
      335   FORMAT(3(9(F8.0)/),/)
      C
            RETURN
            END
```

J.2 Software Listing, ALFMOD

```
      PROGRAM ALF2LP
C
C  MAIN CALLING PROGRAM FOR ALFALFA SIMULATION MODEL.  ALF2LP IS A
C  MODIFIED FORTRAN V VERSION OF:
C
C  ***********************************************************
C          ALSIM1-LEVEL 2, ALFALFA SIMULATION MODEL
C          GARY W. FICK, DEPARTMENT OF AGRONOMY
C          CORNELL UNIVERSITY  (1975,1981)
C  ***********************************************************
C
C  THE FICK MODEL WAS CONVERTED FROM THE CSMP (CONTINUOS SYSTEM
C  MODELING PROGRAM, IBM) SIMULATION LANGUAGE INTO FORTRAN BY:
C
C          LUCAS D. PARSCH
C          DEPARTMENT OF AGRICULTURAL ECONOMICS
C          MICHIGAN STATE UNIVERSITY (10/81)
C
C  CORE ALGORITHMS FROM THE ORIGINAL FICK VERSION OF THE MODEL
C  ARE CONTAINED IN SUBPROGRAMS ALINIT, ALWTHR, ASOIL, ALGROW,
C  ALEVAP, BLOCK DATA ALFLFA, AND TABLI.  ALL OTHER SUBPROGRAMS
C  HAVE BEEN ADDED IN ORDER TO ACCOMODATE:
C            (1) INCREASED EXECUTIVE PROGRAM CONTROL;
C            (2) MULTIPLE-YEAR SIMULATIONS;
C            (3) PREDICTION OF CROP QUALITY;
C            (4) SIMULATION OF MULTIPLE-DAY HARVEST PERIODS WITH
C                APPROPRIATE REGROWTH-RESET MECHANISM;
C            (5) CALCULATION OF SAMPLE STATISTICS FOR MULTI-
C                YEAR RUNS.
C  THESE MODIFICATIONS ARE CONTAINED IN PROGRAM ALF2LP AND IN
C  SUBPROGRAMS ALFIN, ALMAIN, ALYLD, ALRSET, ALTEST, SKIP, ALFOUT,
C  BCTEMP, AND SSTAT.  (L.PARSCH, DEPT OF AG ECON, MSU, 11/81)
C
      COMMON/ALF123/SLA,DTL,SDCLAI,XLDLAI,CSF,DTS,XMLOSC,RCTNC,RGR,
     +      XMLBUD,XMLTNC,XFROST,ALCROP,ALSOIL,U,ALPHA,XL,PTF,XLAT,
     +      XIRRIG,AWFC,AWFS,AWINIT,WTHR(365,5),DAY1(39),DEC(39),
     +      DAY2(14),SRAD(14)
      COMMON/CTRL24/BGNCUT(5),NTHYR,NTHCUT,NDAYSC,NDAYSH,YLD(4),
     +      QUAL(3,4),GDDCUM,METRIC,JYEARF,JYEARL,IPRT1,IPRT2,
     +      JDAYF,JDAYL,JPRT,NYRS,IPRT4,NCUTS,JYEAR,JLALHR,CPLANT
C
      OPEN(4,FILE='WEATHR')
      OPEN(5,FILE='INPUT')
      OPEN(6,FILE='OUTPUT')
C
C  READ NON-CLIMATOLOGICAL INPUT DATA.  FIND APPROPRIATE RECORD
C  ON WEATHER DATA FILE ELANSWTHR5378.
C
      CALL ALFIN(IFEED,ICDF)
C
C  BEGIN SIMULATION CYCLE.  LOOP 10=YEAR CYCLE; LOOP 20=DAY CYCLE.
C  CALLS TO ALFOUT AND BCTEMP ARE FOR OUTPUT CONTROL PURPOSES
C  ONLY.  SEE SUBPROGRAM CODING FOR EXPLANATION.
C
      DO 10 JYEAR=JYEARF,JYEARL
C
      NTHYR=JYEAR-JYEARF+1
      READ(4,200)((WTHR(JDAY,ITYPE),ITYPE=1,5),JDAY=1,365)
      IF(IPRT1.NE.999)CALL ALFOUT(1)
C
      DO 20 JDAY=JDAYF,JDAYL
C
      CALL ALMAIN(JDAY)
C BIG IF(JDAY.EQ.BCTEMP(NDAYSC))CALL ALFOUT(2)
C
20    CONTINUE
      CALL ALFOUT(3)
10    CONTINUE
C
      CALL ALFOUT(4)
C
200   FORMAT(F7.0,1X,F4.0,1X,F4.0,1X,F5.0,1X,F4.0,1X)
      CLOSE(4)
      CLOSE(5)
      CLOSE(6)
C
      END
```

```
C     ************************************************
          SUBROUTINE ALFIN(IFEED,ICDF)
C     ************************************************
C
C     THIS SUBROUTINE READS IN ALL CONTROL VARIABLES FOR TEST RUNS
C     OF THE ALFALFA SIMULATION MODEL.
C     (L. PARSCH, DEPT OF AG ECON, MSU, 11/81)
C
C     EXPLANATION OF INPUT VARIABLES.
C        -JDAYF,JDAYL=FIRST AND LAST JULIAN DAY OF EACH YEAR SIMULATED.
C        -JYEARF,JYEARL=FIRST AND LAST CALENDAR YEARS TO BE SIMULATED.
C                      (RANGE IS 1953-1978 INCLUSIVE FOR ELANSWTHR5378).
C        -IPRT1=OUTPUT PRINT INTERVAL (DAYS), OVERRIDE=999.
C        -METRIC=SUMMARY OUTPUT UNITS: 0=ENGLISH 1=METRIC.
C        -IFEED,ICDF=SWITCHES FOR DIRECT-DISC CATALOGING OF THE AFEED AND
C                 TCOST MATRICES AS SEPARATE PERMANENT FILES FOR USE IN
C                 FURTHER ANALYSES (0=NO, 1=YES).
C        -AWFC=AVAILABLE WATER AT FIELD CAPACITY/RELEVANT SOIL PROFILE
C             DEPTH (MM)
C        -AWINIT=AVAILABLE WATER/PROFILE AT BEGINNING OF SIMULATION YEAR.
C        -AWFS=AVAILABLE WATER FRACTION AT ONSET OF PLANT STRESS.
C        -NCUTS=NUMBER OF CUTTINGS/YEAR, MAXIMUM=4.
C        -BGNCUT=JULIAN DATE FOR INITIATION OF CUTTINGS 1-4, OVERRIDE=365.
C        -NDAYSC,NDAYSH=NUMBER OF DAYS OVER WHICH CUTTING, HARVESTING
C                     TAKES PLACE.  SET BOTH-1 FOR TESTING AGAINST
C                     EMPIRICAL PLOT DATA.
C        -DUMMY1=DUMMY VARIABLE USED ONLY AS COLUMN INDICATOR IN INPUT FILE.
C
        COMMON/ALF123/SLA,DTL,SDCLAI,XLDLAI,CSF,DTS,XMLDSC,RCTNC,RGR,
       +        XMLBUD,XMLTNC,XFROST,ALCROP,ALSOIL,U,ALPHA,XL,PTF,XLAT,
       +        XIRRIG,AWFC,AWFS,AWINIT,WTHR(365,5),DAY1(39),DEC(39),
       +        DAY2(14),SRAD(14)
        COMMON/CTRL24/BGNCUT(5),NTHYR,NTHCUT,NDAYSC,NDAYSH,YLD(4),
       +        QUAL(3,4),GDDCUM,METRIC,JYEARF,JYEARL,IPRT1,IPRT2,
       +        JDAYF,JDAYL,JPRT,NYRS,IPRT4,NCUTS,JYEAR,JLALHR,CPLANT
        DIMENSION DUMMY1(6)
        DATA NDAYSC/0/,CPLANT/0./
C
        DO 5 I=1,5
5       BGNCUT(I)=365.
C
        READ(5,200)(DUMMY1(I),I=1,6)
        READ(5,100)JDAYF,JDAYL,JYEARF,JYEARL
        READ(5,100)IPRT1,METRIC,IFEED,ICDF
        READ(5,200)AWFC,AWINIT,AWFS
        READ(5,100)NCUTS
        READ(5,200)(BGNCUT(NTHCUT),NTHCUT=1,NCUTS)
C BIG   READ(5,100)NDAYSC,NDAYSH
C
        NYRS=JYEARL-JYEARF+1
        IF(JYEARF.GT.1953)CALL SKIP(JYEARF)
C
        WRITE(6,300)
        WRITE(6,302)JYEARF,JYEARL
        WRITE(6,304)JDAYF,JDAYL
        WRITE(6,306)IPRT1,METRIC
        WRITE(6,340)IFEED,ICDF
        WRITE(6,308)AWFC,AWINIT,AWFS
        WRITE(6,310)NCUTS,(BGNCUT(NTHCUT),NTHCUT=1,NCUTS)
C BIG   WRITE(6,312)NDAYSC,NDAYSH
C
100     FORMAT(12I10)
200     FORMAT(12F10.0)
300     FORMAT('1',' INPUT VALUES FOR ALFALFA SIMULATION RUN',
       +       ' READ INTO SUBROUTINE ALFIN',/,33('-'))
302     FORMAT(/' FIRST AND LAST SIMULATION YEARS=',I6,I6)
304     FORMAT(' FIRST AND LAST SIMULATION DAY (JULIAN)=',I6,I6)
306     FORMAT(' IPRT1 (PRINT CONTROL) AND OUTPUT UNITS',
       +' (0=ENGLISH 1=METRIC)=',I6,I6)
308     FORMAT(' SOIL MOISTURE PARAMETERS: AWFC,AWINIT,AWFS=',
       +2(1X,F5.0),1X,F4.3)
310     FORMAT(' CUTTING DATES (JULIAN) FOR',I2,' CUTS/YR=',4(1X,F5.0))
312     FORMAT(' CUTTING AND HARVEST PERIOD, DAYS=',I4,I4)
340     FORMAT(' OPTION TO DIRECT-CATALOG AFEED AND TCOST MATRICES=',
       +       2I8)
        RETURN
        END
```

```
C     ***********************************************************
      SUBROUTINE ALMAIN(JDAY)
C     ***********************************************************
C
C   ALMAIN IS A SECONDARY EXECUTIVE CALLING PROGRAM WHICH CALLS
C   THE CORE CROP GROWTH AND QUALITY SUBROUTINES. (L. PARSCH,
C   DEPT OF AG ECON, MSU, 10/81)
C
      COMMON/ALF123/SLA,DTL,SDCLAI,XLDLAI,CSF,DTS,XMLOSC,RCTNC,RGR,
     +      XMLBUD,XMLTNC,XFROST,ALCROP,ALSOIL,U,ALPHA,XL,PTF,XLAT,
     +      XIRRIG,AWFC,AWFS,AWINIT,WTHR(365,5),DAY1(39),DEC(39),
     +      DAY2(14),SRAD(14)
      COMMON/CTRL24/BGNCUT(5),NTHYR,NTHCUT,NDAYSC,NDAYSH,YLD(4),
     +      QUAL(3,4),GDDCUM,METRIC,JYEARF,JYEARL,IPRT1,IPRT2,
     +      JDAYF,JDAYL,JPRT,NYRS,IPRT4,NCUTS,JYEAR,JLALHR,CPLANT
      COMMON/ALFARG/GDDB5,AVTA,DAYLIN,DAYLEN,YDAYL,DECR,XLAI,AW,
     +      SUMS1,SUMS2,T,WSF,SRADF,DWS,PPT,ESO,ESR,XLEAF,BUDS,
     +      STEM,TOPS,TNC,XMATS,TNCS,TMAXC,TMINC
C
      IF(JDAY.EQ.JDAYF)CALL ALINIT
     +(JDAYF,GDDB5,DWS,AW,XLEAF,STEM,TOPS,TNC,BUDS,XMATS,XLAI,DD,
     +  DDF,YDAYL,SUMS1,SUMS2,T,TNCS)
C
      CALL ALWTHR(JDAY)
      CALL ASOIL(JDAY)
      CALL ALGROW
      CALL ALYLD
C
C   PRINT CONTROL SECTION FOR PHYSIOLOGICAL GROWTH SECTION.
C
      IF((JDAY.NE.JPRT).OR.(IPRT2.EQ.0))GO TO 120
      WRITE(6,110)JDAY,WTHR(JDAY,1),WTHR(JDAY,4),WTHR(JDAY,5),AVTA,XLAI,
     +AW,DWS,WSF,GDDB5,XMATS,TNC,BUDS,STEM,XLEAF,TOPS,(QUAL(3,K),K=2,4)
 110  FORMAT(' ',1X,I3,1X,F7.0,17(1X,F6.2))
      JPRT=JPRT+IPRT1
C
 120  CALL ALRSET(JDAY)
C
      RETURN
      END
```

```
C     ******************************************************************
      SUBROUTINE ALMAIN(JDAY)
C     ******************************************************************
C
C   ALMAIN IS A SECONDARY EXECUTIVE CALLING PROGRAM WHICH CALLS
C   THE CORE CROP GROWTH AND QUALITY SUBROUTINES. (L. PARSCH,
C   DEPT OF AG ECON, MSU, 10/81)
C
      COMMON/ALF123/SLA,DTL,SDCLAI,XLDLAI,CSF,DTS,XMLOSC,RCTNC,RGR,
     +       XMLBUD,XMLTNC,XFROST,ALCROP,ALSOIL,U,ALPHA,XL,PTF,XLAT,
     +       XIRRIG,AWFC,AWFS,AWINIT,WTHR(365,5),DAY1(39),DEC(39),
     +       DAY2(14),SRAD(14)
      COMMON/CTRL24/BGNCUT(5),NTHYR,NTHCUT,NDAYSC,NDAYSH,YLD(4),
     +       QUAL(3,4),GDDCUM,METRIC,JYEARF,JYEARL,IPRT1,IPRT2,
     +       JDAYF,JDAYL,JPRT,NYRS,IPRT4,NCUTS,JYEAR,JLALHR,CPLANT
      COMMON/ALFARG/GDDB5,AVTA,DAYLIN,DAYLEN,YDAYL,DECR,XLAI,AW,
     +       SUMS1,SUMS2,T,WSF,SRADF,DWS,PPT,ESO,ESR,XLEAF,BUDS,
     +       STEM,TOPS,TNC,XMATS,TNCS,TMAXC,TMINC
C
      IF(JDAY.EQ.JDAYF)CALL ALINIT
     +(JDAYF,GDDB5,DWS,AW,XLEAF,STEM,TOPS,TNC,BUDS,XMATS,XLAI,DD,
     +  DDF,YDAYL,SUMS1,SUMS2,T,TNCS)
C
      CALL ALWTHR(JDAY)
      CALL ASOIL(JDAY)
      CALL ALGROW
      CALL ALYLD
C
C   PRINT CONTROL SECTION FOR PHYSIOLOGICAL GROWTH SECTION.
C
      IF((JDAY.NE.JPRT).OR.(IPRT2.EQ.0))GO TO 120
      WRITE(6,110)JDAY,WTHR(JDAY,1),WTHR(JDAY,4),WTHR(JDAY,5),AVTA,XLAI,
     +AW,DWS,WSF,GDDB5,XMATS,TNC,BUDS,STEM,XLEAF,TOPS,(QUAL(3,K),K=2,4)
110   FORMAT(' ',1X,I3,1X,F7.0,17(1X,F6.2))
      JPRT=JPRT+IPRT1
C
120   CALL ALRSET(JDAY)
C
      RETURN
      END
```

```
C     ********************************************************
         SUBROUTINE ALINIT
        +(JDAYF,GDDB5I,DWSI,AWI,XLEAFI,STEMI,TOPSI,TNCI,BUDI,XMATSI,
        +XLAII,DDI,DDFI,YDAYLI,SUMS1I,SUMS2I,TI,TNCSI)
C     ********************************************************
C
C     SUBROUTINE ALINIT INITIALIZES VALUES OF VARIABLES
C     USED IN THE ALFALFA GROWTH SIMULATOR.  IT IS CALLED ON FIRST
C     SIMULATION DAY OF EACH RUN YEAR.  (L. PARSCH VERSION OF FICK,
C     DEPT OF AG ECON, MSU, 10/81)
C
         COMMON/ALF123/SLA,DTL,SDCLAI,XLDLAI,CSF,DTS,XMLOSC,RCTNC,RGR,
     +        XMLBUD,XMLTNC,XFROST,ALCROP,ALSOIL,U,ALPHA,XL,PTF,XLAT,
     +        XIRRIG,AWFC,AWFS,AWINIT,WTHR(365,5),DAY1(39),DEC(39),
     +        DAY2(14),SRAD(14)
C
C     THE FOLLOWING VARIABLES MUST BE INITIALIZED FOR EACH
C     SPECIFIC RUN.
C
         XLEAFI=0.0
         STEMI=0.0
         TOPSI=XLEAFI + STEMI
         TNCI=75.0
         BUDI=10.
         XMATSI=0.0
C
         GDDB5I=0.
         DWSI=0.0
         AWI=AWINIT
C
         DDI=0.
         DDFI=0.
C
         XIRRIG=0.
         TNCSI=0.
C
C     COMPUTE DAYLENGTH OF DAY BEFORE JDAYF
C
         YESTRDY=JDAYF-1
         DECF=TABLI(DEC,DAY1,YESTRDY,39)
         DECY=(2.* 3.1416/360.)*DECF
         XLATR=(3.1416/180.* XLAT)
         COSUNR= -SIN(XLATR) * SIN(DECY)/(COS(XLATR)*COS(DECY))
         SUNRIZ=ACOS(COSUNR) * 12./3.1416
         YDAYLI=2.*SUNRIZ
C
         XLAII=AMAX1(0., SLA*XLEAFI)
         SUMS1I=AMIN1(AWFC-AWI, U)
         SUMS2I=AMAX1(0., AWFC-AWI-U )
         TI=(SUMS2I/ALPHA)**2.
C
         RETURN
         END
```

```
C
C     ****************************************************************
      SUBROUTINE ALWTHR(JDAY)
C     ****************************************************************
C
C     GET AVERAGE TEMPERATURE OF AIR, CUMULATIVE HEAT UNITS,
C     SOLAR RADIATION, DAYLENGTH, AND DETERMINE IF DAYLENGTH IS
C     INCREASING OR DECREASING.
C     WEATHER DATA IS YR/MO/DY,MAXF,MINF,PREC(INCHES*100),SOLRAD(LY/DY).
C     (L. PARSCH VERSION OF FICK, DEPT OF AG ECON, MSU, 10/81)
C
      COMMON/ALF123/SLA,DTL,SDCLAI,XLDLAI,CSF,DTS,XMLOSC,RCTNC,RGR,
     +      XMLBUD,XMLTNC,XFROST,ALCROP,ALSOIL,U,ALPHA,XL,PTF,XLAT,
     +      XIRRIG,AWFC,AWFS,AWINIT,WTHR(365,5),DAY1(39),DEC(39),
     +      DAY2(14),SRAD(14)
      COMMON/ALFARG/GDDB5,AVTA,DAYLIN,DAYLEN,YDAYL,DECR,XLAI,AW,
     +      SUMS1,SUMS2,T,WSF,SRADF,DWS,PPT,ESO,ESR,XLEAF,BUDS,
     +      STEM,TOPS,TNC,XMATS,TNCS,TMAXC,TMINC
C
      TMAXC=(WTHR(JDAY,2)-32.)*(5./9.)
      TMINC=(WTHR(JDAY,3)-32.)*(5./9.)
      AVTA=(TMAXC+TMINC)/2.
      DD=AMAX1(0.,AVTA-5.)
C
      IF((XFROST-AVTA).LT. 0.)DDF=0.
      IF((XFROST-AVTA).GE. 0.)DDF=GDDB5
C
      GDDB5=GDDB5+DD-DDF
C
C     COMPUTE HOURS OF DAYLIGHT FOR TODAY
C
      XDAY=JDAY
      XLATR=2.*3.1416*XLAT/360.
      DECF=TABLI(DEC,DAY1,XDAY,39)
      DECR=2.* 3.1416 * DECF/360.
      COSUNR= -SIN(XLATR) *SIN(DECR)/(COS(XLATR) * COS(DECR))
      SUNRIZ=ACOS(COSUNR) * 12./3.1416
      DAYLIN=2.*SUNRIZ
C
C     DETERMINE IF DAYLENGTH IS INCREASING OR DECREASING
C
      IF(DAYLIN-YDAYL)10,20,20
10    YDAYL=DAYLIN
      DAYLEN=(-1.)*DAYLIN
      GO TO 30
20    DAYLEN=DAYLIN
      YDAYL=DAYLEN
30    CONTINUE
C
      RETURN
      END
```

```
C
C  ***********************************************************
      SUBROUTINE ASOIL(JDAY)
C  ***********************************************************
C
C  CALCULATE EVAPOTRANSPIRATION,WATER STRESS FACTOR, AND DAYS OF
C  WATER STRESS.  (L.PARSCH VERSION OF FICK, DEPT OF AG ECON,
C  MSU, 10/81)
C
      COMMON/ALF123/SLA,DTL,SDCLAI,XLDLAI,CSF,DTS,XMLOSC,RCTNC,RGR,
     +      XMLBUD,XMLTNC,XFROST,ALCROP,ALSOIL,U,ALPHA,XL,PTF,XLAT,
     +      XIRRIG,AWFC,AWFS,AWINIT,WTHR(365,5),DAY1(39),DEC(39),
     +      DAY2(14),SRAD(14)
      COMMON/ALFARG/GDDB5,AVTA,DAYLIN,DAYLEN,YDAYL,DECR,XLAI,AW,
     +      SUMS1,SUMS2,T,WSF,SRADF,DWS,PPT,ESO,ESR,XLEAF,BUDS,
     +      STEM,TOPS,TNC,XMATS,TNCS,TMAXC,TMINC
C
      XLATR=2*3.1416 * XLAT/360.
      HA=ACOS(-TAN(DECR) * TAN(XLATR))
      SUN=(1440./3.1416)*(1.95*(HA*SIN(XLATR)*SIN(DECR)+
     +    COS(XLATR)*COS(DECR)*SIN(HA)))
      EMIS=1. - .261 * EXP(-7.77E-4 * AVTA**2.)
      SRADM=.75*SUN
C
C  CALCULATE TODAY'S SOLAR RADIATION
C
      SRADF=WTHR(JDAY,5)
      FPS=AMIN1(SRADF/SRADM,1.)
      TRAD=(EMIS-.97)*(118.E-9)*((273.+AVTA)**4.)*
     +    (1.35*FPS-.35)
      ALBEDO=ALSOIL+.25*(ALCROP-ALSOIL)* AMIN1(XLAI,4.)
      XNRAD=((1.-ALBEDO) * SRADF + TRAD)
C
C  EVAPOTRANSPIRATION AND SOIL MOISTURE STRESS
C
      XNRADS=XNRAD * EXP(-4.*XLAI)
      PTFS=.92 + (4. * (XNRADS/XNRAD))
      DG=.389 + (.0167*AVTA)-.000141*(AVTA**2.)
      ESO=PTFS * DG * XNRADS/XL
      EO=PTF *DG * XNRAD/XL
      EP=AMIN1(EO, EO*(-.21+.7*AMAX1(.3, SQRT(XLAI))),
     +    (EO/AWFS) * AMAX1(O., AW/AWFC))
C
C  CONVERT DAILY RAINFALL INTO METRIC
C
      PPT=WTHR(JDAY,4) * .254
      CALL ALEVAP(SUMS1,SUMS2,PPT,T,ESO,ESR,AW)
C
      ES=AMIN1(EO-EP,ESR)
      ET=EP+ES
      DRAIN=AMAX1(O., AW+PPT+XIRRIG-ET-AWFC)
      AW=AW+(PPT+XIRRIG-DRAIN-ET)
      WSF=AMIN1(1., (AW/(AWFC*AWFS)))
C
      IF((AW/AWFC-AWFS) .LE. O.) DWS=DWS+1.
      IF((AW/AWFC-AWFS) .GT. O.) DWS=DWS
C
      RETURN
      END
```

```
C
C     ***************************************************
      SUBROUTINE ALEVAP
     +(SUMS1,SUMS2,PPT,T,ESO,ESR,AW)
C     ***************************************************
C
C     EVAPOTRANSPIRATION MODEL BASED ON RITCHIE.  CORE FORTRAN CODING IS
C     TAKEN FROM FICK.  (L. PARSCH, DEPT OF AG ECON, MSU, 10/81)
C
      COMMON/ALF123/SLA,DTL,SDCLAI,XLDLAI,CSF,DTS,XMLOSC,RCTNC,RGR,
     +      XMLBUD,XMLTNC,XFROST,ALCROP,ALSOIL,U,ALPHA,XL,PTF,XLAT,
     +      XIRRIG,AWFC,AWFS,AWINIT,WTHR(365,5),DAY1(39),DEC(39),
     +      DAY2(14),SRAD(14)
C
      IF(SUMS1-U)21,27,27
21    IF(PPT+XIRRIG-SUMS1)22,23,23
22    SUMS1=AMAX1(SUMS1-PPT-XIRRIG, AMIN1(U,AWFC+PPT+XIRRIG-AW))
      GO TO 24
C
23    SUMS1=0.
24    SUMS1=SUMS1 + ESO
      IF(SUMS1-U)25,25,26
25    ESR=ESO
      T=0.
      SUMS2=0.
      GO TO 39
C
26    ESR=ESO-.4 * (SUMS1-U)
      SUMS2= .6*(SUMS1-U)
      T=(SUMS2/ALPHA)**2.
      GO TO 39
C
27    IF(PPT+XIRRIG-SUMS2)29,28,28
28    P=PPT+XIRRIG-SUMS2
      SUMS1=U-P
      IF(P-U)24,24,23
29    T=T+1.
      ESR=ALPHA * SQRT(T) -ALPHA * SQRT(T-1.)
      IF(PPT+XIRRIG)31,31,33
31    IF(ESR-ESO)38,38,32
32    ESR=ESO
      GO TO 38
C
33    ESX=.8 * (PPT+XIRRIG)
      IF(ESX-ESR)34,34,35
34    ESX=ESR+PPT+XIRRIG
35    IF(ESX-ESO)37,37,36
36    ESX=ESO
37    ESR=ESX
38    SUMS2=AMAX1(SUMS2+ESR-PPT-XIRRIG,
     +      AWFC+PPT+XIRRIG-AW-U)
      T=(SUMS2/ALPHA)**2.
      SUMS1=U
39    CONTINUE
C
      RETURN
      END
```

```
C
C  ***********************************************************
      SUBROUTINE ALGROW
C  ***********************************************************
C
C  ALGROW CONTAINS THE BASIC RATE AND STATE VARIABLES FOR
C  ALFALFA GROWTH, DAILY BASIS,  (L.PARSCH VERSION OF FICK,
C  DEPT OF AG ECON, MSU, 10/81)
C
      COMMON/ALF123/SLA,DTL,SDCLAI,XLDLAI,CSF,DTS,XMLOSC,RCTNC,RGR,
     +       XMLBUD,XMLTNC,XFROST,ALCROP,ALSOIL,U,ALPHA,XL,PTF,XLAT,
     +       XIRRIG,AWFC,AWFS,AWINIT,WTHR(365,5),DAY1(39),DEC(39),
     +       DAY2(14),SRAD(14)
      COMMON/ALFARG/GDDB5,AVTA,DAYLIN,DAYLEN,YDAYL,DECR,XLAI,AW,
     +       SUMS1,SUMS2,T,WSF,SRADF,DWS,PPT,ESO,ESR,XLEAF,BUDS,
     +       STEM,TOPS,TNC,XMATS,TNCS,TMAXC,TMINC
C
      COMMON/PLANT/
     +XLAI1(7),SDAB(7),    XLAI2(9),XLDAB(9),   DAYLEN2(6),BEFD(6),
     +SRADA1(9),GFASR(9),  GDDB51(8),ESPM(8),   DAYLEN3(13),EDSG(13),
     +AVTA1(11),ETG(11),   XLEAF1(9),ELLG(9),   DAYLEN4(4),EDS(4),
     +DAYLEN1(10),EDLG(10), XLEAF2(4),FTGL(4),   TNC1(5),BUDC(5),
     +SRADN1(8),ESRBG(8),  STEM1(8), ESSG(8),   TNC2(7),ETNCS(7),
     +AVTA2(4),TEF(4)
C
      IF(DAYLIN.LT.YDAYL)DAYLEN=(-1.)*DAYLIN
      IF(DAYLIN.GE.YDAYL)DAYLEN=DAYLIN
C
C  MATS SECTION
C
      SDABF=TABLI(SDAB,XLAI1,XLAI,7)
      XLDABF=TABLI(XLDAB,XLAI2,XLAI,9)
      IF(DAYLIN.GT.15.)DLFAC=0.
      IF(DAYLIN.LT.12.)DLFAC=1.
      IF((DAYLIN.GE.12.).AND.(DAYLIN.LE.15.))DLFAC=(15.-DAYLIN)/3.
      FSRADA=XLDABF+(SDABF-XLDABF)*DLFAC
      SRADA=SRADF*FSRADA
C
      GFASRF=TABLI(GFASR,SRADA1,SRADA,9)
      ESPMF=TABLI(ESPM,GDDB51,GDDB5,8)
      ETGF=TABLI(ETG,AVTA1,AVTA,11)
      GRM=GFASRF*ESPMF*ETGF*WSF
      XMATS=GRM
C
C  LEAF SECTION
C
      ELLGF=TABLI(ELLG,XLEAF1,XLEAF,9)
      EDLGF=TABLI(EDLG,DAYLEN1,DAYLEN,10)
      FTGLF=TABLI(FTGL,XLEAF2,XLEAF,4)
      PGRL=.2*XLEAF*ELLGF*EDLGF
      GRL=AMIN1(XMATS*FTGLF,PGRL)*WSF
      CLEAF=(XLDLAI-DLFAC*(XLDLAI-SDCLAI))/SLA
      SRL=AMAX1(0.,(XLEAF-CLEAF)/DTL)
C
      SRADN=SRADF-SRADA
      ESRBGF=TABLI(ESRBG,SRADN1,SRADN,8)
      TEFF=TABLI(TEF,AVTA2,AVTA,4)
      BEFDF=TABLI(BEFD,DAYLEN2,DAYLEN,6)
C
      IF(XMATS*(-1.))5,10,10
5     BEF=ESRBGF*BEFDF*TEFF
      GO TO 15
10    BEF=BEFDF*TEFF
15    GRLB=BUDS/XMLBUD*BEF*WSF
C
      IF((XFROST-AVTA).LT.0.)FRL=0.
      IF((XFROST-AVTA).GE.0.)FRL=XLEAF
      XLOSSL=AMAX1(SRL,FRL)
      XLEAF=XLEAF+GRL+GRLB-XLOSSL
      XLAI=AMAX1(0.,SLA*XLEAF)
C
C  STEM SECTION
C
      ESSGF=TABLI(ESSG,STEM1,STEM,8)
      EDSGF=TABLI(EDSG,DAYLEN3,DAYLEN,13)
      PGRS=.499*STEM*ESSGF*EDSGF
      GRS=AMIN1(XMATS*(1.-FTGLF),PGRS)*WSF
```

```
      CSTEM=TOPS*CSF
      SRS=AMAX1(O.,(STEM-CSTEM)/DTS)
C
      IF((XFROST-AVTA).LT.O.)FRS=O.
      IF((XFROST-AVTA).GE.O.)FRS=STEM
      XLOSSS=AMAX1(SRS,FRS)
      GRSB=GRLB*.1
      STEM=STEM+GRS+GRSB-XLOSSS
      TOPS=XLEAF+STEM
C
C  BUDS SECTION
C
      BUDCF=TABLI(BUDC,TNC1,TNC,5)
      GRB=(1.-RCTNC)*
     +        AMIN1((BUDCF-BUDS)/(1.-RCTNC),TNC/XMLTNC,
     +              RGR*(TOPS+BUDS))*ETGF
      BUDS=BUDS+GRB-GRLB-GRSB
C
C  TNC SECTION
C
      IF((DAYLIN-11.5).GT.O.)TNCS=TNC
      IF((DAYLIN-11.5).LE.O.)TNCS=TNCS
      IF(GRM.LE.O.)XMLOSS=TNCS*XMLOSC
      IF(GRM.GT.O.)XMLOSS=O.
      TRESP=XMLOSS+GRB*RCTNC/(1.-RCTNC)
C
      ETNCSF=TABLI(ETNCS,TNC2,TNC,7)
      EDSF=TABLI(EDS,DAYLEN4,DAYLEN,4)
      PSTOR=EDSF*ETNCSF+GRB+TRESP
      STOR=AMIN1(XMATS-GRL-GRS,PSTOR)
      TNC=TNC+STOR-GRB-TRESP
C
C  CROP DEATH SECTION
C
      TNCD=TNC-5.
      CCOND=1.
      IF((TNCD.LE.O.).OR.(GRM.LE.O.))CCOND=O.
      DEATH=O.
C DB  IF(CCOND.EQ.DEATH)WRITE(6,100)
100   FORMAT(' LOW TNC OR ZERO GROWTH RATE ')
C
C
      RETURN
      END
```

```
C ************************************************************
      SUBROUTINE ALYLD
C ************************************************************
C
C ALYLD CONVERTS DRY MATTER ACCUMULATION TO METRIC YIELD
C AND CALCULATES QUALITY CHARACTERISTICS OF THE CROP.
C QUALITY EQUATIONS ESTIMATED BY PARSCH.  (L. PARSCH,
C DEPT OF AG ECON, MSU, 10/81)
C
      COMMON/CTRL24/BGNCUT(5),NTHYR,NTHCUT,NDAYSC,NDAYSH,YLD(4),
     +       QUAL(3,4),GDDCUM,METRIC,JYEARF,JYEARL,IPRT1,IPRT2,
     +       JDAYF,JDAYL,JPRT,NYRS,IPRT4,NCUTS,JYEAR,JLALHR,CPLANT
      COMMON/ALFARG/GDDB5,AVTA,DAYLIN,DAYLEN,YDAYL,DECR,XLAI,AW,
     +       SUMS1,SUMS2,T,WSF,SRADF,DWS,PPT,ESO,ESR,XLEAF,BUDS,
     +       STEM,TOPS,TNC,XMATS,TNCS,TMAXC,TMINC
C
      DO 5 J=1,4
      YLD(J)=0.0
      DO 5 I=1,3
5     QUAL(I,J)=0.0
C
      IF (TOPS .LE. 0.) GO TO 10
      PCL=XLEAF/TOPS
      IF(PCL .LT. .290)PCL=.290
      IF(PCL .GT. .500)PCL=.500
      PCS=1.-PCL
      CPL=.0852+.4672*PCL
      CPS=1.0140-2.8069*PCS+2.1283*(PCS**2.)
      DIGL=.6031+.6250*PCL-.5279*(PCL**2.)
      DIGS=1.0596-.8666*PCS
      PCCFA=.1576+.00029*GDDB5
C
      GDDCUM=GDDB5
C
C FILL ABOVE VALUES INTO QUALITY MATRIX (3,4).
C ROWS=LEAF,STEM,TOTAL PLANT.
C COLUMNS=PLANT COMPOSITION, CP, DIG, CF.
C
      QUAL(1,1)=PCL
      QUAL(1,2)=CPL
      QUAL(1,3)=DIGL
      QUAL(1,4)=PCCFA
      QUAL(2,1)=PCS
      QUAL(2,2)=CPS
      QUAL(2,3)=DIGS
      QUAL(2,4)=PCCFA
      QUAL(3,1)=PCL + PCS
      QUAL(3,2)= (PCL*CPL) + (PCS*CPS)
      QUAL(3,3)= (PCL*DIGL) + (PCS*DIGS)
      QUAL(3,4)=PCCFA
C
C CONVERT VALUES TO METRIC TONS/HECTARE OR ENGLISH TONS/ACRE.
C
      YLD(1)=TOPS*.01
      IF(METRIC.EQ.0)YLD(1)=YLD(1)*.446356
      YLD(2)=QUAL(3,2)*YLD(1)
      YLD(3)=QUAL(3,3)*YLD(1)
      YLD(4)=QUAL(3,4)*YLD(1)
C
10    CONTINUE
      RETURN
      END
```

```
C
C     ***************************************************
      SUBROUTINE ALRSET(JDAY)
C     ***************************************************
C
C     ALRSET CONTROLS REGROWTH STARTING DATE OF THE ALFALFA CROP AND
C     DETERMINES WHEN THE HARVESTING SUBROUTINES ARE CALLED.
C     (L. PARSCH, DEPT OF AG ECON, MSU, 10/81)
C
      COMMON/ALF123/SLA,DTL,SDCLAI,XLDLAI,CSF,DTS,XMLOSC,RCTNC,RGR,
     +       XMLBUD,XMLTNC,XFROST,ALCROP,ALSOIL,U,ALPHA,XL,PTF,XLAT,
     +       XIRRIG,AWFC,AWFS,AWINIT,WTHR(365,5),DAY1(39),DEC(39),
     +       DAY2(14),SRAD(14)
      COMMON/CTRL24/BGNCUT(5),NTHYR,NTHCUT,NDAYSC,NDAYSH,YLD(4),
     +       QUAL(3,4),GDDCUM,METRIC,JYEARF,JYEARL,IPRT1,IPRT2,
     +       JDAYF,JDAYL,JPRT,NYRS,IPRT4,NCUTS,JYEAR,JLALHR,CPLANT
      COMMON/ALFARG/GDD85,AVTA,DAYLIN,DAYLEN,YDAYL,DECR,XLAI,AW,
     +       SUMS1,SUMS2,T,WSF,SRADF,DWS,PPT,ESO,ESR,XLEAF,BUDS,
     +       STEM,TOPS,TNC,XMATS,TNCS,TMAXC,TMINC
      DIMENSION AWTMP(40),DWSTMP(40),BUDTMP(40),TNCTMP(40)
C
C
      IF(JDAY.EQ.JDAYF)GO TO 5
      GO TO 8

C     ON FIRST SIMULATION DAY OF EACH RUN YEAR, INITIALIZE.

5     NTHCUT=1
      JHARV=0
      IRESET=0
      NDYHRV=0

      DO 6 I=1,40
      AWTMP(I)=0.
      DWSTMP(I)=0.
      BUDTMP(I)=0.
6     TNCTMP(I)=0.
C
8     IF((JDAY.LT.BGNCUT(NTHCUT)).AND.(JHARV.EQ.0))GO TO 10
C
C     THE 8 LOOP IS ACTIVE ONLY WHENEVER NO HARVESTING IS
C     BEING DONE.  THE HARVEST SUBROUTINES ARE BYPASSED.
C
      CALL ALHARV(REMCUT,REMHRV,ICUTON,JDAY)
      IF((ICUTON .EQ. 0).AND.(JHARV .EQ. 0)) GO TO 10
C
C     ICUTON=0 IMPLIES CUTTING HASN'T BEGUN; =1 IMPLIES
C     CUTTING HAS BEGUN.  RESET MECHANISM COUNTERS ACTIV-
C     ATED ONLY WHEN CUTTING HAS BEGUN.
C
      NDYHRV=NDYHRV+1
      IF(NDYHRV.GT.40)WRITE(6,110)
      AWTMP(NDYHRV)=AW
      DWSTMP(NDYHRV)=DWS
      BUDTMP(NDYHRV)=BUDS
      TNCTMP(NDYHRV)=TNC
C
C     IF CUTTING ALONE, CUTTING AND HARVESTING, OR HARVEST-
C     ING ALONE, OR IF SIMPLY CUTTING TIME IS APPROPRIATE,
C     JHARV>0 AND HARVESTING SUBROUTINES MUST BE CALLED.
C
      IF(REMCUT.LE.0.)GO TO 9
      IF(REMCUT.GT.0.)JHARV=1
      GO TO 10
C
C     9 LOOP MEANS CUTTING HAS BEEN COMPLETED AND REGROWTH
C     MUST BE RESET.  10-LOOP RETURNS CONTROL TO CONTINUE
C     ANOTHER DAY'S GROWTH.
C
9     IF((REMHRV.GT.0.).AND.(IRESET.EQ.0))JHARV=2
      IF((REMHRV.GT.0.).AND.(IRESET.EQ.1))JHARV=3
      IF((REMHRV.LE.0.).AND.(IRESET.EQ.0))JHARV=4
      IF((REMHRV.LE.0.).AND.(IRESET.EQ.1))JHARV=5
C
C     IRESET=0 MEANS REGROWTH HAS NOT BEEN SET; =1 MEANS IT
C     HAS BEEN RESET.
C     JHARV=2,3 MEANS HARVESTING CONTINUES,BUT CUTTING IS
```

```
C   DONE.   JHARV=4,5 MEANS BOTH ARE FINISHED.
C
        GO TO (10,20,10,20,50),JHARV
C
C   JHARV=2,4 REQUIRE RESETTING OF REGROWTH.
C   RESET REGROWTH HALF-WAY BETWEEN FIRST AND LAST
C   CUTTING DAY.
C
20      NHALF=NDYHRV/2
        JDRSET=JDAY-NHALF
C BIG   WRITE(6,100)NDYHRV,JDRSET,WTHR(JDRSET,1)
        IPRT2=1
        JPRT=JDAY+IPRT1
        XLEAF=0.
        STEM=0.
        TOPS=XLEAF+STEM
        GDDB5=0.
        IF(NHALF  .LT.  1)NHALF=1
        DWS=DWSTMP(NHALF)
        AW=AWTMP(NHALF)
        BUDS=BUDTMP(NHALF)
        TNC=TNCTMP(NHALF)
        XLAI=AMAX1(0.,SLA*XLEAF)
        IF(JDRSET.GT.(JDAY-1))GO TO 26
C
C   SINCE RESET BEGINS AT JDRSET+1, INITIALIZE RELEVANT
C   VARIABLES FOR JDRSET.
C   CALCULATE YESTERDAY'S DAYLENGTH(JDAYRESET)
C
        YESTRDY=JDRSET
        DECF=TABLI(DEC,DAY1,YESTRDY,39)
        DECY=(2.*3.1416/360.)*DECF
        XLATR=(3.1416/180.*XLAT)
        COSUNR=-SIN(XLATR)*SIN(DECY)/(COS(XLATR)*COS(DECY))
        SUNRIZ=ACOS(COSUNR)*12./3.1416
        YDAYL=2.*SUNRIZ
C
        SUMS1=AMIN1(AWFC-AW,U)
        SUMS2=AMAX1(0.,AWFC-AW-U)
        T=(SUMS2/ALPHA)**2.
C
C   RECALCULATE STATE VARIABLES FROM JDRSET+1 TO TODAY.
C
        JSTART=JDRSET+1
        DO 25 JJ=JSTART,JDAY
        CALL ALWTHR(JJ)
        CALL ASOIL(JJ)
        CALL ALGROW
25      CONTINUE
26      IRESET=1
        IF(REMHRV .LE. 0.) GO TO 50
        GO TO 10
C
50      NTHCUT=NTHCUT+1
        JHARV=0
        IRESET=0
        NDYHRV=0
C
C 100   FORMAT(' HARVEST PD. CAL. DAYS=',I4,' GROWTH RESET=',I4,1X,F7.0,/)
110     FORMAT(' LIMIT ON HARVEST DAYS IN SUB ALRSET EXCEEDED (40)')
C
10      CONTINUE
        RETURN
        END
```

```
C   DONE.  JHARV=4,5 MEANS BOTH ARE FINISHED.
C
        GO TO (10,20,10,20,50),JHARV
C
C   JHARV=2,4 REQUIRE RESETTING OF REGROWTH.
C   RESET REGROWTH HALF-WAY BETWEEN FIRST AND LAST
C   CUTTING DAY.
C
20      NHALF=NDYHRV/2
        JDRSET=JDAY-NHALF
C BIG  WRITE(6,100)NDYHRV,JDRSET,WTHR(JDRSET,1)
        IPRT2=1
        JPRT=JDAY+IPRT1
        XLEAF=0.
        STEM=0.
        TOPS=XLEAF+STEM
        GDDB5=0.
        IF(NHALF .LT. 1)NHALF=1
        DWS=DWSTMP(NHALF)
        AW=AWTMP(NHALF)
        BUDS=BUDTMP(NHALF)
        TNC=TNCTMP(NHALF)
        XLAI=AMAX1(0.,SLA*XLEAF)
        IF(JDRSET.GT.(JDAY-1))GO TO 26
C
C   SINCE RESET BEGINS AT JDRSET+1, INITIALIZE RELEVANT
C   VARIABLES FOR JDRSET.
C   CALCULATE YESTERDAY'S DAYLENGTH(JDAYRESET)
C
        YESTRDY=JDRSET
        DECF=TABLI(DEC,DAY1,YESTRDY,39)
        DECY=(2.*3.1416/360.)*DECF
        XLATR=(3.1416/180.*XLAT)
        COSUNR=-SIN(XLATR)*SIN(DECY)/(COS(XLATR)*COS(DECY))
        SUNRIZ=ACOS(COSUNR)*12./3.1416
        YDAYL=2.*SUNRIZ
C
        SUMS1=AMIN1(AWFC-AW,U)
        SUMS2=AMAX1(0.,AWFC-AW-U)
        T=(SUMS2/ALPHA)**2.
C
C   RECALCULATE STATE VARIABLES FROM JDRSET+1 TO TODAY.
C
        JSTART=JDRSET+1
        DO 25 JJ=JSTART,JDAY
        CALL ALWTHR(JJ)
        CALL ASOIL(JJ)
        CALL ALGROW
25      CONTINUE
26      IRESET=1
        IF(REMHRV .LE. 0.) GO TO 50
        GO TO 10
C
50      NTHCUT=NTHCUT+1
        JHARV=0
        IRESET=0
        NDYHRV=0
C
C 100  FORMAT(' HARVEST PD. CAL. DAYS=',I4,' GROWTH RESET=',I4,1X,F7.0,/)
110     FORMAT(' LIMIT ON HARVEST DAYS IN SUB ALRSET EXCEEDED (40)')
C
10      CONTINUE
        RETURN
        END
```

```
C
C     ****************************************************************
      BLOCK DATA ALFLFA
C     ****************************************************************
C
C     ALFLFA CONTAINS STORED DATA FOR TABLE LOOK-UP FUNCTIONS
C     CONTAINED IN THE PHENOLOGICAL CROP GROWTH MODEL, ALSIM.
C     (L. PARSCH, DEPT OF AG ECON, MSU, 10/81)
C
      COMMON/ALF123/SLA,DTL,SDCLAI,XLDLAI,CSF,DTS,XMLOSC,RCTNC,RGR,
     +       XMLBUD,XMLTNC,XFROST,ALCROP,ALSOIL,U,ALPHA,XL,PTF,XLAT,
     +       XIRRIG,AWFC,AWFS,AWINIT,WTHR(365,5),DAY1(39),DEC(39),
     +       DAY2(14),SRAD(14)
C
      COMMON/PLANT/
     +XLAI1(7),SDAB(7),     XLAI2(9),XLDAB(9),    DAYLEN2(6),BEFD(6),
     +SRADA1(9),GFASR(9),   GDDB51(8),ESPM(8),    DAYLEN3(13),EDSG(13),
     +AVTA1(11),ETG(11),    XLEAF1(9),ELLG(9),    DAYLEN4(4),EDS(4),
     +DAYLEN1(10),EDLG(10), XLEAF2(4),FTGL(4),     TNC1(5),BUDC(5),
     +SRADN1(8),ESRBG(8),   STEM1(8), ESSG(8),    TNC2(7),ETNCS(7),
     +AVTA2(4),TEF(4)
C
      DATA XLAI1/O.,  .5,  .75,  1.,  1.5,  2.,  15./
      DATA SDAB/ O., .55,  .70,  .8,   .9, .95, .999/
C
      DATA XLAI2/O.,  .5,  .75,  1.,  1.5,  2.,  3., 4., 15./
      DATA XLDAB/O.,  .3,  .42,  .5,  .65, .75,  .9,.95,.999/

      DATA SRADA1/O.,100.,200.,300.,400.,500.,600.,700.,800./
      DATA GFASR/ O., 5.8,10.4,14.2,16.9,19.0,21.1,23.1,25.0/

      DATA GDDB51/O.,125.,700.,750.,875.,1000.,2000.,4000./
      DATA ESPM/ .95,  1.,  1.,.950, .70,  .60,  .35,  .25/

      DATA AVTA1/-30.,2., 5.,10.,12.,15.,21.,27.,32.,40.,50./
      DATA ETG/    O.,O., .2,.95, 1., 1.,.92,.66,.36,.05, O./

      DATA XLEAF1/O., 100.,110.,120.,145.,155.,165.,200.,350./
      DATA ELLG/ 1.,    1., .95, .80, .40, .20, .10, .05,  O./

      DATA DAYLEN1/-16.,-14.,-13.5,-10.5,-10.,4.,4.5,8.5,9.,16./
      DATA EDLG/     1.,  1.,  .95,  .15,  .1,.1,.15,.95,1., 1./

      DATA XLEAF2/ O.,  190.,  250.,  350./
      DATA FTGL/   .9,   .42,   .40,   .40/

      DATA SRADN1/ O., 30., 40., 50., 80., 90., 100., 800./
      DATA ESRBG/  O.,  O., .05, .15, .85, .95,   1.,   1./

      DATA STEM1/O.,155.,175.,205.,240.,265.,285.,500./
      DATA ESSG/ 1.,  1., .95, .80, .30, .10, .05,  O./

      DATA DAYLEN3/-16.,-14.,-13.5,-12.5,-12.,-11.5,-10.5,
     +             9., 9.5, 10.5, 12.5, 13., 16.0/
      DATA EDSG/      1.,  1.,   .9,  .25,  .15,   .1,  .05,
     +             .05,  .1,   .4,   .9,  1.,  1./

      DATA TNC2/ O., 80., 90., 100.,110.,140.,150./
      DATA ETNCS/1., 1.,  .9,   .5,  .1, .05,  O./

      DATA TNC1/ O.,  50.,  100.,  125.,  150./
      DATA BUDC/ 5.,   8.,   12.,   15.,   20./

      DATA AVTA2/ -30.,  4.,  6.,  50./
      DATA TEF/     O.,  O.,  1.,   1./

      DATA DAYLEN2/ -16., -11.5, -11.0, 11.0, 11.5, 16.0/
      DATA BEFD/      1.,   1.0,    .0,   .0,  1.0,  1.0/

      DATA DAYLEN4/ -16., -5., 5., 16./
      DATA EDS/      3.5, 3.5, 1.,  1./

      DATA DAY1/O.,10.,20.,30.,40.,50.,60.,70.,80.,90.,100.,110.,120.,
     1 130.,140.,150.,160.,170.,180.,190.,200.,210.,220.,230.,240.,250.,
     2 260.,270.,280.,290.,300.,310.,320.,330.,340.,350.,360.,370.,380./
      DATA DEC/-23.,-22.,-20.,-18.,-15.,-11.,-7.,-3.,O.,4.,
     +          8., 11., 14., 18., 20., 22.,23.,24.,23.,22.,
```

```
     +          21., 19., 16., 10.,  6.,  1.,-2.,-6.,-9.,-13.,
     +         -17.,-19.,-21.,-22.,-23.,-24.,-23.,-23.,-22./

      DATA DAY2/ -15.0,  15.0,  45.0,  75.0, 106.0, 136.0, 167.0,
     +            197.0, 228.0, 259.0, 289.0, 320.0, 350.0, 381.0/
      DATA SRAD/ 106.9, 140.5, 221.9, 295.8, 377.6, 479.5, 524.9,
     +           513.0, 448.1, 344.9, 237.1, 130.1, 106.9, 140.5/

      DATA SLA,DTL,SDCLAI,XLDLAI,CSF,DTS,XMLOSC,RCTNC,
     +     RGR,XMLBUD,XMLTNC
     +     /.02,  7.,  1.5  ,.5.   ,.75  ,.14.   ,.00093,.6  ,
     +       .5 ,  2.,   14./
C
      DATA XFROST,ALCROP,ALSOIL,U,ALPHA,XL,PTF,XLAT,XIRRIG
     +     /-3.33,.23  ,.2  ,.10.  ,4.5  ,58.  ,1.32 , 42.7, 0./
C
      END
```

```
C     *****************************************************
      SUBROUTINE ALTEST(REMCUT,REMHRV,ICUTON,JDAY)
C     *****************************************************
C
C  ALTEST IS A TEST SUBROUTINE OF HARVEST WHICH PERMITS THE
C  CUTTING AND HARVEST PERIOD LENGTH TO VARY, AND SETS THE SIGNAL
C  THAT CUTTING HAS BEGUN.  FOR 1-DAY HARVEST PERIOD, (TO CHECK
C  ALSIM1-LEVEL 2 VALUES) SET NDAYSC=NDAYSH=1. (L. PARSCH,
C  DEPT OF AG ECON, MSU, 10/81)
C
      COMMON/ALF123/SLA,DTL,SDCLAI,XLDLAI,CSF,DTS,XMLOSC,RCTNC,RGR,
     +       XMLBUD,XMLTNC,XFROST,ALCROP,ALSOIL,U,ALPHA,XL,PTF,XLAT,
     +       XIRRIG,AWFC,AWFS,AWINIT,WTHR(365,5),DAY1(39),DEC(39),
     +       DAY2(14),SRAD(14)
      COMMON/CTRL24/BGNCUT(5),NTHYR,NTHCUT,NDAYSC,NDAYSH,YLD(4),
     +       QUAL(3,4),GDDCUM,METRIC,JYEARF,JYEARL,IPRT1,IPRT2,
     +       JDAYF,JDAYL,JPRT,NYRS,IPRT4,NCUTS,JYEAR,JLALHR,CPLANT
      COMMON/ALFARG/GDDB5,AVTA,DAYLIN,DAYLEN,YDAYL,DECR,XLAI,AW,
     +       SUMS1,SUMS2,T,WSF,SRADF,DWS,PPT,ESO,ESR,XLEAF,BUDS,
     +       STEM,TOPS,TNC,XMATS,TNCS,TMAXC,TMINC
      COMMON/TEST/YTST(26,20),STST(4,20)
      DATA YTST/520*0./,STST/80*0./
C
      ICUTON=NTHCUT
      IF (JDAY .EQ. BGNCUT(NTHCUT)) THEN
         IDAYS=1
         IPRT2=0
         IF((NTHCUT.EQ.1).AND.(IPRT1.EQ.999))WRITE(6,250)NTHYR,JYEAR
         WRITE(6,100)NTHCUT,WTHR(JDAY,1)
         WRITE(6,105)
      ELSE
         IDAYS=IDAYS+1
      ENDIF
C
      REMCUT=NDAYSC - IDAYS
      REMHRV=NDAYSH - IDAYS
      IF((REMCUT.LE.0.).AND.(NDAYSC.GT.1))ICUTON=0
C
      JCOL=((NTHCUT-1)*4)
      K=16
      DO 10 I=1,4
      IF(I.EQ.1)THEN
         YTST(NTHYR,JCOL+I)=YTST(NTHYR,JCOL+I)+YLD(I)
         YTST(NTHYR,K+I)=YTST(NTHYR,K+I)+YLD(I)
      ELSE
         YTST(NTHYR,JCOL+I)=YTST(NTHYR,JCOL+I)+QUAL(3,I)
         YTST(NTHYR,K+I)=YTST(NTHYR,K+I)+QUAL(3,I)
      ENDIF
10    CONTINUE
C
C  AVERAGE VALUES OF YTST OVER THE NUMBER OF DAYS/CUTTING.
C
      IF((NTHCUT.EQ.NCUTS).AND.(REMCUT.LE.0.))THEN
         DO 20 J=1,20
         IF(J.LE.17)THEN
            YTST(NTHYR,J)=YTST(NTHYR,J)/NDAYSC
         ELSE
            YTST(NTHYR,J)=YTST(NTHYR,J)/(NCUTS*NDAYSC)
         ENDIF
20       CONTINUE
      ENDIF
C
      WRITE(6,110)JDAY,WTHR(JDAY,1),AVTA,WTHR(JDAY,4),DAYLIN,
     +(YLD(I),I=1,4),(QUAL(3,K),K=2,4)
C
100   FORMAT(' ',/,' HARVEST PD  ',I4,' BEGINS ON ',F9.0)
105   FORMAT(' HARVEST OUTPUT COLS:',/,
     +' 1=JDAY 2=CDATE 3=AVTA 4=PREC 5=DAYLIN 6=DMYLD 7=CPDM 8=DIGDM',
     +' 9=CFDM 10=CP 11=DIG 12=CF')
110   FORMAT(' ',1X,I3,1X,F7.0,17(1X,F6.2))
250   FORMAT(////,' BEGIN SIMULATION YEAR',I3,' (',I4,')',/)
      RETURN
      END
```

```
C  ****************************************
      SUBROUTINE ALFOUT(ILINE)
C  ****************************************
C
C   THIS SUBROUTINE STORES AND WRITES OUT YIELD AND QUALITY
C   VALUES OF THE ALFALFA CROP GENERATED ON THE FIRST DAY OF
C   THE ALFALFA CUTTING.  HENCE, VALUES REPRESENT THE PRE-
C   HARVEST STATUS OF THE STANDING CROP GENERATED BY THE ALSIM
C   MODEL.  (L. PARSCH, DEPT OF AG ECON, MSU, 3/82)
C
      COMMON/ALFARG/GDDB5,AVTA,DAYLIN,DAYLEN,YDAYL,DECR,XLAI,AW,
     +       SUMS1,SUMS2,T,WSF,SRADF,DWS,PPT,ESO,ESR,XLEAF,BUDS,
     +       STEM,TOPS,TNC,XMATS,TNCS,TMAXC,TMINC
      COMMON/CTRL24/BGNCUT(5),NTHYR,NTHCUT,NDAYSC,NDAYSH,YLD(4),
     +       QUAL(3,4),GDDCUM,METRIC,JYEARF,JYEARL,IPRT1,IPRT2,
     +       JDAYF,JDAYL,JPRT,NYRS,IPRT4,NCUTS,JYEAR,JLALHR,CPLANT
      COMMON/TEST/YTST(26,20),STST(4,20)
C
      DIMENSION YALF(26,25),SALF(4,25)
      DATA YALF/650*0./,SALF/100*0./,MCOL/0/
C
      GO TO (10,20,30,40)ILINE
C
C   PRINT CONTROL MECHANISM FOR OUTPUTTING VALUES ON DAILY BASIS
C   FROM PHENOLOGICAL CROP GROWTH MODEL, ALSIM2.
C
10    WRITE(6,250)NTHYR,JYEAR
      WRITE(6,255)
      JPRT=JDAYF+IPRT1
      IPRT2=1
      RETURN
C
C   ON FIRST DAY OF ANTICIPATED HARVEST, STORE VALUES
C   REFLECTING STANDING ALFALFA CROP QUANTITY/QUALITY ON A
C   CUTTING BY CUTTING BASIS.
C
20    YALF(NTHYR,MCOL+1)=YLD(1)
      YALF(NTHYR,MCOL+2)=QUAL(3,2)
      YALF(NTHYR,MCOL+3)=QUAL(3,3)
      YALF(NTHYR,MCOL+4)=QUAL(3,4)
      YALF(NTHYR,MCOL+5)=GDDCUM
      YALF(NTHYR,21)=YALF(NTHYR,21)+YLD(1)
      YALF(NTHYR,22)=YALF(NTHYR,22)+YLD(2)
      YALF(NTHYR,23)=YALF(NTHYR,23)+YLD(3)
      YALF(NTHYR,24)=YALF(NTHYR,24)+YLD(4)
      YALF(NTHYR,25)=YALF(NTHYR,25)+GDDCUM
      MCOL=MCOL+5
      RETURN
C
C   AT END OF EACH SIMULATION YEAR, SUMMARIZE STANDING QUANTITY/
C   QUALITY OVER ALL CUTTINGS THIS YEAR.
C
30    YALF(NTHYR,22)=YALF(NTHYR,22)/YALF(NTHYR,21)
      YALF(NTHYR,23)=YALF(NTHYR,23)/YALF(NTHYR,21)
      YALF(NTHYR,24)=YALF(NTHYR,24)/YALF(NTHYR,21)
      MCOL=0
      RETURN
C
C   AT END OF SIMULATION RUN, PRINT OUT SUMMARY MATRIX, CALCULATE
C   AND PRINT OUT SAMPLE STATISTICS.
C
40    WRITE(6,1000)NYRS,JYEARF,JYEARL
      WRITE(6,1100)
      WRITE(6,1199)((JCOL),JCOL=1,25)
      DO 50 N=1,NYRS
50    WRITE(6,1200)N,(YALF(N,JCOL),JCOL=1,25)
      WRITE(6,1125)
      CALL SSTAT(25,YALF,NTHYR,SALF)
      WRITE (6,1150)
      DO 60 ISTAT=1,2
60    WRITE(6,1200)ISTAT,(SALF(ISTAT,JCOL),JCOL=1,25)
      WRITE(6,1201)ISTAT,((SALF(ISTAT,JCOL),JCOL=1,25),ISTAT=3,3)
      WRITE(6,1125)
C
      IF(NDAYSC.GT.1)THEN
         WRITE(6,1290)NDAYSC
         DO 70 N=1,NYRS
```

```
70          WRITE(6,1300)N,(YTST(N,J),J=1,20)
C
            CALL SSTAT(20,YTST,NYRS,STST)
            WRITE(6,1150)
            DO 80 I=1,2
80          WRITE(6,1301)I,(STST(I,J),J=1,20)
            WRITE(6,1301)I,((STST(I,J),J=1,20),I=3,3)
         ENDIF
C
1000     FORMAT('1','SUMMARY OUTPUT FOR',I3,' SIMULATION YEARS,',
     +          I5,'-',I4,': MATRIX YALF, PRE-HARVEST ALFALFA ',
     +          ' YIELD, QUALITY.')
1100     FORMAT(//' SUMMARY OUTPUT COLUMNS: EVERY 5 COLS=1 CUTTING.',
     +' INDIVIDUAL COLS ARE: 1=DMYLD  2=CP  3=DIG  4=CF  5=GDDB5.'
     +/' COLS 1-20 SUMMARIZE CUTTINGS 1-4; COLS 21-25 SUMMARIZE TOTAL',
     +' ANNUAL PRODUCTION.',/,' EACH ROW IS ONE SIMULATION YEAR.',
     +' ALL MEASURES ARE TAKEN ON FIRST DAY OF CUTTING.',/)
1125     FORMAT(3X,4(1X,25('-')),2X,26('-'))
1150     FORMAT(///' SAMPLE STATISTICS FOR SIMULATION OUTPUT.',
     +' ROWS: 1=MEAN  2=STANDARD DEVIATION 3=COEF. OF VARIATION',/)
C
C1200    FORMAT(//26(5(1X,F5.2,3(1X,F4.2),1X,F5.0)/))
1199     FORMAT(3X,4(1X,I5,3(1X,I4),1X,I4),
     +          2X,I5,3(1X,I4),1X,I5,/)
1200     FORMAT(1X,I2,4(1X,F5.2,3(1X,F4.2),1X,F4.0),
     +          2X,F5.2,3(1X,F4.2),1X,F5.0)
1201     FORMAT(1X,I2,4(1X,F5.2,3(1X,F4.2),1X,F4.2),
     +          2X,F5.2,3(1X,F4.2),1X,F5.2)
C
250      FORMAT(////,' BEGIN SIMULATION YEAR',I3,' (',I4,')',/)
255      FORMAT(' OUTPUT COLS FROM CROP GROWTH PHASE (LONG FORMAT):'/,
     +' 1=JDAY 2=DATE 3=PREC 4=SRAD 5=AVTA 6=LAI 7=AW 8=DWS 9=WSF',
     +' 10=GDD 11=MATS 12=TNC 13=BUDS 14=STEM 15=LEAF 16=TOPS 17=CP',
     +' 18=DIG 19=CF')
C
1290     FORMAT('1','SUMMARY OUTPUT (2) FOR MATRIX YALF ',
     +          ':  PRE-HARVEST ALFALFA YIELD/QUALITY.  ',/,
     +          ' ALL MEASURES AVERAGED OVER',I4,'-DAY CUTTING PERIOD.',/,
     +          ' EVERY 4 COLUMNS=1 CUTTING.  COLS:  1=DMYLD  2=CP  3=DIG ',
     +          ' 4=CF.',/)
1300     FORMAT(1X,I2,4(1X,F5.2,3(1X,F4.2),5X),
     +          2X,F5.2,3(1X,F4.2),6X)
1301     FORMAT(1X,I2,4(1X,F5.2,3(1X,F4.2),5X),
     +          2X,F5.2,3(1X,F4.2),6X)
C
         RETURN
         END
```

```
70          WRITE(6,1300)N,(YTST(N,J),J=1,20)
C
            CALL SSTAT(20,YTST,NYRS,STST)
            WRITE(6,1150)
            DO 80 I=1,2
80          WRITE(6,1301)I,(STST(I,J),J=1,20)
            WRITE(6,1301)I,((STST(I,J),J=1,20),I=3,3)
        ENDIF
C
1000    FORMAT('1','SUMMARY OUTPUT FOR',I3,' SIMULATION YEARS.',
       +        I5,'-',I4,': MATRIX YALF, PRE-HARVEST ALFALFA ',
       +        ' YIELD, QUALITY.')
1100    FORMAT(//' SUMMARY OUTPUT COLUMNS: EVERY 5 COLS=1 CUTTING.',
       +' INDIVIDUAL COLS ARE: 1=DMYLD  2=CP  3=DIG  4=CF  5=GDDB5.',
       +/' COLS 1-20 SUMMARIZE CUTTINGS 1-4; COLS 21-25 SUMMARIZE TOTAL',
       +' ANNUAL PRODUCTION.',/,' EACH ROW IS ONE SIMULATION YEAR.',
       +' ALL MEASURES ARE TAKEN ON FIRST DAY OF CUTTING.',/)
1125    FORMAT(3X,4(1X,25('-')),2X,26('-'))
1150    FORMAT(///' SAMPLE STATISTICS FOR SIMULATION OUTPUT.',
       +' ROWS: 1=MEAN  2=STANDARD DEVIATION 3=COEF. OF VARIATION',/)
C
C1200 FORMAT(//26(5(1X,F5.2,3(1X,F4.2),1X,F5.0)/))
1199    FORMAT(3X,4(1X,I5,3(1X,I4),1X,I4),
       +        2X,I5,3(1X,I4),1X,I5,/)
1200    FORMAT(1X,I2,4(1X,F5.2,3(1X,F4.2),1X,F4.0),
       +        2X,F5.2,3(1X,F4.2),1X,F5.0)
1201    FORMAT(1X,I2,4(1X,F5.2,3(1X,F4.2),1X,F4.2),
       +        2X,F5.2,3(1X,F4.2),1X,F5.2)
C
250     FORMAT(////,' BEGIN SIMULATION YEAR',I3,' (',I4,')',/)
255     FORMAT(' OUTPUT COLS FROM CROP GROWTH PHASE (LONG FORMAT):',/,
       +' 1=JDAY 2=DATE 3=PREC 4=SRAD 5=AVTA 6=LAI 7=AW 8=DWS 9=WSF',
       +' 10=GDD 11=MATS 12=TNC 13=BUDS 14=STEM 15=LEAF 16=TOPS 17=CP',
       +' 18=DIG 19=CF')
C
1290    FORMAT('1','SUMMARY OUTPUT (2) FOR MATRIX YALF ',
       +        ':  PRE-HARVEST ALFALFA YIELD/QUALITY.  ',/,
       +        ' ALL MEASURES AVERAGED OVER',I4,'-DAY CUTTING PERIOD.',/,
       +        ' EVERY 4 COLUMNS=1 CUTTING.  COLS:  1=DMYLD  2=CP  3=DIG ',
       +       .' 4=CF.',/)
1300    FORMAT(1X,I2,4(1X,F5.2,3(1X,F4.2),5X),
       +        2X,F5.2,3(1X,F4.2),6X)
1301    FORMAT(1X,I2,4(1X,F5.2,3(1X,F4.2),5X),
       +        2X,F5.2,3(1X,F4.2),6X)
C
        RETURN
        END
```

```
C
C     ******************************************************
      SUBROUTINE SSTAT(NVAR,SMPL,NOBS,XMOMNT)
C     ******************************************************
C
C     SSTAT CALCULATES MEAN, STANDARD DEVIATION, COEFFICIENT OF
C     VARIATION, AND SKEWNESS OF A SAMPLE DISTRIBUTION.
C     (L. PARSCH, DEPT OF AG ECON, MSU, 12/81)
C
      DIMENSION SMPL(26,25),XMOMNT(4,25)
      DIMENSION SUM(26),SX(25),SV(25),SS(25)
C
      DO 10 I=1,NVAR
      SUM(I)=0.0
      DO 20 J=1,NOBS
   20 SUM(I)=SUM(I)+SMPL(J,I)
   10 SX(I)=SUM(I)/NOBS
C
      DO 30 II=1,NVAR
      SUM(II)=0.0
      DO 40 JJ=1,NOBS
   40 SUM(II)=SUM(II)+(SMPL(JJ,II)-SX(II))**2.
      SV(II)=SUM(II)/(NOBS-1)
   30 IF(NOBS.LE.1)SV(II)=0.0
C
      DO 50 III=1,NVAR
      SUM(III)=0.0
      DO 60 JJJ=1,NOBS
      IF(SV(III).EQ.0.0)GO TO 50
   60 SUM(III)=SUM(III)+((SMPL(JJJ,III)-SX(III))**3./(SV(III)**.5))
   50 SS(III)=SUM(III)/NOBS
C
      DO 70 I=1,NVAR
      XMOMNT(1,I)=SX(I)
      XMOMNT(2,I)=SQRT(SV(I))
      XMOMNT(3,I)=XMOMNT(2,I)/XMOMNT(1,I)
      IF(SX(I).EQ.0.0)XMOMNT(3,I)=0.0
   70 XMOMNT(4,I)=SS(I)
C
      RETURN
      END
```

```
C
C  ***********************************************
      SUBROUTINE SKIP(JYEARF)
C  ***********************************************
C
C  THIS SUBROUTINE SEARCHES CLIMATOLOGICAL DATA FILE (ELANSWTHR5378)
C  TO FIND APPROPRIATE BEGINNING RECORD FOR SIMULATION.
C  (L. PARSCH, AG ECON, MSU, 11/81)
C
      NYRS=JYEARF-1953
      NSKIP=NYRS*365
      DO 100 I=1,NSKIP
      READ(4,9010,END=900)
100   CONTINUE
C
      GO TO 999
900   CONTINUE
C
      WRITE(6,200)I
200   FORMAT(' ERROR DETECTED BY SUBROUTINE SKIP.  EOF ENCOUNTERED
     +BEGINNING YEAR',I4)
C
      STOP
999   CONTINUE
      RETURN
9010  FORMAT(1X)
      END
```

```
C  **********************************************************
      FUNCTION TABLI(VAL,ARG,DUMMY,K)
C  **********************************************************
C
      DIMENSION VAL(1),ARG(1)
      DUM=AMAX1(AMIN1(DUMMY,ARG(K)),ARG(1))
      DO 1 I=2,K
      IF(DUM.GT.ARG(I))GO TO 1
      TABLI=(DUM-ARG(I-1))*(VAL(I)-VAL(I-1))/
     +      (ARG(I)-ARG(I-1)) + VAL(I-1)
      RETURN
1     CONTINUE
      RETURN
      END
```

```
C  ***********************************************
      FUNCTION BCTEMP(NDAYS)
C  ***********************************************
C
C  THIS FUNCTION IS FOR PRINT CONTROL PURPOSES ONLY.
C  (L. PARSCH, DEPT OF AG ECON, MSU, 11/81)
C
      COMMON/CTRL24/BGNCUT(5),NTHYR,NTHCUT,NDAYSC,NDAYSH,YLD(4),
     +      QUAL(3,4),GDDCUM,METRIC,JYEARF,JYEARL,IPRT1,IPRT2,
     +      JDAYF,JDAYL,JPRT,NYRS,IPRT4,NCUTS,JYEAR,JLALHR,CPLANT
C
      IF(NDAYS.LE.1)THEN
         IF(NTHCUT.LE.1)THEN
            BCTEMP=BGNCUT(1)
         ELSE
            BCTEMP=BGNCUT(NTHCUT-1)
         ENDIF
      ELSE
         BCTEMP=BGNCUT(NTHCUT)
      ENDIF
C
      RETURN
      END
```

J.3 Software Listing, CRNMOD

```
      PROGRAM CRNPRG
C
C  CRNPRG IS A FORTRAN V STOCHASTIC PROCESS MODEL WHICH SIMULATES
C  THE PLANTING OF THE CORN CROP, AND ITS HARVEST AS CORN SILAGE,
C  HIGH MOISTURE CORN AND CORN GRAIN.  MODEL OUTPUT REFLECTS HOW
C  FINAL HARVESTED PRODUCTION IS AFFECTED BY TIMELINESS OF FIELD
C  OPERATIONS OVER A MULTIPLE-YEAR SIMULATION.  SUBPROGRAMS REQUIRED
C  ARE CRNIN, CORN, CRNPLT, CRNHRV, CRNOUT, SSTAT, CRNENG, VCOST,
C  ANPV, IROW, AND MISC.  INPUT DATA IS READ INTO CRNIN.  OUTPUT FROM
C  BTAGEN, A SEPARATE STOCHASTIC PROCESS MODEL, IS ATTACHED AND READ
C  INTO SUBROUTINE CORN.
C  (LUCAS PARSCH, DEPT OF AG ECON, MICH STATE UNIV, 2/82)
C
      OPEN(3,FILE='BMATRX')
      OPEN(5,FILE='INPUT')
      OPEN(6,FILE='OUTPUT')
C
C  READ IN REQUIRED DATA FOR SIMULATION.
C
      CALL CRNIN(NYRS,IPRT4)
C
C  SIMULATE FOR NYRS.  PRINT DETAILED WITHIN-YEAR DATA IF REQUIRED.
C
      DO 10 NTHYR=1,NYRS
      CALL CRNPLT(NTHYR,CPLANT)
      CALL CRNHRV(NTHYR,JLALHR)
10    IF(IPRT4.EQ.1)CALL CRNOUT(NTHYR,NYRS,1)
C
C  AT END OF SIMULATION CYCLE CALCULATE AND PRINT OUT SAMPLE AND
C  SAMPLE STATISTICS.
C
      CALL CRNOUT(NTHYR,NYRS,2)
C
      END
```

```
C
C     ***************************************************
         SUBROUTINE CRNIN(NYRS,IPRT4)
C     ***************************************************
C
C     THIS SUBROUTINE READS ALL INPUT DATA REQUIRED FOR TEST RUNS
C     OF THE STOCHASTIC PROCESS CORN MODEL.  EXPLANATION OF INPUT
C     VARIABLES READ IN FOLLOWS:
C
C      -IPRT4=PRINT OPTION: O=END OF SIMULATION RUN RESULTS ONLY;
C             1=WITHIN YEAR RESULTS + END OF SIMULATION RUN RESULTS.
C      -NOPNCS=CS OPERATION NUMBER WHEN USED W/SAVOIE'S FORHRV (140-149).
C      -HADSRD(3)=AREA TO BE PLANTED TO CS, HMC, CG, HECTARES.
C      -STGCS,STGHMC=STORAGE CAPACITY OF CS, HMC,  TONS DM.
C      -PSTGCS, PSTGHM=INVESTMENT IN STORAGE STRUCTURES (SILOS AND
C               UNLOADERS) FOR CORN SILAGE AND HIGH MOISTURE CORN, ($).
C      -HPDPLT,HPDHRV=CLOCK HRS/DAY AVAILABLE FOR PLANTING AND HARVEST.
C
C      -WIDTH(I)=OPERATING WIDTH OF I-TH FIELD IMPLEMENT, METERS.
C      -PPM(I)=PURCHASE PRICE OF I-TH FIELD IMPLEMENT, $.
C      -XMEN(I)=NUMBER OF PERSONNEL REQUIRED FOR I-TH ACTIVITY,MANHRS/HR:
C             INCLUDES FIELD WORK, TRANSPORTING, UNLOADING.
C      -NTRAC(I)=POWER SOURCE FOR FIELD IMPLEMENT OF WIDTH(I), MCODE.
C      -NTBLOW(I)=POWER SOURCE FOR BLOWER UNLOADING ACTIVITY I OUTPUT,
C             MCODE.
C      -NBLOWR(I)=MCODE FOR BLOWER UNLOADING PRODUCT I.
C      -(I) INDEX FOR ABOVE CORN ACTIVITIES:
C            1=CORN PLANTING  2= CS HARVESTING  3=HMC HARVESTING.
C      -RATEIS,-M,-L=DISCOUNT RATE: SHORT, MEDIUM, AND LONG TERM (DEC).
C      -PLABOR=LABOR CHARGE, $/HR.
C      -PFUELD,-G=PRICE OF DIESEL, GASOLINE FUEL, $/L.
C      -PFSCA1,-A2=CHARGE FOR FERT/SEED/CHEMS FOR ALFALFA SEEDING YR, EST-
C               ABLISHED, $/HA.
C      -PFSCCS,-HM=CHARGE FOR FERT/SEED/CHEMS FOR CS, HMC/CG, $/HA.
C      -PDRYCG=DRYING CHARGE FOR CG SOLD, $/PT/BU.
C      -PHRVCG=CUSTOM HARVEST CHARGE FOR CG SOLD, $/HA.
C      -XLIFE(1),COEFSV(1)=STORAGE STRUCTURE LIFE (YRS), SV/INVEST (DEC).
C      -XLIFE(2),COEFSV(2)=MACHINE LIFE (YRS), SV/INVEST (DEC).
C      -DUMMY2,-3=DUMMY VARIABLES USED AS COLUMN INDICATORS IN INPUT FILE.
C              (E.G.:123456789.123456789.123. . .ETC.)
C
C     (L. PARSCH, DEPT. OF AG. ECON, MSU, 2/82)
C
         COMMON/PRICE/PLABOR,PFUELD,PFUELG,RATEIM,PDRYCG,PHRVCG,COEFSV(3),
        +        PFSCA1,PFSCA2,PFSCCS,PFSCHM,ALFYRS,RATEIS,RATEIL,XLIFE(3)
         COMMON/TILL/PTILLC,PTILLA
C
         COMMON/CRNDT1/BTAGEN(26,17),RTPLT,HAPLTD(26,6),COSTCG(26,2),
        +        JFNHRV(26),JDPLT(6),JDHRV(7),JFNPLT(26),DMCORN(26,3),
        +        CRNYLD(26,3),COEFCS(6,5),COEFCG(6,5),JBGHRV(26),RTHRV(3),
        +        CLOSSH(3),HADSRD(4),STGCS,STGHMC,HPDHRV,HPDPLT,HACORN(26,4),
        +        JFNAL3(26),COEFMC(6,5),BASEMC,DMFEED(26,3),CRNFSC(26),
        +        TWATER(26),CLOSSF(3),RTFEED(4),CLOSSS(3)
C
         COMMON/CRNDT3/WIDTH(3),PPM(3),NTRAC(3),XMEN(3),NTBLOW(3),RMBLOW,
        +        NBLOWR(3),CLAB1,VCM(4,4),FCPICK,FCPLT,RMM(3),RMT,
        +        HRSPLT(4),HRSCS(4),HRSHMC(4),FUEL(4),FUELRT,CLAB2,
        +        NOPNCS,FECG,FECS,FEPLT,FEHMC,SPDCG,SPDCS,SPDHMC,SPDPLT,
        +        RTBLOW,WCOMB,PSTGCS,PSTGHM
         DIMENSION DUMMY2(6),DUMMY3(6)
C
         READ(5,100)(DUMMY2(I),I=1,6)
         READ(5,110)IPRT4,NOPNCS
         READ(5,100)(HADSRD(I),I=1,3)
         READ(5,100)STGCS,PSTGCS,STGHMC,PSTGHM
         READ(5,100)HPDPLT,HPDHRV
         READ(5,120)WIDTH(1),PPM(1),XMEN(1),NTRAC(1)
         READ(5,120)WIDTH(2),PPM(2),XMEN(2),NTRAC(2),NTBLOW(2),NBLOWR(2)
         READ(5,120)WIDTH(3),PPM(3),XMEN(3),NTRAC(3),NTBLOW(3),NBLOWR(3)
         READ(5,100)(DUMMY3(I),I=1,6)
         READ(5,100)RATEIS,RATEIM,RATEIL
         READ(5,100)PLABOR,PFUELD,PFUELG
         READ(5,100)PFSCA1,PFSCA2,PFSCCS,PFSCHM
         READ(5,100)PDRYCG,PHRVCG,PTILLC,PTILLA
         READ(5,100)XLIFE(1),XLIFE(2),COEFSV(1),COEFSV(2)
C
         CALL CORN(NYRS)
```

```
C    *****************************************************
        SUBROUTINE CORN(NYRS)
C    *****************************************************
C
C    SUBROUTINE CORN CONTAINS DATA WHICH SPECIFIES: (A) CORN SILAGE AND
C    GRAIN YIELDS AS A FUNCTION OF PLANTING AND HARVESTING DATES; (B)
C    AVAILABLE FIELD WORKING DAYS FOR THE PLANTING AND HARVEST PERIODS.
C    THIS DATA IS INITIALLY GENERATED IN BTAGEN, A MULTIVARIATE BETA
C    STOCHASTIC PROCESS GENERATOR.  THE GENERATED SAMPLE OBSERVATION
C    MATRIX--BASED ON EMPIRICAL ESTIMATES OF PARAMETERS OF EACH MARGINAL
C    DISTRIBUTION--IS THEN STORED ON FILE AND READ INTO SUBROUTINE CORN.
C    THIS MATRIX HAS DIMENSIONS (YEARS,DISTRIBUTIONS).  THE DISTRIBUTIONS
C    (COLUMNS) ARE DEFINED AS FOLLOWS:
C       (1) COLS 1-5:   AVAILABLE FIELD  WORK DAYS (PLANTING) PER PERIOD,
C                       APRIL 20-JUNE 15.  PERIODS=420-430,501-510,511-520,
C                       521-531,601-615.
C       (2) COLS 6-11:  AVAILABLE FIELD WORK DAYS (HARVEST) PER PERIOD,
C                       SEPT 1-NOV 30.  PERIODS=901-915,916-930,1001-1015,
C                       1016-1031,1101-1115,1116-1130.
C       (3) COLS 12-16:CORN GRAIN YIELDS PLANTED IN EACH PLANTING PERIOD
C                       ABOVE WITH AVERAGE HARVEST DATE = OCT 4.  (BU/A)
C       (4) COL  17:    CORN SILAGE YIELD, AVERAGE PLANTING AND HARVEST
C                       DATES, MAY 1, SEPT 4 (DM TONS/ACRE)
C    (L. PARSCH, DEPT OF AGRIC. ECON., MICHIGAN STATE UNIV., 12/81)
C
C
        COMMON/CRNDT1/BTAGEN(26,17),RTPLT,HAPLTD(26,6),COSTCG(26,2),
     +        JFNHRV(26),JDPLT(6),JDHRV(7),JFNPLT(26),DMCORN(26,3),
     +        CRNYLD(26,3),COEFCS(6,5),COEFCG(6,5),JBGHRV(26),RTHRV(3),
     +        CLOSSH(3),HADSRD(4),STGCS,STGHMC,HPDHRV,HPDPLT,HACORN(26,4),
     +        JFNAL3(26),COEFMC(6,5),BASEMC,DMFEED(26,3),CRNFSC(26),
     +        TWATER(26),CLOSSF(3),RTFEED(4),CLOSSS(3)
C
        DO 5 NTHYR=1,NYRS
5       READ(3,100)(BTAGEN(NTHYR,JDIST),JDIST=1,17)
C
C    CONVERT CORN YIELDS FROM ENGLISH UNITS TO METRIC UNITS (TONS/HA)
C
        DO 10 NTHYR=1,NYRS
        DO 20 JDIST=12,16
20      BTAGEN(NTHYR,JDIST)=BTAGEN(NTHYR,JDIST)*.052984624
10      BTAGEN(NTHYR,17)=BTAGEN(NTHYR,17)*2.2401434
C
        DO 30 NTHYR=1,NYRS
        TWATER(NTHYR)=0.
        HACORN(NTHYR,4)=0.0
        DO 30 JCOL=1,3
        HACORN(NTHYR,JCOL)=0.0
        DMCORN(NTHYR,JCOL)=0.0
        DMFEED(NTHYR,JCOL)=0.0
30      CRNYLD(NTHYR,JCOL)=0.0
C
100     FORMAT(17(1X,F7.2))
C
        RETURN
        END
```

```
C     ****************************************************
         SUBROUTINE CORN(NYRS)
C     ****************************************************
C
C     SUBROUTINE CORN CONTAINS DATA WHICH SPECIFIES: (A) CORN SILAGE AND
C     GRAIN YIELDS AS A FUNCTION OF PLANTING AND HARVESTING DATES; (B)
C     AVAILABLE FIELD WORKING DAYS FOR THE PLANTING AND HARVEST PERIODS.
C     THIS DATA IS INITIALLY GENERATED IN BTAGEN, A MULTIVARIATE BETA
C     STOCHASTIC PROCESS GENERATOR.  THE GENERATED SAMPLE OBSERVATION
C     MATRIX--BASED ON EMPIRICAL ESTIMATES OF PARAMETERS OF EACH MARGINAL
C     DISTRIBUTION--IS THEN STORED ON FILE AND READ INTO SUBROUTINE CORN.
C     THIS MATRIX HAS DIMENSIONS (YEARS,DISTRIBUTIONS).  THE DISTRIBUTIONS
C     (COLUMNS) ARE DEFINED AS FOLLOWS:
C         (1) COLS 1-5:  AVAILABLE FIELD  WORK DAYS (PLANTING) PER PERIOD,
C                        APRIL 20-JUNE 15.  PERIODS=420-430,501-510,511-520,
C                        521-531,601-615.
C         (2) COLS 6-11: AVAILABLE FIELD WORK DAYS (HARVEST) PER PERIOD,
C                        SEPT 1-NOV 30.  PERIODS=901-915,916-930,1001-1015,
C                        1016-1031,1101-1115,1116-1130.
C         (3) COLS 12-16:CORN GRAIN YIELDS PLANTED IN EACH PLANTING PERIOD
C                        ABOVE WITH AVERAGE HARVEST DATE = OCT 4. (BU/A)
C         (4) COL 17:    CORN SILAGE YIELD, AVERAGE PLANTING AND HARVEST
C                        DATES, MAY 1, SEPT 4 (DM TONS/ACRE)
C    (L. PARSCH, DEPT OF AGRIC. ECON., MICHIGAN STATE UNIV., 12/81)
C
C
       COMMON/CRNDT1/BTAGEN(26,17),RTPLT,HAPLTD(26,6),COSTCG(26,2),
     +        JFNHRV(26),JDPLT(6),JDHRV(7),JFNPLT(26),DMCORN(26,3),
     +        CRNYLD(26,3),COEFCS(6,5),COEFCG(6,5),JBGHRV(26),RTHRV(3),
     +        CLOSSH(3),HADSRD(4),STGCS,STGHMC,HPDHRV,HPDPLT,HACORN(26,4),
     +        JFNAL3(26),COEFMC(6,5),BASEMC,DMFEED(26,3),CRNFSC(26),
     +        TWATER(26),CLOSSF(3),RTFEED(4),CLOSSS(3)
C
       DO 5 NTHYR=1,NYRS
5      READ(3,100)(BTAGEN(NTHYR,JDIST),JDIST=1,17)
C
C   CONVERT CORN YIELDS FROM ENGLISH UNITS TO METRIC UNITS (TONS/HA)
C
       DO 10 NTHYR=1,NYRS
       DO 20 JDIST=12,16
20     BTAGEN(NTHYR,JDIST)=BTAGEN(NTHYR,JDIST)*.052984624
10     BTAGEN(NTHYR,17)=BTAGEN(NTHYR,17)*2.2401434
C
       DO 30 NTHYR=1,NYRS
       TWATER(NTHYR)=0.
       HACORN(NTHYR,4)=0.0
       DO 30 JCOL=1,3
       HACORN(NTHYR,JCOL)=0.0
       DMCORN(NTHYR,JCOL)=0.0
       DMFEED(NTHYR,JCOL)=0.0
30     CRNYLD(NTHYR,JCOL)=0.0
C
100    FORMAT(17(1X,F7.2))
C
       RETURN
       END
```

```
C
      HADSRD(4)=HADSRD(1)+HADSRD(2)+HADSRD(3)
C
C  PRINT OUT ALL DATA READ IN.
C
      WRITE(6,200)
      WRITE(6,210)NYRS,(HADSRD(I),I=1,4)
      WRITE(6,220)STGCS,STGHMC
      WRITE(6,225)PSTGCS,PSTGHM
      WRITE(6,230)HPDPLT
      WRITE(6,240)HPDHRV
      WRITE(6,245)NOPNCS
      WRITE(6,250)
      WRITE(6,255)WIDTH(1),PPM(1),XMEN(1),NTRAC(1)
      WRITE(6,260)WIDTH(2),PPM(2),XMEN(2),NTRAC(2),NTBLOW(2),NBLOWR(2)
      WRITE(6,265)WIDTH(3),PPM(3),XMEN(3),NTRAC(3),NTBLOW(3),NBLOWR(3)
      WRITE(6,270)RATEIS,RATEIM,RATEIL
      WRITE(6,272)PLABOR,PFUELD,PFUELG
      WRITE(6,274)PFSCA1,PFSCA2,PFSCCS,PFSCHM
      WRITE(6,276)PDRYCG,PHRVCG
      WRITE(6,277)PTILLC,PTILLA
      WRITE(6,278)XLIFE(1),COEFSV(1)
      WRITE(6,279)XLIFE(2),COEFSV(2)
      WRITE(6,280)
      WRITE(6,301)((JCOL),JCOL=1,17)
      DO 315 IYR=1,NYRS
315   WRITE(6,300)IYR,(BTAGEN(IYR,JCOL),JCOL=1,17)
      WRITE(6,302)
C
100   FORMAT(12F10.0)
110   FORMAT(12I10)
120   FORMAT(3F10.0,3I10)
200   FORMAT(////,' INPUT VALUES FOR CORN SIMULATION',
     +       ':  SUBROUTINES CRNIN AND CORN ')
210   FORMAT(//,' SIMULATION LENGTH, YEARS=',I4,
     +    /,' AREA INTENDED AS CS HMC CG AND TOTAL(HA)=',4(2X,F6.2))
220   FORMAT(' STORAGE CAPACITY OF CS AND HMC (DM TONS)=',2(1X,F8.2))
225   FORMAT(' INVESTMENT IN STORAGE STRUCTURES FOR CS',
     +       ' AND HMC, $',2(3X,F7.0))
230   FORMAT(' WORK DAYLENGTH, PLANT PD (HRS/DAY)= ',F6.2)
240   FORMAT(' WORK DAYLENGTH, HARVEST PD (HRS/DAY)=',1X,F6.2)
245   FORMAT(' CS OPERATION NO. (140-149 W/SAVOIE MODEL ONLY)=',I4)
250   FORMAT(' CORN MACHINERY INPUT DATA, COLS:  1=WIDTH (M)',
     +       ' 2=PPM ($)  3=XMEN (MANHRS/HR)  4=NTRAC (MCODE)',
     +       '  5=NTBLOW (MCODE)  6=NBLOWR (MCODE)')
255   FORMAT(' CORN PLANTING:',T30,F6.2,F10.0,2X,F3.1,2X,3I4)
260   FORMAT(' CS HARVEST:',T30,F6.2,F10.0,2X,F3.1,2X,3I4)
265   FORMAT(' HMC HARVEST:',T30,F6.2,F10.0,2X,F3.1,2X,3I4)
270   FORMAT(' DISCOUNT RATES CHARGED: SHORT, MEDIUM, LONG-TERM=',3F6.2)
272   FORMAT(' LABOR CHARGE($/HR); DIESEL, GAS CHARGE($/L)=',F6.2,2F6.3)
274   FORMAT(' FERTILIZER/SEED/CHEMICALS ($/HA): SEEDING YEAR ALFALFA,',
     +      'ESTABLISHED ALFALFA, CS, HMC/CG=',4(1X,F7.2))
276   FORMAT(' DRYING CHARGE, CG-SOLD ($/PT/BU);',
     +       ' CUSTOM HARVEST CHARGE, CG ($/HA)=',F6.2,2X,F7.2)
277   FORMAT(' CUSTOM CHARGE FOR PRE-PLANT TILLAGE, CORN; PRE-HARVEST',
     +       ' TILLAGE/SEEDING, ALFALFA ($/HA)=',F6.2,2X,F6.2)
278   FORMAT(' STORAGE STRUCTURE LIFE (YRS); SV/INVEST=',F6.1,F5.2)
279   FORMAT(' MACHINERY LIFE (YRS); SV/INVEST=',F6.1,F5.2)
C
280   FORMAT(//,' MATRIX GENERATED IN BTAGEN, READ FROM CORN:',
     +    ' ROWS=SAMPLE OBSERVATIONS (YRS)',/,
     +    ' COLS: (1-5)=AVAIL DAYS PLANTING  (6-11)=AVAIL DAYS HARVEST ',
     +    ' (12-16)=HMC AND CG YLD, T/HA  (17)=CS YLD, T/HA ',/)
300   FORMAT(I3,17(1X,F6.2))
301   FORMAT(1X,17(1X,I6)/)
302   FORMAT('1')
C
      RETURN
      END
```

```
C     *************************************************
      SUBROUTINE CRNPLT(NTHYR,CPLANT)
C     *************************************************
C
C     THIS SUBROUTINE DETERMINES THE AREA OF CORN PLANTED IN EACH OF
C     FIVE PLANTING PERIODS, APRIL 20-JUNE 15.
C     (L. PARSCH, DEPT OF AG ECON, MICH STATE UNIV, 12/81)
C

      COMMON/CRNDT1/BTAGEN(26,17),RTPLT,HAPLTD(26,6),COSTCG(26,2),
     +      JFNHRV(26),JDPLT(6),JDHRV(7),JFNPLT(26),DMCORN(26,3),
     +      CRNYLD(26,3),COEFCS(6,5),COEFCG(6,5),JBGHRV(26),RTHRV(3),
     +      CLOSSH(3),HADSRD(4),STGCS,STGHMC,HPDHRV,HPDPLT,HACORN(26,4),
     +      JFNAL3(26),COEFMC(6,5),BASEMC,DMFEED(26,3),CRNFSC(26),
     +      TWATER(26),CLOSSF(3),RTFEED(4),CLOSSS(3)
C
C     INITIALIZE CORN AREA.  ESTABLISH PLANTING RATE AND HARVEST RATES
C     FOR CORN THIS YEAR.
C
      CALL CRNENG(NTHYR,1)
C
      REMPLT=HADSRD(4)
      DO 5 I=1,6
5     HAPLTD(NTHYR,I)=0.0
C
      DO 10 I=1,5
      PLTCPY=BTAGEN(NTHYR,I)*HPDPLT*RTPLT
      HAPLTD(NTHYR,I)=AMIN1(PLTCPY,REMPLT)
      HAPLTD(NTHYR,6)=HAPLTD(NTHYR,6)+HAPLTD(NTHYR,I)
      REMPLT=REMPLT-HAPLTD(NTHYR,I)
C
C     DETERMINE LAST JULIAN DATE OF PLANTING BY INTERPOLATION.
C
      IF((REMPLT.LE.O.).AND.(PLTCPY.GT.O.))THEN
         JFNPLT(NTHYR)=(HAPLTD(NTHYR,I)/PLTCPY)*
     +        (FLOAT(JDPLT(I+1)-JDPLT(I)))+(JDPLT(I)+1)
         GO TO 20
      ELSEIF((REMPLT.LE.O.).AND.(PLTCPY.LE.O.))THEN
         JFNPLT(NTHYR)=(JDPLT(I+1)-JDPLT(I))+JDPLT(I)+1
         GO TO 20
      ENDIF
10    CONTINUE
C
C     SPECIFY JULIAN DATE IF PLANTING WAS NOT FINISHED.
C
      JFNPLT(NTHYR)=JDPLT(6)+1
C
20    CONTINUE
C
      CPLANT=FLOAT(JFNPLT(NTHYR))
C
      RETURN
      END
```

```
C    ****************************************************
        SUBROUTINE CRNHRV(NTHYR,JLALHR)
C    ****************************************************
C
C    THIS SUBROUTINE DETERMINES THE AREA (HA) AND QUANTITY (DM) OF CORN
C    SILAGE, HIGH MOISTURE CORN, AND CORN GRAIN HARVESTED IN EACH OF
C    SIX HARVEST PERIODS FOR ACREAGE PLANTED IN EACH OF FIVE PLANTING
C    PERIODS. (L. PARSCH, AG ECON, MSU, 12/81)
C
        COMMON/CRNDT1/BTAGEN(26,17),RTPLT,HAPLTD(26,6),COSTCG(26,2),
     +        JFNHRV(26),JDPLT(6),JDHRV(7),JFNPLT(26),DMCORN(26,3),
     +        CRNYLD(26,3),COEFCS(6,5),COEFCG(6,5),JBGHRV(26),RTHRV(3),
     +        CLOSSH(3),HADSRD(4),STGCS,STGHMC,HPDHRV,HPDPLT,HACORN(26,4),
     +        JFNAL3(26),COEFMC(6,5),BASEMC,DMFEED(26,3),CRNFSC(26),
     +        TWATER(26),CLOSSF(3),RTFEED(4),CLOSSS(3)
C
        COMMON/CRNDT2/HAREM(5),HRVCPY(6),DMHRV(3,6,5),HAHRV(4,6,5),
     +        CSYLD(6,5),CGYLD(6,5)
C
        DATA ZERO /1.0E-6/
C
C    BEGIN INITIALIZATION FOR THIS YEARS VALUES.
C
        DO 10 I=1,6
        HRVCPY(I)=0.0
        DO 10 J=1,5
        HAREM(J)=HAPLTD(NTHYR,J)
        CSYLD(I,J)=BTAGEN(NTHYR,17)*COEFCS(I,J)
        CGYLD(I,J)=BTAGEN(NTHYR,J+11)*COEFCG(I,J)
        HAHRV(4,I,J)=0.0
        DO 10 K=1,3
        HAHRV(K,I,J)=0.0
10      DMHRV(K,I,J)=0.0

        CSREQ=STGCS
        HMCREQ=STGHMC
        JFNAL3(NTHYR)=JLALHR
        JBGHRV(NTHYR)=244
C
        DO 20 I=1,6
C
C    BEGIN CORN HARVEST LOOPS FOR NTHYR. LOOP I=HARVEST PERIOD; LOOP
C    J=PLANTING DATE ACREAGE LIMITATION.  FIRST, DETERMINE WHETHER 3RD
C    CUT ALFALFA HARVEST HAS FINISHED SO CORN HARVEST CAN BEGIN.
C
        IF(JFNAL3(NTHYR).LT.JDHRV(I))THEN
           RATIO1=0.0
        ELSEIF((JFNAL3(NTHYR).GE.JDHRV(I)).AND.
     +        (JFNAL3(NTHYR).LT.JDHRV(I+1)))THEN
           JBGHRV(NTHYR)=JFNAL3(NTHYR)+1
           RATIO1=FLOAT(JBGHRV(NTHYR)-JDHRV(I))/
     +           FLOAT(JDHRV(I+1)-JDHRV(I))
        ELSE IF(JFNAL3(NTHYR).GE.JDHRV(I+1))THEN
           IF(I.EQ.6)JBGHRV(NTHYR)=335
           GO TO 20
        ENDIF
C
C    KTYPE DEFINES THE HARVESTING SYSTEM:  1=CS 2=HMC 3=CG
C
        KTYPE=3
        IF(CSREQ.GT.0.)KTYPE=1
        IF((CSREQ.LE.0.).AND.(HMCREQ.GT.0.))KTYPE=2
        HRVCPY(I)=BTAGEN(NTHYR,I+5)*HPDHRV*RTHRV(KTYPE)*(1.-RATIO1)
        CPCTY=HRVCPY(I)
C
        DO 40 J=1,5
        IF(HAREM(J).LE.0.)GO TO 40
C
C    -----------------------------------------------------------------
C    NESTED IF-THEN BLOCK DEFINES FOUR GENERAL CONDITIONS:
C       (1) BOTH CS AND HMC ARE IN FARM PLAN, STRG UNITS ARE UNFILLED.
C       (2) CS ONLY IS IN FARM PLAN, STRG UNIT IS UNFILLED.
C       (3) HMC IS IN FARM PLAN, STRG UNIT IS UNFILLED.  CS IS IN FARM
C           PLAN AND STRG IS FILLED/OR CS IS NOT IN FARM PLAN.
C       (4) EITHER CS AND HMC ARE NOT IN FARM PLAN, OR ALL STRG IS FILLED.
C    HARVEST SEQUENCE ALWAYS ASSUMED IS CS-HMC-CG (DRY SHELLED).
C    THE QUANTITY OF CORN HARVESTED AS EITHER OF THESE K (K=1,2,3) ENT-
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```
C  ERPRISES IN EACH OF I (I=1,..6) HARVEST PERIODS, ON AREA PLANTED
C  IN EACH OF J (J=1,..5) PLANT PERIODS IS DETERMINED BY MOST LIMITING
C  OF THREE CONSTRAINTS:
C    (1) AREA PLANTED IN J-TH PLANT PERIOD.
C    (2) FIELD CAPACITY OF MACH COMPLEMENT GIVEN AVAIL DAYS IN HARVEST
C        PERIOD I.
C    (3) REMAINING UNUSED STORAGE SPACE FOR THE K-TH CORN ENTERPRISE.
C  ------------------------------------------------------------------
C
      IF ((CSREQ.GT.O.).AND.(HMCREQ.GT.O.))THEN
         XLIMDM=(CSREQ*(1.+ZERO))/(CSYLD(I,J)*(1.-CLOSSH(1)))
         IF(CSYLD(I,J).EQ.O.)XLIMDM=O.
         XLIMHA=AMAX1(O.,(AMIN1(HAREM(J),HRVCPY(I),XLIMDM)))
         HAHRV(1,I,J)=XLIMHA
         DMHRV(1,I,J)=HAHRV(1,I,J)*CSYLD(I,J)*(1.-CLOSSH(1))
         CSREQ=CSREQ-DMHRV(1,I,J)
C DBG    PRINT*,'-1-',I,J,XLIMDM,HAREM(J),HRVCPY(I),XLIMHA,HAHRV(1,I,J)
C
         IF(CSREQ.GT.O.)THEN
C DBG       PRINT*,'-1A-'
            GO TO 50
         ELSE
            HAREM(J)=HAREM(J)-HAHRV(1,I,J)
            HRVCPY(I)=(HRVCPY(I)-HAHRV(1,I,J))*(RTHRV(2)/RTHRV(1))
            CPCTY=CPCTY*(RTHRV(2)/RTHRV(1))
            XLIMDM=(HMCREQ*(1.+ZERO))/(CGYLD(I,J)*(1.-CLOSSH(2)))
            IF(CGYLD(I,J).EQ.O.)XLIMDM=O.
            XLIMHA=AMAX1(O.,(AMIN1(HAREM(J),HRVCPY(I),XLIMDM)))
            HAHRV(2,I,J)=XLIMHA
            DMHRV(2,I,J)=HAHRV(2,I,J)*CGYLD(I,J)*(1.-CLOSSH(2))
            HMCREQ=HMCREQ-DMHRV(2,I,J)
C DBG       PRINT*,'-1B-',I,J,XLIMDM,HAREM(J),HRVCPY(I),XLIMHA,
C DBG+           HAHRV(2,I,J)
C
            IF(HMCREQ.GT.O.)THEN
C DBG          PRINT*,'-1B1-'
               GO TO 50
            ELSE
               HAREM(J)=HAREM(J)-HAHRV(2,I,J)
               HRVCPY(I)=(HRVCPY(I)-HAHRV(2,I,J))*(RTHRV(3)/RTHRV(2))
               CPCTY=CPCTY*(RTHRV(3)/RTHRV(2))
C DBG          PRINT*,'-1B2-',I,J,HAREM(J),HRVCPY(I)
            ENDIF
C
         ENDIF
C
      ELSEIF((CSREQ.GT.O.).AND.(HMCREQ.LE.O.))THEN
         XLIMDM=(CSREQ*(1.+ZERO))/(CSYLD(I,J)*(1.-CLOSSH(1)))
         IF(CSYLD(I,J).EQ.O.)XLIMDM=O.
         XLIMHA=AMAX1(O.,(AMIN1(HAREM(J),HRVCPY(I),XLIMDM)))
         HAHRV(1,I,J)=XLIMHA
         DMHRV(1,I,J)=HAHRV(1,I,J)*CSYLD(I,J)*(1.-CLOSSH(1))
         CSREQ=CSREQ-DMHRV(1,I,J)
C DBG    PRINT*,'-2-',I,J,XLIMDM,HAREM(J),HRVCPY(I),XLIMHA,HAHRV(1,I,J)
C
         IF(CSREQ.GT.O.)THEN
C DBG       PRINT*,'-2A-'
            GO TO 50
         ELSE
            HAREM(J)=HAREM(J)-HAHRV(1,I,J)
            HRVCPY(I)=(HRVCPY(I)-HAHRV(1,I,J))*(RTHRV(3)/RTHRV(1))
            CPCTY=CPCTY*(RTHRV(3)/RTHRV(1))
C DBG       PRINT*,'-2B-'
            GO TO 48
         ENDIF
C
      ELSEIF((CSREQ.LE.O.).AND.(HMCREQ.GT.O.))THEN
         XLIMDM=(HMCREQ*(1.+ZERO))/(CGYLD(I,J)*(1.-CLOSSH(2)))
         IF(CGYLD(I,J).EQ.O.)XLIMDM=O.
         XLIMHA=AMAX1(O.,(AMIN1(HAREM(J),HRVCPY(I),XLIMDM)))
         HAHRV(2,I,J)=XLIMHA
         DMHRV(2,I,J)=HAHRV(2,I,J)*CGYLD(I,J)*(1.-CLOSSH(2))
         HMCREQ=HMCREQ-DMHRV(2,I,J)
C DBG    PRINT*,'-3-',I,J,XLIMDM,HAREM(J),HRVCPY(I),XLIMHA,HAHRV(2,I,J)
C
         IF(HMCREQ.GT.O.)THEN
C DBG       PRINT*,'-3A-'
```

```
                  GO TO 50
               ELSE
                  HAREM(J)=HAREM(J)-HAHRV(2,I,J)
                  HRVCPY(I)=(HRVCPY(I)-HAHRV(2,I,J))*(RTHRV(3)/RTHRV(2))
                  CPCTY=CPCTY*(RTHRV(3)/RTHRV(2))
C DBG             PRINT*,'-38-'
               ENDIF
C
            ENDIF
C
48          XLIMHA=AMAX1(O.,AMIN1(HAREM(J),HRVCPY(I)))
            IF(CGYLD(I,J).EQ.O.)XLIMHA=O.
            HAHRV(3,I,J)=XLIMHA
            DMHRV(3,I,J)=HAHRV(3,I,J)*CGYLD(I,J)*(1.-CLOSSH(3))
C
50          HAREM(J)=HAREM(J)-XLIMHA
            HRVCPY(I)=HRVCPY(I)-XLIMHA
            HAHRV(4,I,J)=HAHRV(1,I,J)+HAHRV(2,I,J)+HAHRV(3,I,J)
            HACORN(NTHYR,4)=HACORN(NTHYR,4)+HAHRV(4,I,J)
            IF(HAREM(J).GT.O.)GO TO 19
40          CONTINUE
C
19          IF(HACORN(NTHYR,4).GE.(HAPLTD(NTHYR,6)*(1.-ZERO)))THEN
               RATIO4=(CPCTY-HRVCPY(I))/CPCTY
               IF(CPCTY.LE.O.)RATIO4=O.O
               JFNHRV(NTHYR)=RATIO4*(JDHRV(I+1)-JDHRV(I))+JDHRV(I)+1
               GO TO 55
            ENDIF
20          CONTINUE
C
C  CORN HARVEST IS COMPLETED FOR THIS YEAR. SUMMARIZE AREA,
C  DM PRODUCTION, AND YIELD OF CS, HMC, AND CG.  CALCULATE
C  TOTAL QUANTITY OF DRY-DOWN REQUIRED (METRIC TONS WATER)
C  FOR CORN GRAIN.
C
55          CONTINUE
            DO 60 K=1,3
            DO 70 I=1,6
            DO 70 J=1,5
            DMCORN(NTHYR,K)=DMCORN(NTHYR,K)+DMHRV(K,I,J)
            IF((K.EQ.3).AND.(DMHRV(K,I,J).GT.O))THEN
               XWATER=((1./(1.-COEFMC(I,J)))-(1./(1.-BASEMC)))*DMHRV(K,I,J)
               TWATER(NTHYR)=TWATER(NTHYR)+XWATER
            ENDIF
70          HACORN(NTHYR,K)=HACORN(NTHYR,K)+HAHRV(K,I,J)
            CRNYLD(NTHYR,K)=DMCORN(NTHYR,K)/HACORN(NTHYR,K)
            DMFEED(NTHYR,K)=DMCORN(NTHYR,K)*((1.-CLOSSS(K))*(1.-CLOSSF(K)))
60          IF(HACORN(NTHYR,K).LE.O.)CRNYLD(NTHYR,K)=O.
C
C  CALCULATE MACHINE HOURS, LABOR HOURS, AND FUEL USE FOR
C  CORN CROP THIS YEAR.
C
            CALL CRNENG(NTHYR,2)
            RETURN
            END
```

```
C
C ***************************************************
      SUBROUTINE CRNOUT(NTHYR,NYRS,ILINE)
C ***************************************************
C
C THIS SUBROUTINE WRITES OUT: (1) WITHIN-YEAR SIMULATION RESULTS:
C (2) END OF SIMULATION-RUN RESULTS; AND, (3) SAMPLE STATISTICS
C CALCULATED OVER THE CORN SIMULATION RUN.
C (L. PARSCH, DEPT OF AG ECON, MSU, 2/82)
C
      COMMON/CRNDT1/BTAGEN(26,17),RTPLT,HAPLTD(26,6),COSTCG(26,2),
     +       UFNHRV(26),JDPLT(6),JDHRV(7),JFNPLT(26),DMCORN(26,3),
     +       CRNYLD(26,3),COEFCS(6,5),COEFCG(6,5),JBGHRV(26),RTHRV(3),
     +       CLOSSH(3),HADSRD(4),STGCS,STGHMC,HPDHRV,HPDPLT,HACORN(26,4),
     +       JFNAL3(26),COEFMC(6,5),BASEMC,DMFEED(26,3),CRNFSC(26),
     +       TWATER(26),CLOSSF(3),RTFEED(4),CLOSSS(3)
C
      COMMON/CRNDT2/HAREM(5),HRVCPY(6),DMHRV(3,6,5),HAHRV(4,6,5),
     +       CSYLD(6,5),CGYLD(6,5)
      COMMON/SUMRY1/YCORN(26,19),SCORN(4,19),CCOST(26,16),SCOST(4,16)
C
      GO TO (5,100),ILINE
C
C OUTPUT WITHIN-YEAR SIMULATION RUN RESULTS.
C
5     WRITE(6,210)NTHYR
      WRITE(6,220)(HAPLTD(NTHYR,I),I=1,6)
      WRITE(6,230)(HACORN(NTHYR,K),K=1,4)
      WRITE(6,240)JFNPLT(NTHYR),JBGHRV(NTHYR),JFNHRV(NTHYR)
C
      WRITE(6,250)
      DO 10 IHRV=1,6
10    WRITE(6,200)((HAHRV(K,IHRV,JPLT),JPLT=1,5),K=1,3)
C
      WRITE(6,260)
      DO 20 IHRV=1,6
20    WRITE(6,200)((DMHRV(K,IHRV,JPLT),JPLT=1,5),K=1,3)
C
      WRITE(6,270)
      DO 30 IHRV=1,6
      WRITE(6,310)(CSYLD(IHRV,JPLT),JPLT=1,5)
      WRITE(G,310)(CGYLD(IHRV,JPLT),JPLT=1,5)
30    WRITE(6,202)
C
      RETURN
C
C OUTPUT END OF SIMULATION RUN RESULTS AND SAMPLE STATISTICS.
C
100   DO 40 N=1,NYRS
      YCORN(N,1)=FLOAT(JFNPLT(N))
      YCORN(N,2)=FLOAT(JFNAL3(N))
      YCORN(N,3)=FLOAT(JBGHRV(N))
      YCORN(N,4)=FLOAT(JFNHRV(N))
      YCORN(N,5)=HAPLTD(N,6)
      YCORN(N,16)=TWATER(N)
      DO 45 J=1,4
45    YCORN(N,J+5)=HACORN(N,J)
      DO 50 J=1,3
      YCORN(N,J+9)=DMCORN(N,J)
      YCORN(N,J+12)=CRNYLD(N,J)
50    YCORN(N,J+16)=DMFEED(N,J)
40    CONTINUE
C
      WRITE(6,280)NYRS
      WRITE(6,301)((JCOL),JCOL=1,16)
      DO 60 N=1,NYRS
60    WRITE(6,300)N,(YCORN(N,J),J=1,16)
C
      WRITE(6,202)
      CALL SSTAT(19,YCORN,NYRS,SCORN)
      WRITE(6,290)
      DO 70 I=1,3
70    WRITE(6,300)I,(SCORN(I,J),J=1,16)
C
      WRITE(6,284)
      WRITE(6,321)((JCOL),JCOL=17,19)
      DO 72 N=1,NYRS
```

```
 72     WRITE(6,320)N,(YCORN(N,J),J=17,19)
        WRITE(6,202)
 C
        WRITE(6,290)
        DO 74 I=1,3
 74     WRITE(6,320)I,(SCORN(I,J),J=17,19)
 C
        WRITE(6,330)NYRS
        WRITE(6,318)((JCOL),JCOL=1,14)
        DO 80 N=1,NYRS
 80     WRITE(6,319)N,(CCOST(N,J),J=1,14)
 C
        CALL SSTAT(14,CCOST,NYRS,SCOST)
        WRITE(6,202)
        WRITE(6,290)
        DO 90 I=1,2
 90     WRITE(6,319)I,(SCOST(I,J),J=1,14)
        WRITE(6,320)I,((SCOST(I,J),J=1,14),I=3,3)
 C
 300    FORMAT(I3,4(1X,F6.2),8(1X,F8.2),3(2X,F5.2),1X,F6.2)
 301    FORMAT(1X,4(1X,I6),8(1X,I8),3(2X,I5),1X,I6,/)
 200    FORMAT(3(5(F12.2)/))
 310    FORMAT(5(F12.2))
 319    FORMAT(I3,14(1X,F8.0))
 318    FORMAT(1X,14(1X,I8),/)
 320    FORMAT(I3,14(1X,F8.2))
 321    FORMAT(1X,3(1X,I8),/)
 202    FORMAT(/)
 210    FORMAT(///,' CORN SIMULATION RESULTS FOR SIMULATION YEAR=',I4,/)
 220    FORMAT(' AREA PLANTED IN FIVE PLANT PERIODS, TOTAL=',6(2X,F6.2))
 230    FORMAT(' AREA HARVESTED AS CS HMC CG, TOTAL=',4(2X,F6.2))
 240    FORMAT(' DATES, END PLANTING, BEGIN AND END HARVEST,JULIAN=',
       +    3(1X,I4))
 250    FORMAT(' AREA HARVESTED: SIX HARVEST PDS (ROWS):',
       +      ' FIVE PLANT PDS (COLS): THREE ELEMENTS (CS,HMC,CG)',/)
 260    FORMAT(' DM (TONS) HARVESTED: SIX HARVEST PDS (ROWS):',
       +      ' FIVE PLANT PDS (COLS): THREE ELEMENTS (CS,HMC,CG)',/)
 270    FORMAT(' STANDING DM YLD (T/HA): SIX HARVEST PDS (ROWS):',
       +      ' FIVE PLANT PDS (COLS): TWO ELEMENTS (CS,HMC-CG)',/)
 C
 280    FORMAT('1','CORN SIMULATION OUTPUT: SECTION (1).',/,
       +    ' SUMMARY OUTPUT FOR',I3,' SIMULATION YEARS.',
       +    ' MATRIX YCORN. ',/,
       +    '  EACH ROW REPRESENTS ONE SIMULATION YEAR.',
       +    ' COLUMNS REPRESENT:',/,' 1=JFNPLT 2=JFNALF 3=JBGHRV 4=JFNHRV',
       +    ' 5=HAPLTD 6=HACS 7=HAHMC 8=HACG 9=HACORN 10=DMCS 11=DMHMC',
       +    ' 12=DMCG 13=CSYLD 14=HMCYLD 15=CGYLD 16=WTR',/)
 284    FORMAT(///,' MATRIX YCORN (CONTINUED): ',/,' 17=CSFEED ',
       +      ' 18=HMCFEED  19=CGSELL ',/)
 290    FORMAT(' SAMPLE STATISTICS FOR SIMULATION RUN:',
       +    ' ROWS 1=MEAN  2=STANDARD DEVIATION  3=COEF OF VARIATION',/)
 C
 330    FORMAT('1','CORN SIMULATION OUTPUT: SECTION (2).',/,
       +    ' SUMMARY OUTPUT FOR',I3,' SIMULATION YEARS.',
       +    ' MATRIX CCOST.',/,
       +    ' EACH ROW REPRESENTS ONE SIMULATION YEAR.',
       +    ' COLUMNS REPRESENT:',/,' 1=RM$ 2=FUEL$ 3=LABR1$ 4=LABR2$ ',
       +    ' 5=FUEL(L) 6=LABR1 7=LABR2 8=CUSTOM$ 9=CGDRY$ ',
       +    ' 10=CRNFSC$ 11=MCHINV$ 12=STGINV$ 13=FCM$ 14=FCSTG$',/)
 C
        RETURN
        END
```

```
C
C     ****************************************************
         SUBROUTINE SSTAT(NVAR,SMPL,NOBS,XMOMNT)
C     ****************************************************
C
C     SSTAT CALCULATES MEAN, STANDARD DEVIATION, COEFFICIENT OF
C     VARIATION, AND SKEWNESS OF A SAMPLE DISTRIBUTION.
C     (L. PARSCH, DEPT. OF AG ECON, MSU, 12/81)
C
         DIMENSION SMPL(26,25),XMOMNT(4,25)
         DIMENSION SUM(26),SX(25),SV(25),SS(25)
C
         DO 10 I=1,NVAR
         SUM(I)=0.0
         DO 20 J=1,NOBS
   20    SUM(I)=SUM(I)+SMPL(J,I)
   10    SX(I)=SUM(I)/NOBS
C
         DO 30 II=1,NVAR
         SUM(II)=0.0
         DO 40 JJ=1,NOBS
   40    SUM(II)=SUM(II)+(SMPL(JJ,II)-SX(II))**2.
         SV(II)=SUM(II)/(NOBS-1)
   30    IF(NOBS.LE.1)SV(II)=0.
C
         DO 50 III=1,NVAR
         SUM(III)=0.0
         DO 60 JJJ=1,NOBS
         IF(SV(III).EQ.0.0)GO TO 50
   60    SUM(III)=SUM(III)+((SMPL(JJJ,III)-SX(III))**3./(SV(III)**.5))
   50    SS(III)=SUM(III)/NOBS
C
         DO 70 I=1,NVAR
         XMOMNT(1,I)=SX(I)
         XMOMNT(2,I)=SQRT(SV(I))
         XMOMNT(3,I)=XMOMNT(2,I)/XMOMNT(1,I)
         IF(SX(I).EQ.0.0)XMOMNT(3,I)=0.0
   70    XMOMNT(4,I)=SS(I)
C
         RETURN
         END
```

```
C     **************************************************
         SUBROUTINE CRNENG(NTHYR,ILINE)
C     **************************************************
C
C   THIS SUBROUTINE IS CALLED TWICE EACH YEAR:  PRIOR TO PLANTING
C   (ILINE=1) AND AT THE END OF CORN HARVEST (ILINE=2).  PRIOR TO PLANT-
C   ING , BOTH PLANTING AND HARVEST RATES (HA/HR) ARE DETERMINED.
C   AT THE END OF HARVEST, ANNUAL MACHINE AND LABOR HOURS, AS WELL AS
C   FUEL USE ARE CALCULATED (LITERS) FOR THE CORN CROP.  WHEN THIS SUB-
C   ROUTINE IS USED WITH SAVOIE'S MODEL FORHRV, THE APPROPRIATE CORN
C   SILAGE SECTIONS FOR HARVEST RATE, HOURS, AND FUEL ARE COMMENTED
C   OUT.  (L. PARSCH, DEPT OF AG ECON, MSU, 3/82)
C
      COMMON/CRNDT1/BTAGEN(26,17),RTPLT,HAPLTD(26,6),COSTCG(26,2),
     +       JFNHRV(26),JDPLT(6),JDHRV(7),JFNPLT(26),DMCORN(26,3),
     +       CRNYLD(26,3),COEFCS(6,5),COEFCG(6,5),JBGHRV(26),RTHRV(3),
     +       CLOSSH(3),HADSRD(4),STGCS,STGHMC,HPDHRV,HPDPLT,HACORN(26,4),
     +       JFNAL3(26),COEFMC(6,5),BASEMC,DMFEED(26,3),CRNFSC(26),
     +       TWATER(26),CLOSSF(3),RTFEED(4),CLOSSS(3)
C
      COMMON/CRNDT3/WIDTH(3),PPM(3),NTRAC(3),XMEN(3),NTBLOW(3),RMBLOW,
     +       NBLOWR(3),CLAB1,VCM(4,4),FCPICK,FCPLT,RMM(3),RMT,
     +       HRSPLT(4),HRSCS(4),HRSHMC(4),FUEL(4),FUELRT,CLAB2,
     +       NOPNCS,FECG,FECS,FEPLT,FEHMC,SPDCG,SPDCS,SPDHMC,SPDPLT,
     +       RTBLOW,WCOMB,PSTGCS,PSTGHM
      COMMON/CSARG/CSVAL(26,3)
      COMMON/Y1/XINFO(7),MCODE(100),XMDATA(100,13)
C
      GO TO (10,100)ILINE
C
C   THIS SECTION CALCULATES PLANTING AND HARVESTING RATES OF CORN.
C   IT IS CALLED AT THE BEGINNING OF EACH HARVEST SEASON.
C   ESTABLISH CORN PLANTING RATE, HA/HR.
C
10    IF((HADSRD(4).GT.O.).AND.(WIDTH(1).GT.O.))THEN
         RTPLT=(SPDPLT*WIDTH(1)*FEPLT)/10.
      ELSE
         RTPLT=O.
      ENDIF
C
C   ESTABLISH CORN SILAGE HARVEST RATE.  USE CSRATE FUNCTION ONLY WITH
C   SAVOIE FORHARV MODEL.
C
      IF((STGCS.GT.O.).AND.(WIDTH(2).GT.O.))THEN
C BIG    RTHRV(1)=(SPDCS*WIDTH(2)*FECS)/10.
         RTHRV(1)=CSRATE(BTAGEN(NTHYR,17),NOPNCS)
      ELSE
         RTHRV(1)=O.
      ENDIF
C
C   ESTABLISH HIGH MOISTURE CORN HARVESTING RATE.
C
      IF((STGHMC.GT.O.).AND.(WIDTH(3).GT.O.))THEN
         RTHRV(2)=(SPDHMC*WIDTH(3)*FEHMC)/10.
      ELSE
         RTHRV(2)=O.
      ENDIF
C
C   RESIDUAL CORN IS CUSTOM HARVESTED AS A CASH CROP WITH A SIX ROW,
C   COMBINE (76 CM/ROW).
C
      RTHRV(3)=(SPDCG*WCOMB*FECG)/10.
C
      RETURN
C
C   THIS SECTION IS CALLED EVERY YEAR AT END OF CORN HARVEST TO
C   DETERMINE MACHINE HOURS, LABOR HOURS, AND FUEL USE  ASSOCIATED
C   WITH PLANTING CORN, HARVESTING CS AND HMC.  THE HRS-- ARRAYS ARE:
C   1=IMPLEMENT/TRACTOR HRS  2=LABOR HRS (FIELD,STRG)  3=BLOWER HRS
C   4=LABOR HOURS, FEEDING.
C
100   DO 110 J=1,4
      HRSPLT(J)=O.
      HRSCS(J)=O.
      HRSHMC(J)=O.
110   FUEL(J)=O.
C
```

```
C   CALCUALTE CORN PLANTING HOURS, FUEL USE (LITERS).
C
        IF(RTPLT.GT.O.)THEN
           HRSPLT(1)=HAPLTD(NTHYR,6)*(1./RTPLT)
           HRSPLT(2)=HRSPLT(1)*XMEN(1)
           FUEL(1)=HRSPLT(1)*XMDATA(IROW(NTRAC(1)),11)*FUELRT
        ENDIF
C
C   CALCUALTE CS HOURS, FUEL.  COMMENT OUT APPROPRIATE LINES FOR USE
C   WITH SAVOIE'S FORHRV MODEL.
C
        IF(RTHRV(1).GT.O.)THEN
C BIG      HRSCS(1)=HACORN(NTHYR,1)*(1./RTHRV(1))
C BIG      HRSCS(2)=HRSCS(1)*XMEN(2)
C BIG      HRSCS(3)=DMCORN(NTHYR,1)/RTBLOW
C BIG      HRSCS(4)=DMCORN(NTHYR,1)*(1.-CLOSSS(1))*RTFEED(1)
C BIG      FUEL(2)=HRSCS(1)*XMDATA(IROW(NTRAC(2)),11)*FUELRT
C BIG+              +HRSCS(3)*XMDATA(IROW(NTBLOW(2)),11)*FUELRT
C
C          COMMENT OUT PREVIOUS FIVE LINES WITH SAVOIE'S MODEL.
C
           CSVAL(NTHYR,1)=RTHRV(1)
           CSVAL(NTHYR,2)=HACORN(NTHYR,1)
           CSVAL(NTHYR,3)=DMCORN(NTHYR,1)
           CALL ENDCS(HACORN(NTHYR,1),(DMCORN(NTHYR,1)*(1.-CLOSSS(1))))
C
        ELSEIF(RTHRV(1).LE.O.)THEN
           DO 120 I=1,3
120        CSVAL(NTHYR,I)=0.
        ENDIF
C
C   CALCULATE HOURS, FUEL FOR HMC.
C
        IF(RTHRV(2).GT.O.)THEN
           HRSHMC(1)=HACORN(NTHYR,2)*(1./RTHRV(2))
           HRSHMC(2)=HRSHMC(1)*XMEN(3)
           HRSHMC(3)=DMCORN(NTHYR,2)/RTBLOW
           HRSHMC(4)=DMCORN(NTHYR,2)*(1.-CLOSSS(2))*RTFEED(2)
           FUEL(3)=HRSHMC(1)*XMDATA(IROW(NTRAC(3)),11)*FUELRT
     +           +HRSHMC(3)*XMDATA(IROW(NTBLOW(3)),11)*FUELRT
        ENDIF
C
        CLAB1=HRSPLT(2)+HRSCS(2)+HRSHMC(2)
        CLAB2=HRSCS(4)+HRSHMC(4)
        FUEL(4)=FUEL(1)+FUEL(2)+FUEL(3)
C
C   CALCULATE SELECTED VARIABLE COSTS ASSOCIATED WITH CORN PLANTING,
C   CS AND HMC HARVESTING.
C
        CALL VCOST(NTHYR)
C
        RETURN
        END
```

```
C  ******************************************************
      SUBROUTINE VCOST(NTHYR)
C  ******************************************************
C
C  THIS SUBROUTINE IS CALLED EVERY YEAR AT END OF CORN HARVEST.
C  VARIABLE COSTS ASSOCIATED WITH PLANTING AND HARVESTING OF CS,
C  HMC, AND CG ARE CALCUALTED FOR THE YEAR AND STORED IN CCOST.
C  ANNUALIZED FIXED COSTS OF THE PICKER AND PLANTER ARE ALSO DET-
C  ERMINED HERE.  WHEN THIS SUBROUTINE IS USED WITH SAVOIE'S
C  FORHRV MODEL, APPROPRIATE COST SECTIONS FOR CS ARE COMMENTED OUT.
C  (L. PARSCH, DEPT OF AG ECON, MSU, 3/82)

      COMMON/CRNDT1/BTAGEN(26,17),RTPLT,HAPLTD(26,6),COSTCG(26,2),
     +      JFNHRV(26),JDPLT(6),JDHRV(7),JFNPLT(26),DMCORN(26,3),
     +      CRNYLD(26,3),COEFCS(6,5),COEFCG(6,5),JBGHRV(26),RTHRV(3),
     +      CLOSSH(3),HADSRD(4),STGCS,STGHMC,HPDHRV,HPDPLT,HACORN(26,4),
     +      JFNAL3(26),COEFMC(6,5),BASEMC,DMFEED(26,3),CRNFSC(26),
     +      TWATER(26),CLOSSF(3),RTFEED(4),CLOSSS(3)

      COMMON/CRNDT3/WIDTH(3),PPM(3),NTRAC(3),XMEN(3),NTBLOW(3),RMBLOW,
     +      NBLOWR(3),CLAB1,VCM(4,4),FCPICK,FCPLT,RMM(3),RMT,
     +      HRSPLT(4),HRSCS(4),HRSHMC(4),FUEL(4),FUELRT,CLAB2,
     +      NOPNCS,FECG,FECS,FEPLT,FEHMC,SPDCG,SPDCS,SPDHMC,SPDPLT,
     +      RTBLOW,WCOMB,PSTGCS,PSTGHM
C
      COMMON/PRICE/PLABOR,PFUELD,PFUELG,RATEIM,PDRYCG,PHRVCG,COEFSV(3),
     +      PFSCA1,PFSCA2,PFSCCS,PFSCHM,ALFYRS,RATEIS,RATEIL,XLIFE(3)
      COMMON/TILL/PTILLC,PTILLA
C
      COMMON/SUMRY1/YCORN(26,19),SCORN(4,19),CCOST(26,16),SCOST(4,16)
      COMMON/CSARG/CSVAL(26,3)
      COMMON/Y1/XINFO(7),MCODE(100),XMDATA(100,13)
C
C  CALCULATE FERTILIZER, SEED AND CHEMICAL COSTS OF THE CORN CROP.
C  THESE COSTS (CRNFSC) ARE A FUNCTION OF PLANTING INTENTION (HADSRD)
C  AND ACTUAL AREA PLANTED EACH YEAR (HAPLTD).
C
      IF(HAPLTD(NTHYR,6).GE.HADSRD(4))THEN
         CRNFSC(NTHYR)=PFSCCS*HADSRD(1)+PFSCHM*(HADSRD(2)+HADSRD(3))
      ELSEIF(HAPLTD(NTHYR,6).LT.HADSRD(4))THEN
         UNDONE=HADSRD(4)-HAPLTD(NTHYR,6)
C
         IF(HAPLTD(NTHYR,6).GT.HADSRD(1))THEN
            CRNFSC(NTHYR)=PFSCCS*HADSRD(1)+PFSCHM*(HADSRD(2)+HADSRD(3)
     +                    -UNDONE)
         ELSEIF(HAPLTD(NTHYR,6).LE.HADSRD(1))THEN
            CRNFSC(NTHYR)=PFSCCS*HAPLTD(NTHYR,6)
         ENDIF
C
      ENDIF
C
C  THE VCM MATRIX IS THE VARIABLE MACHINE COST MATRIX FOR PLANTING
C  CORN, HARVESTING CS AND HMC.  ROWS:  1=PLANTING  2=CS  3=HMC
C  COLS:  1=REPAIR AND MAINT $  2=FUEL $  3=LABOR (FIELD,STORAGE), $
C  4=LABOR (FEEDING), $
C
      DO 10 I=1,4
      DO 10 J=1,4
10    VCM(I,J)=0.
C
C  CORN PLANTING COSTS (MACHINERY, LABOR).
C
      VCM(1,1)=HRSPLT(1)*(RMM(1)*PPM(1)+(RMT*XMDATA(IROW(NTRAC(1)),2)))
      VCM(1,2)=FUEL(1)*PFUELD
      VCM(1,3)=HRSPLT(2)*PLABOR
C
C  CS HARVESTING COSTS (MACHINERY, LABOR).  COMMENT OUT WHEN USED
C  WITH SAVOIE'S FORHRV MODEL.
C
C BIG VCM(2,1)=HRSCS(1)*((RMM(2)*PPM(2))+(RMT*XMDATA(IROW(NTRAC(2)),2)))
C BIG+      +HRSCS(3)*((RMT*XMDATA(IROW(NTBLOW(3)),2))
C BIG+                +(RMBLOW*XMDATA(IROW(NBLOWR(3)),2)))
C BIG VCM(2,2)=FUEL(2)*PFUELD
C BIG VCM(2,3)=HRSCS(2)*PLABOR
C BIG VCM(2,4)=HRSCS(4)*PLABOR
C
C  HIGH MOISTURE CORN HARVESTING COSTS (MACHINERY, LABOR).
```

```
C
      VCM(3,1)=HRSHMC(1)*(RMM(3)*PPM(3)+(RMT*XMDATA(IROW(NTRAC(3)),2)))
     +        +HRSHMC(3)*((RMT*XMDATA(IROW(NTBLOW(3)),2))+
     +                 (RMBLOW*XMDATA(IROW(NBLOWR(3)),2)))
      VCM(3,2)=FUEL(3)*PFUELD
      VCM(3,3)=HRSHMC(2)*PLABOR
      VCM(3,4)=HRSHMC(4)*PLABOR
C
      DO 20 J=1,4
      DO 30 I=1,3
30    VCM(4,J)=VCM(4,J)+VCM(I,J)
20    CCOST(NTHYR,J)=VCM(4,J)
C
      CCOST(NTHYR,5)=FUEL(4)
      CCOST(NTHYR,6)=CLAB1
      CCOST(NTHYR,7)=CLAB2
      CCOST(NTHYR,8)=HACORN(NTHYR,3)*PHRVCG+HADSRD(4)*PTILLC
      CCOST(NTHYR,9)=TWATER(NTHYR)*(PDRYCG/.01)*32.878
      CCOST(NTHYR,10)=CRNFSC(NTHYR)
      CCOST(NTHYR,11)=PPM(1)+PPM(3)
      CCOST(NTHYR,12)=PSTGCS+PSTGHM
C
C  CALCULATE FIXED MACHINE COSTS OF CORN PLANTER, CORN PICKER-SHELLER.
C
      FCPLT=ANPV(PPM(1),COEFSV(2),XLIFE(2),RATEIM)+.0025*PPM(1)
      FCPICK=ANPV(PPM(3),COEFSV(2),XLIFE(2),RATEIM)+.0025*PPM(3)
      CCOST(NTHYR,13)=FCPICK+FCPLT
      CCOST(NTHYR,14)=ANPV((PSTGCS+PSTGHM),COEFSV(1),XLIFE(1),RATEIL)
C
      RETURN
      END
```

```
C    ************************************************
         BLOCK DATA MISC
C    ************************************************
C
C    DATA STORAGE FOR MISCELLANEOUS VARIABLES USED IN THE MODEL.
C    (L. PARSCH, DEPT OF AG ECON, MSU, 3/82)
C
         COMMON/PRICE/PLABOR,PFUELD,PFUELG,RATEIM,PDRYCG,PHRVCG,COEFSV(3),
     +           PFSCA1,PFSCA2,PFSCCS,PFSCHM,ALFYRS,RATEIS,RATEIL,XLIFE(3)
C
         COMMON/CRNDT1/BTAGEN(26,17),RTPLT,HAPLTD(26,6),COSTCG(26,2),
     +        JFNHRV(26),JDPLT(6),JDHRV(7),JFNPLT(26),DMCORN(26,3),
     +        CRNYLD(26,3),COEFCS(6,5),COEFCG(6,5),JBGHRV(26),RTHRV(3),
     +        CLOSSH(3),HADSRD(4),STGCS,STGHMC,HPDHRV,HPDPLT,HACORN(26,4),
     +        JFNAL3(26),COEFMC(6,5),BASEMC,DMFEED(26,3),CRNFSC(26),
     +        TWATER(26),CLOSSF(3),RTFEED(4),CLOSSS(3)
C
         COMMON/CRNDT3/WIDTH(3),PPM(3),NTRAC(3),XMEN(3),NTBLOW(3),RMBLOW,
     +        NBLOWR(3),CLAB1,VCM(4,4),FCPICK,FCPLT,RMM(3),RMT,
     +        HRSPLT(4),HRSCS(4),HRSHMC(4),FUEL(4),FUELRT,CLAB2,
     +        NOPNCS,FECG,FECS,FEPLT,FEHMC,SPDCG,SPDCS,SPDHMC,SPDPLT,
     +        RTBLOW,WCOMB,PSTGCS,PSTGHM
C
C    STORAGE SECTION FOR PRICES OF VARIABLE INPUTS.  ALL PRICES ARE
C    IN METRIC UNITS EXCEPT FOR CORN GRAIN DRYING CHARGE RATE WHICH
C    IS IN $/PT/BU.  ALFYRS=NO. OF YRS ALFALFA IS IN ROTATION.
C
         DATA ALFYRS/4./
C
C BIG DATA PLABOR,PFUELD,PFUELG/5.00, .309, .317/
C BIG DATA RATEIS,RATEIM,RATEIL/.17, .15, .13/
C BIG DATA PDRYCG,PHRVCG/.03,59.77/
C BIG DATA PFSCA1,PFSCA2,PFSCCS,PFSCHM/301.09, 118.58, 227.73, 207.11/
C
C    BOUNDARY JULIAN DATES DEFINING PLANTING AND HARVEST PERIODS FOR CORN.
C
         DATA JDPLT/110,121,131,141,152,166/,
     +        JDHRV/244,259,274,289,305,320,334/
         DATA JFNHRV/26*335/
C
C    HARVEST, STORAGE, AND FEEDING LOSSES OF CS, HMC, AND CG (DRY) ON A
C    DM BASIS.
C
         DATA CLOSSH/.06,.035,.075/,BASEMC/.155/
         DATA CLOSSS/.100,.050,.000/
         DATA CLOSSF/.05,.03,.00/
C
C    COEFFICIENTS OF YIELD (CS AND HMC/CG) AND MOISTURE CONTENT (CG)
C    AS FUNCTION OF CORN PLANTING AND HARVESTING DATES.
C    COLS=PLANT DATES FOR EACH HARVEST PERIOD.  ROWS=HARVEST PERIODS FOR
C    EACH PLANT DATE.
C
         DATA COEFCS/1.000,1.000, .980, .940, .880, .806,
     +               .980,1.000, .980, .940, .880, .817,
     +               .000, .980, .960, .940, .900, .855,
     +               .000, .960, .940, .900, .870, .817,
     +               .000, .000, .900, .870, .817, .780/
         DATA COEFCG/ .000,1.021,1.000, .979, .927, .865,
     +               .000, .000,1.000, .980, .900, .900,
     +               .000, .000,1.000, .978, .934, .901,
     +               .000, .000,1.000, .976, .952, .916,
     +               .000, .000,1.000, .986, .973, .919/
         DATA COEFMC/ .300, .280, .260, .240, .210, .200,
     +               .320, .300, .260, .260, .230, .220,
     +               .000, .000, .280, .270, .250, .230,
     +               .000, .000, .300, .300, .280, .240,
     +               .000, .000, .320, .310, .290, .270/
C
C    CORN MACHINERY ENGINEERING COEFFICIENTS.
C
         DATA SPDPLT,FEPLT,SPDCS,FECS/4.8, .55, 4.0, .55/
         DATA SPDHMC,FEHMC,SPDCG,FECG,WCOMB/4.0, .60, 4.0, .65, 4.58/
C
         DATA XLIFE(3)/7./,COEFSV(3)/.20/
         DATA RMT,RMBLOW/.00012,.00025/,RMM/.0007,.00029,.00032/
         DATA FUELRT,RTBLOW/.22265,35./
         DATA RTFEED/.802,.324,.674,1.13/

         DATA NTBLOW(1),NBLOWR(1)/0,0/
C
         END
```

```
C     ********************************************
      FUNCTION IROW(IVAL)
C     ********************************************
C
C     FOR A GIVEN MACHINE INDEX NUMBER, THIS FUNCTION FINDS THE
C     APPROPRIATE MACHINE DATA ROW IN THE XMDATA MATRIX.
C     (L. PARSCH, DEPT OF AG ECON, MSU, 3/82)
C
      COMMON/Y1/XINFO(7),MCODE(100),XMDATA(100,13)
C
      IROW=0
      DO 10 I=1,100
      IF(IVAL.EQ.MCODE(I))THEN
         IROW=I
         RETURN
      ELSEIF((I.EQ.100).AND.(IVAL.NE.MCODE(I)))THEN
         PRINT*,' MACHINE DATA ROW NOT FOUND FOR MCODE= ',IVAL
         STOP
      ENDIF
10    CONTINUE
C
      RETURN
      END
```

```
C     ********************************************
      FUNCTION ANPV(PP,COEFSV,XLIFE,RATEI)
C     ********************************************
C
C     THIS FUNCTION CONVERTS A CAPITAL INVESTMENT (STOCK) INTO AN
C     ANNUALIZED COST (FLOW) REFLECTING DEPRECIATION AND INTEREST.
C     THE RETURNED VALUE EQUALS A CAPITAL RECOVERY FACTOR (CRF) *
C     PURCHASE PRICE (PP) PLUS INTEREST ON SALVAGE VALUE.
C     (L. PARSCH, DEPT OF AG ECON, MSU, 3/82)
C
      IF((PP.LE.0.).OR.(XLIFE.LE.0.))THEN
         ANPV=0.
         RETURN
      ELSE
         CRF=(RATEI*((1.0+RATEI)**XLIFE))/(((1.0+RATEI)**XLIFE)-1.0)
         ANPV=((PP*(1.0-COEFSV))*CRF)+((PP*COEFSV)*RATEI)
      ENDIF
C
      RETURN
      END
```

LIST OF REFERENCES

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