THE ANALYSIS OF FORAGE HARVEST, STORAGE AND FEEDING SYSTEMS

By

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ABSTRACT

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A computer model was developed in cooperation with other researchers to simulate forage systems on dairy farms. The model simulates alfalfa growth, corn silage and corn grain yields, harvest, storage, feeding and ration formulation for a dairy herd. Alfalfa growth is simulated on a daily basis and harvest is simulated on a half-daily basis. Storage, feeding and ration formulation are simulated once per year. A 26-year series of historical weather data from East Lansing, Michigan was used to estimate the average and the distribution of net returns of forage systems.

The analysis focused on alfalfa harvest. Early harvest (May 20 for the first cut) resulted in relatively high quality, low yield and high net return. Low milk producing cows may however use more efficiently an

intermediate maturity harvest (June 1 for the first cut) by substituting yield for quality.

Extending the alfalfa harvest period to four weeks reduced the total dry matter and crude protein conserved. The loss in crop value did not however justify the high cost of larger machinery, as long as each harvest is done within a four week period.

More dry matter and a higher crude protein concentration can be conserved by reducing the field-curing delay. Additional curing treatments that would increase the drying rate by 20% increased the feeding value of hay by 10 to 15%. Baling hay at a higher moisture content had a similar effect. Shifting from hay to haylage would yield about 20% more feed per unit area. The feed quality of haylage and hay is practically the same due to the lower dry matter intake of haylage.

The simulation results indicate promising research areas. Applied reseach could be directed towards the development of conditioning treatments that increase the drying rate without increasing dry matter losses, the improvement of conservation of wet hay and the increase of animal intake of alfalfa haylage. More basic research should consider quality changes in silos during filling and fermentation, modeling animal response to hay, haylage and

large variations in feed quality, and improving estimates of drying rates and dry matter losses.

Approved by:

Major Professor

Department Chairman

To my parents

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to my major professor, Dr. R. C. Brook, for his continual support during my sojourn at Michigan State University.

I am very grateful towards Dr. J. R. Black for his financial support and intellectual stimulation through the dairy-forage research group. Dr. C. A. Rotz was also very helpful with suggestions and material support for the field research. The presence of Dr. H. E. Koenig and Dr. M. B. Tesar on my guidance committee added precious insights in the area of multidisciplinary research.

The simulation model would only be half done without the faithful cooperation of Luke Parsch. The field experiments would not have been done at all without the enthousiasm of Dr. H. F. Bucholz, director of the Upper Peninsula Experiment Station.

The dissertation is dedicated to my parents who patiently laid the path and bravely let me go on the wonderful adventure of life.

Finally I should not forget my affectionate wife and cheerful children who have shared with me the joys and pains of the present endeavor.

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CHAPTER 1

INTRODUCTION

1.1 The dynamics of forage systems

An increase in the use of cereal grains and protein concentrates in ruminant feeding has been observed in recent years, partly because of low feed prices (Raymond et al., 1978; Blaser, 1976). The current low feed prices may still make the practice feasible, but the FAO (1979) predicts a long term increase of demand and prices of grain and protein. High quality forages, espacially legumes, are a good source of protein and can reduce the need of cereal grains and protein meal in the diet of dairy cows (Thomas, 1980). Good harvesting, storage and feeding practices play an important role in maintaining forage quality.

Important technological changes have occurred in the last twenty years in forage systems. Larger machines (round balers, large hay stackers) have been designed especially to reduce labor requirements (Bowers and Rider, 1974). Hoglund (1967) noted that farmers were shifting from dry hay to more haylage. He also reported an increase in corn silage as a forage. Most of the technological changes have meant more capital expenditures (machinery, silos, feeding equipment) and have been justified on the basis of labor and risk reductions.

Meanwhile the 1970's have witnessed some important structural changes in the availibility of some resources, especially fossil energy, and capital due to high interest rates. Holtman et al. (1977) noted that technological adjustments become desirable as the relative scarcity of resources changes with time.

In view of these technological and structural changes, a new assesment of forage harvesting, storage and feeding systems has become highly desirable. A great deal of agronomic, engineering and nutritional knowledge about forages has been published over the last two decades. Modeling tools have become ever more sophisticated. The systems approach, including simulation of the forage system, will be useful in assessing the various technological and management choices available to the farmer in the 1980's.

1.2 Forage research at Michigan State University

Agronomists, animal scientists, economists and engineers have been doing research on various components of the forage system for several years. A multidisciplinary research group was formed in 1979 at Michigan State University to study the dairy-forage system. The group's main objective has been to link the components together and thus gain a better understanding of the whole system. In this context, Sisco (1980) published a detailed model of forage machinery systems.

The present dissertation was also initiated within the mulidisciplinary group. A simulation model of forage growth, harvest, storage, handling and feeding was developed in close cooperation with Parsch (1982). Parsch deals mainly with the impact of various ratios of corn/alfalfa production whereas the present dissertation is concerned mainly with machinery and storage alternatives and with management of the alfalfa crop.

1.3 Objectives

The broad goal of this thesis is to present a methodology and develop a simulation model to analyze and compare forage systems. The model should be versatile enough to allow the analysis of future technological or managerial changes. The specific objectives are:

1. To develop a detailed model of forage harvesting, storage and feeding on the dairy farm. The model will not include field operations other than forage harvesting. The model will include alfalfa harvest as either dry hay, wilted haylage or direct-cut silage as well as harvest of corn silage. The analysis will focus mainly on alfalfa harvest as hay and haylage.
2. To compare forage systems on the basis of a detailed economic analysis that includes income from milk production, income from the sale of excess forages, and fixed and variable costs of harvesting, storage, feeding and ration formulation (purchase of supplemental feeds). Simulation over several years, based on historical weather data, provides samples of annual profits and an insight into the variability of a system. Comparisons will

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be based not only on expected profit but also on the profit distribution by stochastic dominance analysis (Dillon, 1977).

3. To compare alternative technologies: hay versus haylage, direct-cut alfalfa, additional curing treatments to increase the drying rate (maceration or spraying a chemical solution at mowing), chemical additives to preserve high moisture hay or direct-cut alfalfa.
4. To compare alternative management strategies: alfalfa maturity and starting date for harvest, three versus four alfalfa cuts, the timeliness cost and choice of machinery size with respect to area.

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CHAPTER 2

LITERATURE REVIEW

A brief review of the literature is presented which covers past research efforts to model forage systems and experimental work on various parts of the system. The literature will again be referred to extensively in later chapters to estimate technical parameters required by the model.

A number of researchers have analyzed forage systems with respect to the dairy cow performance. McGuckin and Schoney (1980) compared hay and haylage systems as they are affected by weather. They focused on estimating the economic advantage of switching from a highly variable hay system to a less risky haylage system. Under Wisconsin weather conditions, their model predicted that haylage systems were both more profitable and less variable than hay systems on typical dairy farms. Their model did not deal with discrete aspects of harvest and storage. It charged an annual storage cost per unit harvested and assumed a

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assumed a constant dry matter harvest rate independent of yield.

Millier and Rehkugler (1972) compared various harvesting rates and harvest starting dates. Using a simple crop model that predicted yield and quality only on the basis of calendar days, they observed that milk production was negatively affected by slow harvest rates and low forage quality.

Some authors have focused on more specific components of forage systems. Bowers and Rider (1974) surveyed forage harvesting equipment in Oklahoma. Kjelgaard and Quade (1975) analyzed forage transport and conveying equipment for Pennsylvania farms. Audsley et al. (1976) compared various storage and feeding methods in the United Kingdom. These studies, along with others (Hendrix, 1960; Moser, 1980), will provide much of the information needed for a detailed analysis of operations related to forage systems.

New technologies abound in the area of forage systems. Bruhn and Koegel (1977) discussed the value of mechanically dewatering alfalfa. Such a process would virtually eliminate all weather risks associated with making haylage. Charlick et al. (1980) have shown some advantages in using preservatives for the storage of high moisture hay. Nehrir et al. (1978) conducted field studies in which hay preservatives were shown to reduce dry matter losses on the average by 650 kg/ha, compared with hay on which no preservativ

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preservatives were applied. Harris and Tullberg (1980) and Wieghart et al. (1980) noted that chemical spraying of forages at the time of mowing could accelerate drying and hence reduce exposure and weather risk. Krutz et al. (1979) proposed a shredding-type conditioner, the macerator, to increase the drying rate. Under Indiana conditions, the macerator has been used to dry alfalfa as hay within one day. The dry matter losses may however be considerable. Some European researchers (Dernedde, 1979; Jones and Harris, 1979) noted increased drying rates by tedding grasses after mowing. Alfalfa is not as well suited for tedding as grasses because of the fragile link between the stem and the leaves, through the petiole, and the higher risk of dry matter losses.

A number of harvest models have been presented in the literature. Some authors have used workday probability distributions to establish optimum machinery sets (Hayhoe, 1980; Donaldson, 1968; Sisco et al., 1980; Von Bargen, 1966). As Dumont and Boyce (1974) have observed though, the use of daily weather data is more appropriate in forage harvesting models since the weather of previous days has a definite impact on the work that can be done today and on the forage losses due to weather exposure. In fact, several researchers have used historical daily weather data in machinery selection models (Edwards and Boehlje, 1980; Tulu et al., 1974; Wolak, 1980; Van Elderen, 1980). The use of hist

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use of historical weather data implies that past trends represent future trends. Van Kampen (1971) showed that weather between 1931 and 1945 in central Netherland was more favorable for grain harvesting than between 1946 and 1965. An optimal machinery complement for the first period was smaller than for the second period. One should be aware of significant weather changes in the same location from one decade to the next.

Alfalfa growth simulators have been developed by several researchers. Millier and Rehkugler (1972) presented a simple model where yield and TDN (total digestible nutrients) were a function of the number of calendar days of growth. Fick (1977) and Holt et al. (1978) have developed more sophisticated models which use daily weather data as input such as solar radiation, precipitation and degree days.

When the harvest of a crop is delayed because of slow harvest rates, there may be yield and quality losses. The decrease in crop value due to slow harvest rates is called timeliness cost. Timeliness costs are sometimes estimated simply as a linear function of the number of days required for harvesting (ASAE, 1981). However, two different forage harvesting methods, extended over the same time period, might well have a different timeliness cost. Indeed forage harvesting losses should include both quantitative and qualitative losses. Dale et al. (1978) simulated alfalfa dry matte

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dry matter losses during harvest. Alfalfa quality also decreases with harvest delay (National Research Council, 1978). The real measure of quality losses is the additional corn and soybean meal required to re-balance the dairy ration and the possible milk production losses if the minimal nutrient concentration requirement cannot be met.

Much literature is available to help build a detailed model of forage harvesting-storage-feeding systems. It is important however that the model be generic in the sense that parameters are specified symbolically throughout the model. Hence adjustments for geographical location, for technological changes or for managerial choices can be made simply by changing these parameters.

Basically a forage model should include crop growth, harvest, storage and feed utilization on the farm. Indeed, corn silage and alfalfa haylage are not easily marketed because of their short conservation period once they are taken out of storage; their value is usually best estimated in the form of milk production and the relative changes in the purchase of concentrates due to forage quality changes. Even alfalfa hay, which can be sold on the market, is often more efficiently used on the farm for animal production.

The six following chapters describe a general approach to forage systems and the details of harvest, storage, handling and ration formulation. Chapter 9 relies on the simulation model to make inferences about technological and management a

management alternatives in forage systems.

CHAPTER 3

A GENERAL APPROACH TO FORAGE SYSTEMS

3.1 The Systems's Boundaries

The primary emphasis of the present dissertation is to refine the simulation of the harvest, storage and feeding components of forage systems. In a sense, it is a continuation of the work done by Sisco (1980) on forage harvesting. While Sisco considered only the harvesting component, the forage systems's boundaries are now extended to include crop growth, harvest, storage, handling and ration formulation on a dairy farm. Figure 3.1 illustrates the boundaries within which forage systems will be analyzed.

Only two forage crops are considered in the present study: alfalfa and corn silage. An important characteristic of alfalfa is its regrowth in the same year, allowing multiple harvests. There can be time conflicts

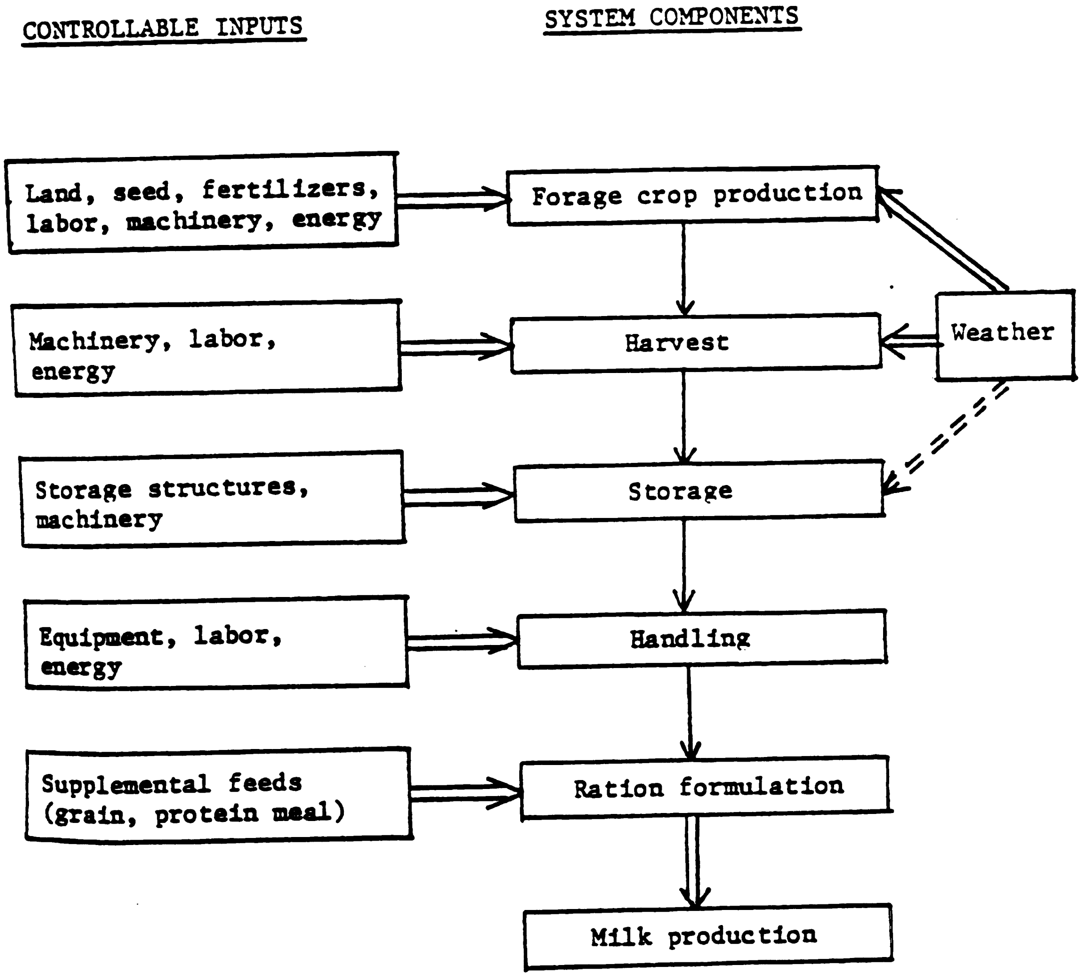

Figure 3.1. The forage system.

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between the end of corn planting and the beginning of the first alfalfa harvest, between the end of the third alfalfa cut and the beginning of corn silage harvest, and between the end of corn harvest and the fourth alfalfa cut. First priority is given to finishing corn planting, the third alfalfa harvest and the corn harvest before starting the competing operations.

The crop growth component is driven by daily weather data: solar radiation, precipitation and growing degree days. Yields are likely to vary from one harvest to the next and from year to year. Yields and quality of the harvested crop are also affected by the rate of harvest: as the calendar time required for harvest increases, more material and quality losses occur. Several other issues related to crop growth will influence the overall system performance: the harvest starting date, the regrowth pattern, the alfalfa's winterhardiness, the establishment of forage fields, fertilization, irrigation. The harvest date and the regrowth pattern are allowed to vary but the other production parameters (winterhardiness, establishment, fertilizer, irrigation) do not vary in the present growth model.

Parsch (1982) has adapted a physiological alfalfa growth model based on research done by Fick (1977). The model predicts growth and regrowth of alfalfa after subsequent cuttings. Parsch (1982) has also developed a corn silage

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corn silage yield model based on Michigan experimental data. Both crop models are included in the present simulation model.

What time increment should one use to simulate forage systems? A detailed harvesting model would simulate harvesting activities (machinery operation, field drying, forage quality changes) on a daily or even on an hourly basis. A detailed storage model would simulate fermentation and quality changes on a daily basis. A ration formulation model would allocate various quality forages to dairy animals according to their needs. The quantity of supplements required would be estimated by a milk-feed optimization model. It was decided to simulate growth on a daily basis, harvest on a half daily basis to provide some management flexibility and storage and feeding on a yearly basis. All the harvested feed is allocated at the end of the year to a dairy herd.

The harvest, storage and handling components will be dealt with in more detail in later chapters. Their role is to convert the field crop into a feed ready for animal consumption. An important aspect of the simulation is to closely track changes in dry matter and in quality between the time the forages are mowed and the time they are fed.

The ration formulation model will estimate amounts of grain and high-protein supplements required to balance the ration of a complete dairy herd. It will also predict milk productio

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production. The value of the forage crop harvested is converted into milk production and net profit. This is the only realistic way to evaluate forages since in general forages are not sold on the market but are transformed into animal product. Computerized models for ration formulation have been discussed by Black and Hlubik (1980) and also by Waller et al. (1981). In the present model, rations for a dairy herd composed of lactating cows at four possible milk production levels are balanced using the harvested crops (alfalfa, corn silage and high-moisture corn) and purchased feeds (corn grain and soybean meal) to satisfy energy and protein requirements. The ration formulation model is described in section 8.1.

3.2 The Objective Function

The inputs of a forage system include labor, energy, capital, land and supplemental feeds. The outputs are milk production and excess forages that may be sold on the market. These material flows will be identified in the simulation on a yearly basis. For comparison purposes however, material flows are converted into a monetary value as follows:

$$PR = I(1) + I(2) - C(1) - C(2) - C(3) \qquad (3.1)$$

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where PR is the total yearly profit;
I(1) is income from milk production;
I(2) is income from the sale of excess forages;
C(1) is the annual cost of labor, energy, repair and maintenance for harvest, storage and feeding;
C(2) is the cost of purchased supplemental feeds;
and C(3) is the annualized cost of fixed assets (machinery, silos, land).

The objective function above can be used to compare different forage systems. Cost C(3) is practically independent of weather. All other terms are weather dependent. Even milk production might vary from year to year as the forage quality and the optimum feeding formula change.

The influence of weather can be assesed by simulating the same forage system over several years of weather data. Each year will provide a different total annual profit. A series of annual profits can be used to draw a histogram or a frequency curve as in figure 3.2. The expected total yearly profit is simply the average and can be used to compare different systems. The frequency curve provides further information on the relative risk of a system. It can be converted into the cumulative probability of annual profit such as in figure 3.3. The comparison of two systems shows that system 1 generates on the average (probability = 0.5) a greater profit than system 2. However system 1 is more variable than system 2: in some years it may provide unusually large profits; in other years, it may incur very low profits or even losses. A

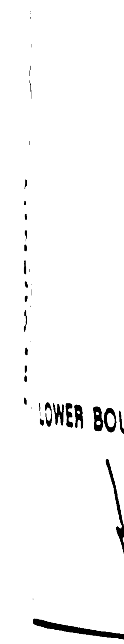

Figure 3.

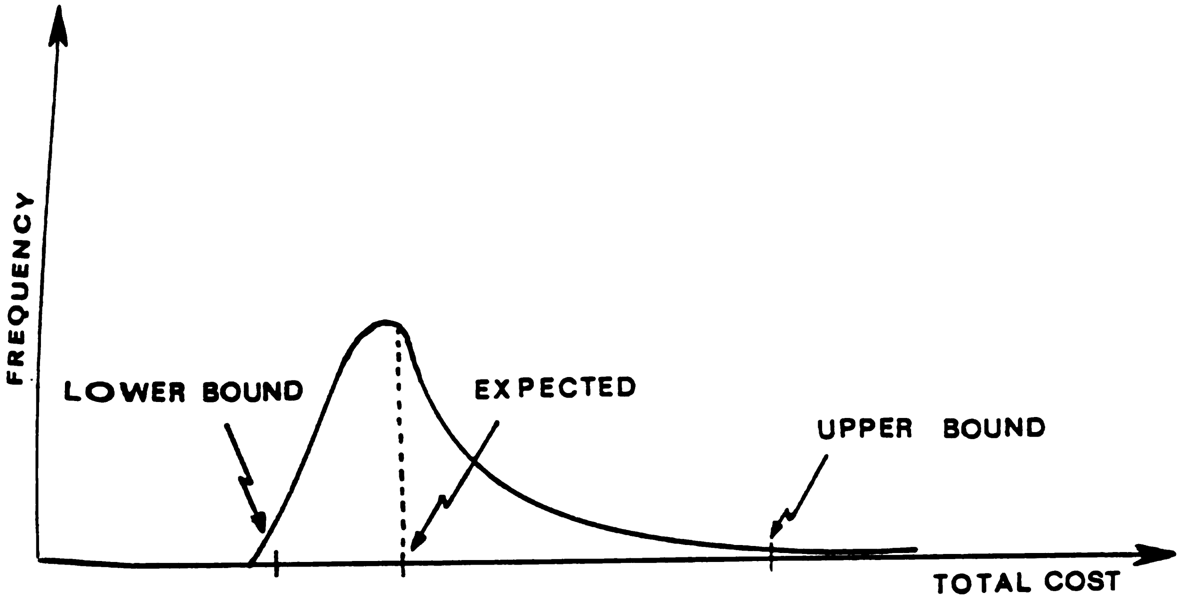

Figure 3.2. Frequency diagram of total cost of a forage system.

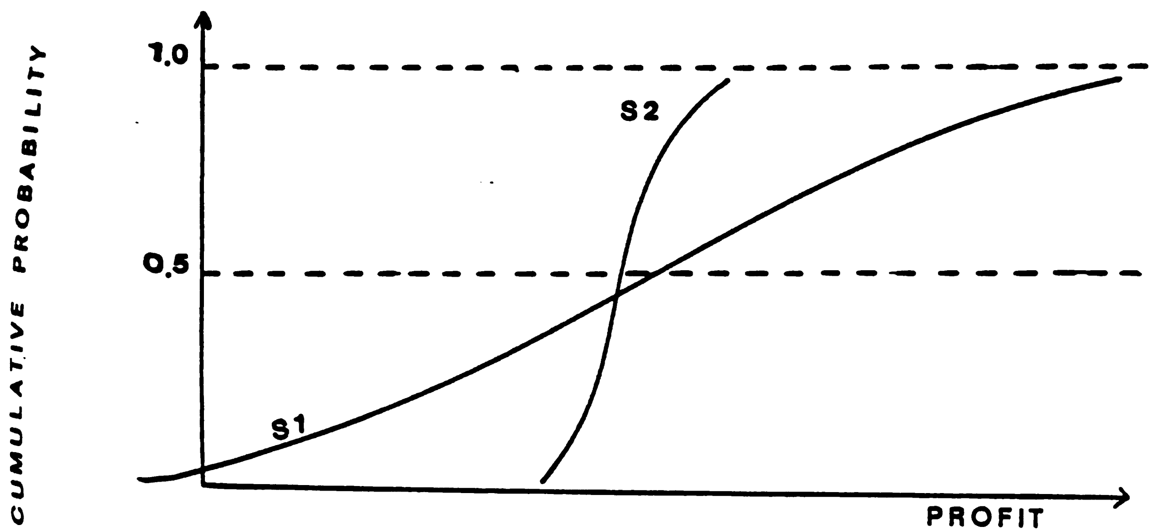

Figure 3.3 The cumulative probability of net profits of two hypothetical forage systems.

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risk-neutral manager would choose system 1. A risk-adverse person may prefer system 2: it yields a lower average profit but it is also less risky than system 1. Comparison of forage systems will be based on the expected yearly profit and on the relative riskiness of each system.

3.3 A continuous versus discrete approach

Forage systems can be simulated either as continuous systems or as discrete systems. The continuous approach implies that small, discontinuous events are aggregated and that average flow rates are used. The discrete approach retains a detailed description of discontinuous events. The discrete approach is usually more complex than the continuous approach but provides a more realistic representation of actual events. The continuous approach is considered first.

3.3.1 The optimum date to begin harvest

The continuous approach is helpful in assessing some important issues in forage systems. A first question that arises is the optimum date to begin harvest. Figure 3.4, adapted from Gervais (1974), illustrates the changes in yield and quality of alfalfa during the first cut. The

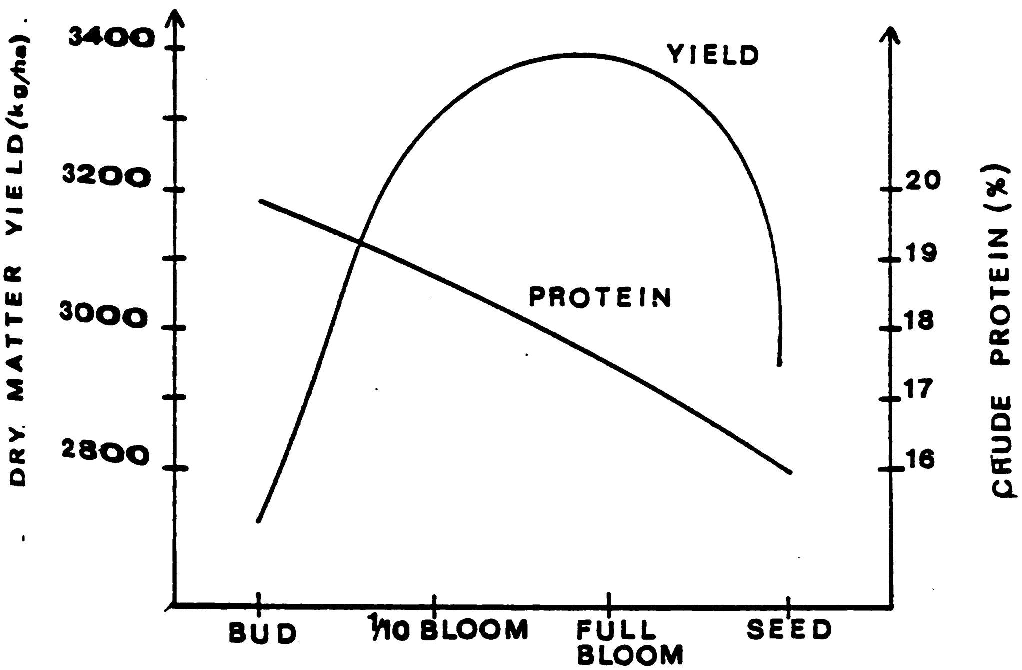

Figure 3.4. Yield and protein concentration of alfalfa versus maturity stage during the first harvest (adapted from Gervais, 1974).

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crude protein decreases almost linearly with the mowing date or the maturity stage. Meanwhile the total dry matter yield continues to increase at least until the full bloom stage.

Yield and quality can be expressed as a function of the mowing date:

$$YDM = f_1(t) \tag{3.2}$$

$$QL = f_2(t) \tag{3.3}$$

$$VAL = f_3(QL) = f_3(t) \tag{3.4}$$

where YDM is the total dry matter yield (kg/ha);
QL is the forage quality, here expressed as crude protein (dec.);
VAL is the value of the crop ($);
and t is the calendar date (day).

In equation 3.4, crop value is a function of crop quality. This is reasonable since milk production is highly and positively correlated to feed quality. If alfalfa could be harvested instantaneously, then the total value would be:

$$TV = YDM * VAL = f_1(t) * f_3(t) \tag{3.5}$$

where TV is the total value of the crop.

The optimal date to harvest would occur at maximum total value. The optimal date is found by differentiating equation 3.5 with respect to time, setting the equation equal to 0 and solving for t.

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$$\frac{dTV}{dt} = f_1'(t) * f_3(t) + f_1(t) * f_3'(t) = 0 \qquad (3.6)$$

Solving equation 3.6 for t will give the optimal harvest date to maximize profit if the harvest could be done in a single day.

3.3.2 Harvest rate

In practice the alfalfa cannot be harvested instantaneously and the harvest rate becomes an important factor in system performance. The harvest is extended over a number of calendar days. The average value of the harvest period may be estimated as follows:

$$u = A / (EFC * h * r) \qquad (3.7)$$

where u is the average number of calendar days required to harvest the crop;
A is the total area of harvest (ha);
EFC is the effective field capacity calculated from equation 4.2 (ha/h);
h is the number of field working hours per day (h/day);
and r is the average ratio of harvesting days to total calendar days over which the harvest period extends.

When the harvest is not instantaneous (u > 0.), the total value of the harvested crop is :

$$TV = \frac{1}{u} \int_{t_0}^{t_0 + u} f_1(t) * f_3(t) * dt \qquad (3.8)$$

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The optimal starting date is found by differentiating equation 3.8 with respect to t_0, equating to 0 and solving for t_0.

$$\frac{dTV}{dt} = \frac{1}{u}\frac{d}{dt} \int_{t_0}^{t_0 + u} f_1(t) * f_3(t) * dt = 0 \quad (3.9)$$

Solving equation 3.9 for t_0 will give the optimal date on which harvest should begin to maximize profit. Parameter u, the average number of calendar days required to complete the harvest is not really a constant and will vary from year to year depending on weather.

3.3.3 Field curing delay

The quality of alfalfa ($f_2(t)$) is not only affected by the date at which it is mowed but also by the amount of time it is left curing in the field. The curing delay is a function of technology, management, yield and environmental conditions. Quality and value of the alfalfa crop should be expressed as a function of both the date of mowing and the field-curing delay.

$$QL = f_2(t,v) \quad (3.10)$$

$$VAL = f_3(t,v) \quad (3.11)$$

where v is the field curing delay.

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A more complete equation for total value is therefore

$$TV = \frac{1}{u} \int_{t_0}^{t_0 + u} f_1(t) * f_3(t,v) * dt \qquad (3.12)$$

From the above equation, at least three important parameters need to be optimized:

t_0, the time when harvest should start;

u, the harvest period equal to the average number of calendar days required to complete the harvest (related to harvest rate);

and v, the average field curing delay (days).

The total value of the crop (TV) is likely to increase if u and v are decreased, i.e. if the harvest period and the field curing delay are decreased. The harvest period can be decreased by increasing the harvest rate (usually with larger machinery). The annualized fixed costs (C(3)) would then increase. It is not so clear how C(1), the yearly variable costs, would be affected. Labor costs would decrease while energy and machinery maintenance costs might remain the same or increase slightly. The field curing delay can be decreased by a change in the harvest technology. For example shifting from a hay technology to a haylage technology will substantially reduce the field curing time and will usually result in a higher quality, more valuable feed. (The problem of comparing alfalfa hay with hayla

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with haylage is however compounded by the fact that animals respond differently to hay and haylage of the same quality (see section 5.4.) In general, reducing the field curing delay will increase the value of the crop. However short exposure time technologies are often more capital or energy intensive. So as TV increases, so will C(3).

Clearly there will be tradeoffs between the value of the crop that may be obtained and the additional cost of capital and energy required to increase this value. The continuous approach helps to clarify some of the important issues in forage systems, especially with regards to the size of machinery and the technology used for harvest.

3.3.4 Problems with the continuous approach

Two important parameters, the number of calendar days to complete the harvest (u) and the average field curing delay (v), need to be optimized but vary from year to year because they are weather dependent. Average values of u and v can be used, but information about the magnitude of year-to-year variations due to weather will be lost. A discrete approach would allow the estimation of year-to-year variations and establish distributions of yearly profits.

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Alfalfa can be harvested up to four times per year in the U.S. North-Central region. The starting harvest date (t_0) and the total harvest period (u) of the first harvest will affect the yield of all subsequent harvests in the same year. The total value of a multiple harvest crop would be the summation of the value of each harvest:

$$TV = TV(1) + TV(2) + \ldots + TV(n) \qquad (3.13)$$

where n is the total number of harvests in a year.

Total value of each harvest, TV(i), could be estimated by equation 3.12, but yields ($f_1(t)$) of subsequent harvests would be affected by t_0 and u. Even n, the total number of harvests in a year, might vary from year to year on account of weather and previous harvests. The interaction between previous management decisions and the yield of subsequent harvests can be most efficiently simulated by the inclusin of an alfalfa growth model in a discrete simulation.

Many management decisions are discrete and sequential, especially during forage harvest when there is a field curing delay. A discrete approach is more appropriate to analyze management decisions such as priority between mowing and harvest, mowing policy with regards to weather expectations or changing the harvest sequence after unfavorable weather. The discrete approach is considered next.

3.4 A discrete approach

The discrete approach to analyze forage systems is summarized by the flowchart in figure 3.5. The discrete model is preferred to the continuous model because it follows more closely the discrete decisions and events involved in forage harvesting. It also retains information about year-to-year variations and risk.

The discrete model will simulate forage growth and harvest on a daily basis. After accounting for dry matter losses and quality changes throughout harvest, storage and handling, all forages are used to balance the ration of a complete dairy herd on a yearly basis. The yearly profits are estimated according to equation 3.1. After the simulation has been repeated for a given number of years (N), a frequency curve of yearly profits can be established as in figure 3.2.

More specifically, the discrete model starts by reading input data required for the whole simulation. The crop growth information includes first and last growth days each year for alfalfa, the yield distribution for corn silage, the number of years of simulation and the related historical weather data. The machinery information is used to generate harvest rates over a wide range of yields by

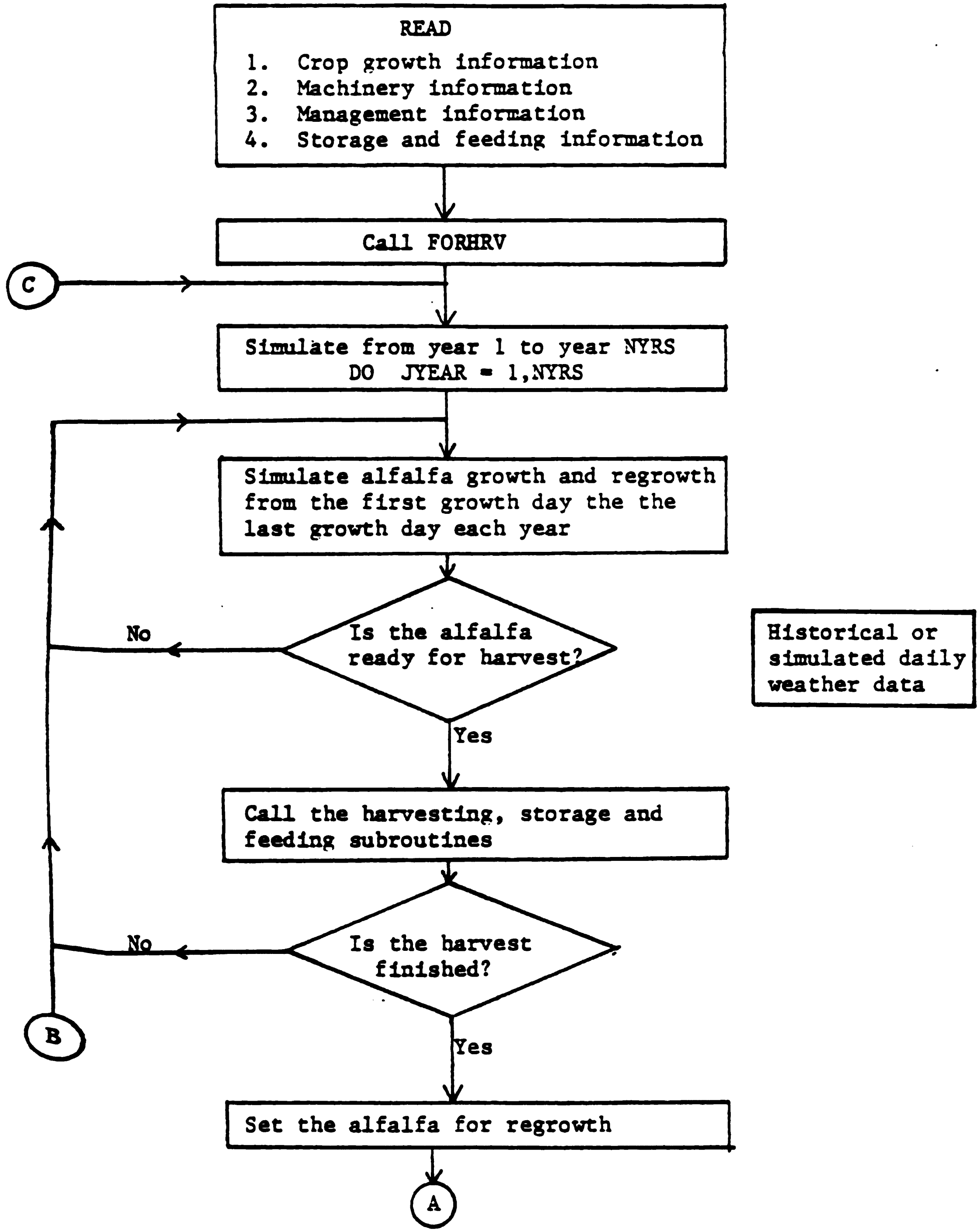

Figure 3.5. Flow chart of the discrete approach to analyze forage systems (continued on the next page).

Figure 3

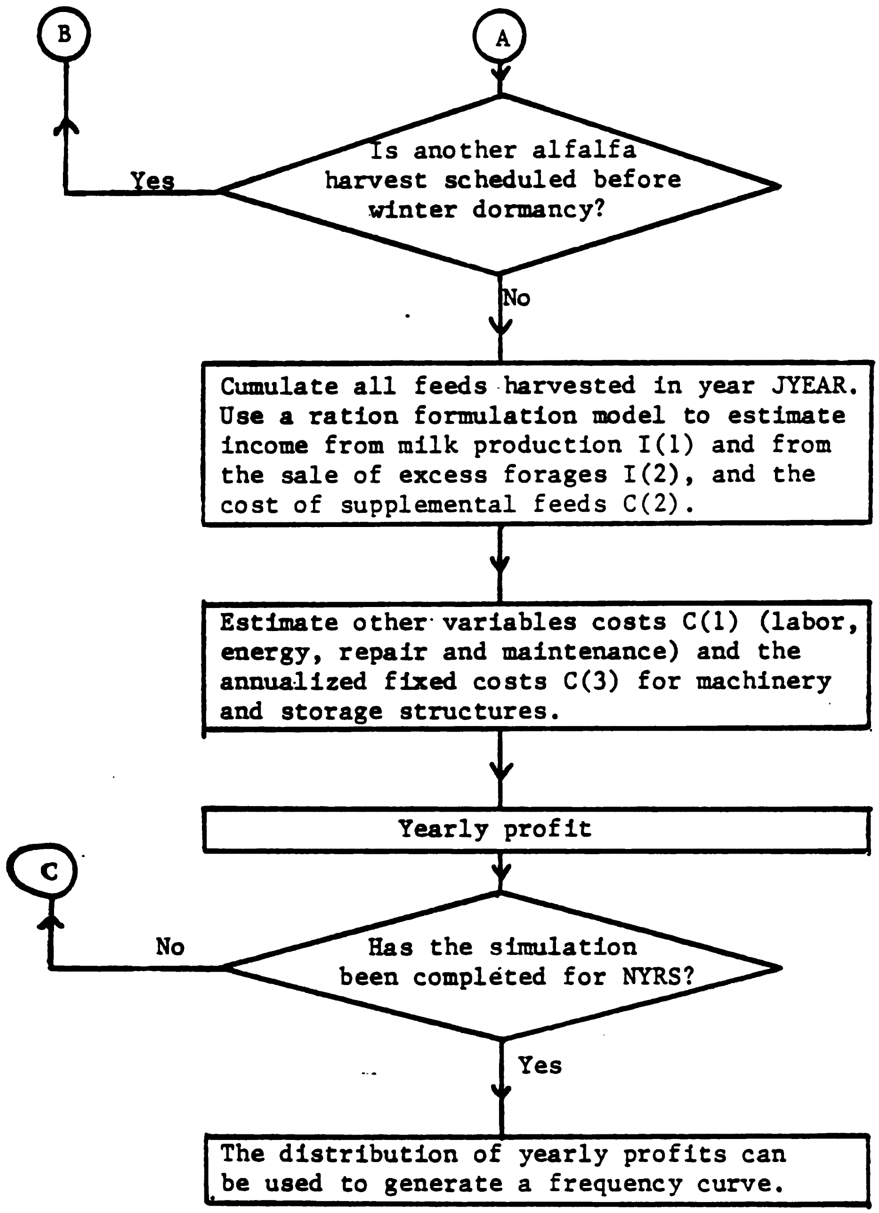

Figure 3.5 (continued from the previous page) Flow chart of the discrete approach to analyze forage systems.

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calling a set of subroutines headed by subroutine FORHRV. Chapter 4 and appendix B describe the machinery algorithm in greater detail. The management information includes the area under cultivation, the sequence of operations and decision criteria related to harvest and storage. The decision algorithms are documented in chapter 7 and in appendix C. The storage and feeding information concerns fixed assets other than field machinery: silos, hay barns and feeding equipment. The information is later used to estimate the annualized cost of fixed assets.

The simulation is repeated for N years. The present weather file being used contains data for 26 years at East Lansing, Michigan (Parsch, 1982). Within each year, the alfalfa growth is simulated on a daily basis. In general, three or four harvest dates per year are defined for alfalfa. When the calendar date equals the current harvest date, harvest may begin. Growth will continue until the end of the harvest. At this point, the alfalfa is set for regrowth and the cut number (NTHCUT) is increased by one. The second and all subsequent harvests will start at the specified harvest dates. When no more harvests are scheduled in a given year, all the harvested forages are accumulated according to their storage location. The feeds are balanced with supplemental grains and protein-meal to optimize milk production of a dairy herd.

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The continuous model is helpful in identifying important issues: the date when harvest should start, the harvest rate and the field-curing delay. These issues will be considered in chapter 9 from the simulation results.

The discrete model provides the basic structure to simulate forage growth and harvest on a daily basis and forage allocation to a dairy herd on a yearly basis. Year-to-year variations in growth and harvest, and ultimately in available feed and net returns, will be estimated with the use of historical weather data.

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CHAPTER 4

MACHINERY MODEL

4.1 Forage harvest alternatives

The object of the machinery model is to predict harvest rates and fuel and labor requirements for practically any combination of machines at any yield. The present chapter establishes the relationships that will be used to estimate the performance of forage harvesting systems.

The boundaries of the forage sytem were defined earlier, in section 3.1, to include hay, haylage and direct-cut forages. The more important harvest alternatives will be outlined here.

A detailed survey of harvest alternatives can hardly be done without making an inventory of the forage harvest machinery available on the U.S. market. A generic summary of forage harvesting machinery is presented in appendix A. It lists sizes and capacities of most forage harvest related r

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related machines available on the U.S. market in the fall of 1981.

4.1.1 Hay making alternatives

Tseng and Mears (1975) presented a detailed flow chart of most technologies available for forage harvesting. Figure 4.1 is a simplified version of their flow chart. Hay making alternatives include all harvest sequences that produce dry hay. Dry hay can be packaged in several forms. The more common hay packages are conventional small rectangular bales, large round bales and large hay stacks.

Hay making can be broken down into a number of operations that may occur in the following sequence:

1. Mowing;
2. Conditioning, to enhance drying;
3. Further curing treatment, such as desiccant spraying or tedding;
4. Raking, to bring the material in a narrow windrow for easy pickup;
5. Additional treatment after rain;
6. Pickup and packaging;
7. Hauling to the storage site;
8. Conveying into storage.

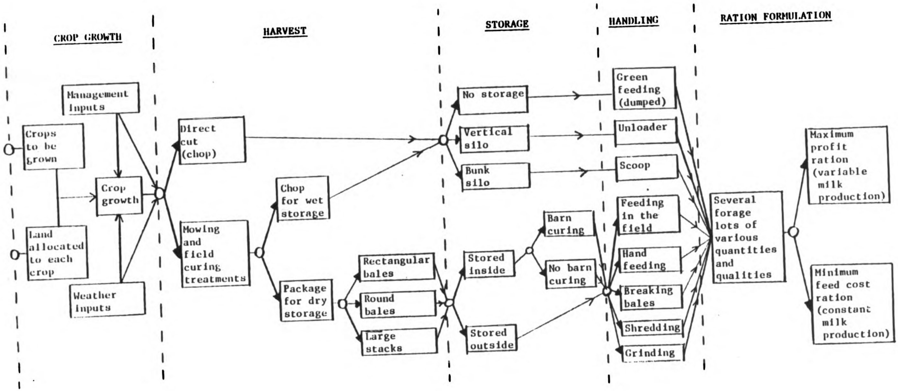

Figure 4.1. Some of the alternatives in forage systems.

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Mowing and conditioning are usually simultaneous. Even some additional curing treatments are sometimes simultaneous with mowing-conditioning (e.g. spraying a chemical solution to enhance drying). Tedding however is sequential. Raking is not always necessary. When it is, it is often done just before packaging. Packaging, hauling and conveying may be simultaneous as in the use of a small baler, with an ejector throwing bales into a wagon, operating simultaneously with a transport unit and a bale unloading component at the storage site (figure 4.2). Packaging may also be independent of hauling and conveying when bales are dropped and left in the field (figure 4.3).

Round bale and large hay stack systems usually make packaging and transport two independent operations. Bales may be left several days in the field before they are moved into a storage area. These systems are simpler to manage and are less labor intensive than the traditional, simultaneous baling-transport-unloading systems.

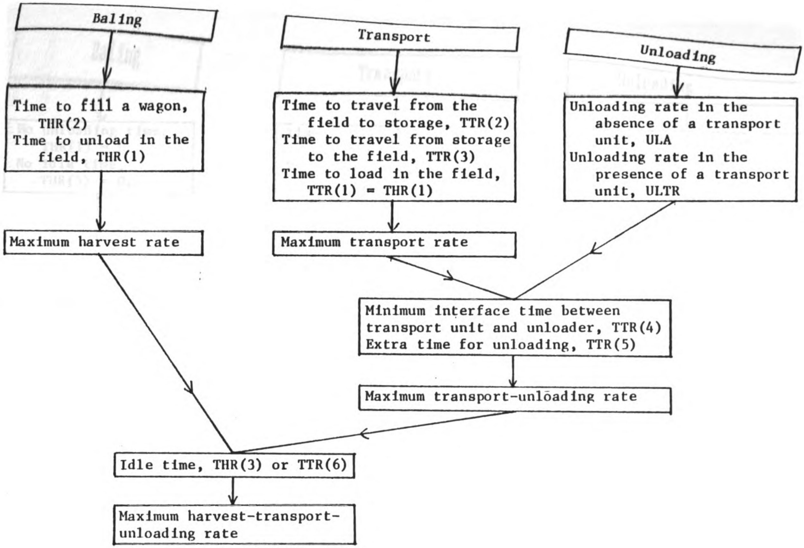

Figure 4.2. The estimation of cycle time for simultaneous baling, transport and unloading.

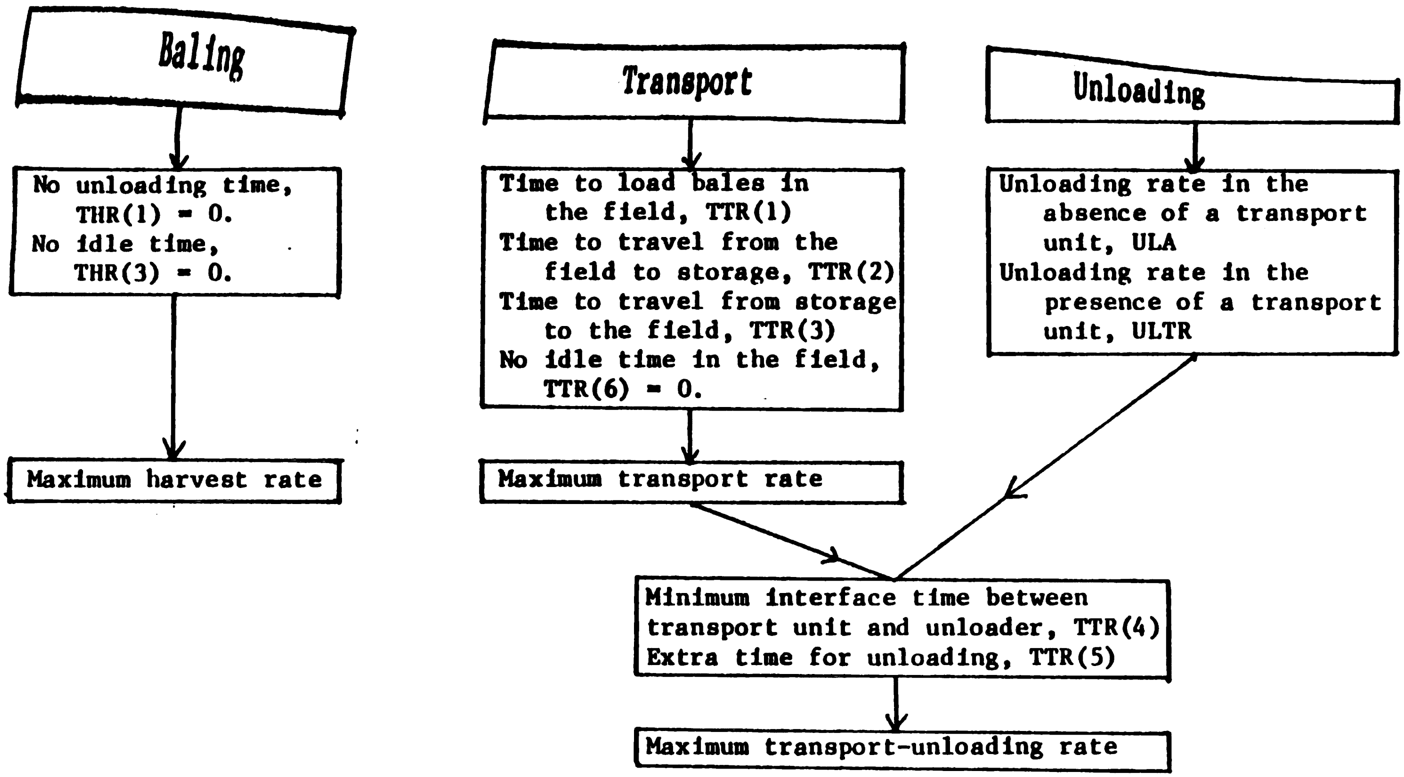

Figure 4.3. Independent baling and transport. Transport and unloading occur subsequently to baling.

4.1.2 Haylage and direct cutting

Haylage and direct cutting systems require that harvest and transport to storage or to the feeding bunk be simultaneous operations. Conceptually they are very similar to the baler-transport-unloader system illustrated in figure 4.2. One occasional difference is the parallel use of trucks or wagons pulled by a second tractor in haylage or silage systems. Hitching and unhitching wagons are eliminated. Dump trucks allow rapid unloading into bunk silos.

Another difference between the haylage system and the baler-ejector-wagon system is the impossibility of leaving haylage on the ground for later pickup. The option of blowing chopped haylage onto the ground may nonetheless be useful in dealing with hay which has molded in the windrow.

4.2 Field capacity

Field capacity is a function of speed, of working width and of field efficiency. It is usually expressed in area per unit time (e.g. hectares per hour). Throughput capacity is usually expressed in material flow per unit

time (e.g. tons of dry matter per hour). Throughput may be a function of field capacity and yield for harvesting machines or may be a function of the machine's own ability to process material.

Individual and parallel operations are defined according to ASAE (1981), standard S322. Individual operations are continuous and independent from other operations. Parallel operations involve two or more machinery systems performing their differing functions simultaneously and interdependently. These two types of machinery operations will be analyzed in greater detail below.

4.2.1 Individual operations

Mowing, raking and round baling are examples of individual operations. None can start before a set of management and environmental conditions is met. But once these conditions are met, the individual operation can proceed continuously and independently from other operations.

The theoretical field capacity of an individual operation is calculated as follows:

$$TFC = (V * WW)/10. \tag{4.1}$$

where TFC is the theoretical field capacity (ha/h);
V is the speed (km/h);
WW is the working width (m);
and 10. is a conversion factor (km-m/ha).

The effective field capacity is lower than the theoretical due to turning, idling, minor field adjustments, temporarily slowing down, etc.

$$EFC = (V * WW * FE)/10. \quad (4.2)$$

where EFC is the effective field capacity (ha/h);
and FE is field efficiency (decimal).

ASAE (1981) provides some data (D230.3) about the range of field efficiencies for various operations. A field efficiency of 0.80 will be assumed for all individual forage harvesting operations (mowing, raking, tedding, baling, forage chopping independently from transport) except for round balers (FE = 0.75) and large stack wagons (FE = 0.70). The last two machines need to stop to unload the hay packages. The stack wagon moreover must stop periodically to compress the stack. These considerations justify the lower field efficiencies.

The theoretical throughput is

$$TTP = TFC * YDM \quad (4.3)$$

where TTP is theoretical throughput (t DM/h);
and YDM is dry matter yield (t DM/ha).

The effective throughput is

$$ETP = EFC * YDM \tag{4.4}$$

where ETP is effective dry matter throughput (t DM/h).

4.2.2 Parallel operations

The most important parallel operation in forage harvesting is harvest-transport-unloading. Each part of the system can affect the overall efficiency and throughput. Estimating overall field capacity and material throughput for a given set of parallel operations can be done in three basic steps:

1. Calculate the maximum harvest and transport rates per single unit;

2. Calculate the maximum harvest and transport rates for all units;

3. Balance the harvest and transport rates by including idle time to one or another of the operations.

The concept of cycle time must be introduced to estimate maximum rates. The complete cycle of a forage harvesting machine is the total time required to hitch an empty wagon, to fill it, to unhitch the filled wagon and to idle while waiting for the transport unit. The hitching and unhitching times are fairly predictable; they are grouped and called the minimum interface time in the field between the harvester and the transport unit.

$$TOTHRC = THR(1) + THR(2) + THR(3) \quad (4.5)$$

where TOTHRC is the total harvest cycle time (h);
THR(1) is the minimum interface time in the field between the harvester and the transport unit (h);
THR(2) is the time required to fill a wagon (h);
and THR(3) is the idle time the harvester spends waiting for a transport unit (h).

The hitching and unhitching times (THR(1)) are fairly predictable and can be provided from experience. Values between 0.05 and 0.08 hour are generally used in the model for total interface time. The time to fill a wagon, THR(2), will depend on throughput of the harvester and wagon capacity. Throughput is generally expressed as the mass of dry matter processed per unit time whereas wagon capacity is in mass of wet matter. The wagon's dry matter capacity is:

$$DMCAP = WCAP/(1. + M) \quad (4.6)$$

where DMCAP is the wagon's dry matter capacity (t DM);
WCAP is the wagon's actual capacity (t WM);
and M is the moisture content (dec, dry basis).

The actual time to fill a wagon is

$$THR(2) = DMCAP/ETP \quad (4.7)$$

Assuming no idle time (THR(3)=0), the maximum harvest rate of a single harvester is

$$HR = DMCAP/TOTHRC \quad (4.8)$$

where HR is the maximum harvest rate of a single harvester (t DM/h).

On very large farms, several harvesters may be working simultaneously. The total maximum harvest rate would then be

$$XHR = NHU * HR \quad (4.9)$$

where XHR is the overall maximum harvest rate when no idle time is considered (t DM/h);
and NHU is the number of harvesting units.

When more than one harvester is used, it is implicitly assumed that they all are of the same size and capacity.

The cycle time of each transport unit is estimated as follows:

$$TOTTRC = TTR(1) + TTR(2) + TTR(3) + TTR(4) + TTR(5) + TTR(6) \quad (4.10)$$

where TOTTRC is the total transport cycle time (h);
TTR(1) is the minimum interface time in the field between the transport unit and the harvester (h);

TTR(2) is the time to travel from the field to storage with a full load (h);
TTR(3) is the time to travel from storage to the field with an empty wagon (h);
TTR(4) is the minimum interface time at storage, excluding unloading (h);
TTR(5) is extra time the transport unit must spend at the storage site to help with unloading (h);
and TTR(6) is idle time waiting for the harvester (h).

The minimum interface time between the harvester and the transport unit TTR(1) is the same as THR(1). Travel times TTR(2) and TTR(3) are calculated by assuming the maximum allowable speed, based on tractor power and physical speed limitations, will be used to travel the distance between storage and the field back and forth. The minimum interface time at storage TTR(4) includes unhitching and hitching if extra wagons are available and extra labor is working continuously at the storage site, or the time to set up a wagon so it may be ready for unloading. If the transport unit can exchange a full wagon for an empty one at storage without any delay besides unhitching and hitching, then TTR(5) is zero. In many cases however, the transport unit will have to wait for the unloading system to empty the wagon. The waiting time is estimated as

$$TTR(5) = (DMCAP - QULA)/ULTR \qquad (4.11)$$

where QULA is the quantity unloaded during the transport unit's absence (t DM);
and ULTR is the unloading rate in the presence of the transport unit (t DM/h).

The quantity unloaded during the transport unit's absence is estimated as follows:

$$QULA = ULA * (TTR(1) + TTR(2) + TTR(3))/NTU \quad (4.12)$$

where ULA is the unloading rate in the absence of the transport units (t-DM/h);
and NTU is the number of transport units.

The term ULA will usually have a value of zero in the case of haylage and corn silage but it may be significant in the case of baled hay. Hundtoft (1965) reported the unloading rate of baled hay as about 6 U.S. tons/man.h. This rate was obtained when bales were randomly piled with the use of an elevator. In the present model, an unloading rate of 5 metric tons DM/man.h with a bale elevator and 3.5 metric tons DM/man.h without an elevator was assumed. The unloading rate in the presence of the transport unit, ULTR, usually uncreases as the labor available increases.

In the case of a mechanical blower, the maximum wet material flow rate is

$$FWM = \frac{PTO * XLD * EMECH * 3.6}{HEIGHT * G} \quad (4.13)$$

where FWM is the flow of wet matter (t WM/h);
PTO is the maximum power available from the power take-off driving tracto (W);
XLD is the maximum allowable continuous load (dec);
EMECH is the mechanical efficiency (dec);
3.6 is a conversion factor (t-s/kg-h);
G is the earth's acceleration (9.8 m/s^2);

and HEIGHT is the silo height (m).

The unloading rate expressed in dry matter is

ULTR = FWM/(1. + M) (4.14)

The maximum allowable continuous load is usually defined as 0.71. The mechanical efficiency is set at 0.08 for blowing corn silage and at 0.06 for blowing alfalfa haylage (Kepner et al., 1972; PAMI, 1979).

Assuming no idle time (TTR(6)=0), the maximum transport rate per unit is

TR = DMCAP/TOTTRC (4.15)

where TR is the maximum transport rate per transport unit (t DM/H).

The overall transport rate is

XTR = NTU * TR (4.16)

where XTR is the overall maximum transport rate when no idle time is considered (t DM/h).

When more than one transport unit is used, it is implicitly assumed that they all are of the same size and capacity.

In general the overall transport capacity XTR will not be equal to the overall harvest rate XHR. If the transport rate is greater than the harvest rate, each transport unit will have to idle and wait for the harvester. The average waiting time per transport unit is

$$TTR(6) = \frac{NTU * TOTHRC - NHU * TOTTRC}{NHU} \qquad (4.17)$$

If the harvest rate is greater than the transport rate, then the harvester will have to idle and wait for a transport unit. The average waiting time per harvest unit is

$$THR(3) = \frac{NHU * TOTTRC - NTU * TOTHRC}{NTU} \qquad (4.18)$$

The actual harvest rate is the lowest rate between XTR and XHR.

The above relationships describe the harvest rates for individual and parallel operations. They are used in the computer simulation described in section 4.5.

4.3 Power requirements

Designers and analysts of machinery systems must be concerned especially by two types of power requirements: peak demand and average demand. The peak power requirement occurs at maximum load or at maximum throughput, under slippery or sloped conditions. The peak power requirement dictates what minimum tractor size can be matched with a given implement. The average power requirement occurs at average load, average throughput and under normal soil conditions. It is most useful for estimating average and total fuel consumption.

Only average power requirement will be calculated in the present analysis. A safety factor is introduced to make sure the actual tractor will also satisfy peak demands.

$$LOAD = PWR/XPWR = 1./SF \quad (4.19)$$

where SF is a safety factor for tractor power design;
XPWR is the maximum PTO power available from the tractor (W);
PWR is the average power requirement (in PTO power equivalent) (W);
and LOAD is the ratio of average power required to maximum power available.

Typical values of the safety factor range between 1.25 and 1.6, and sometimes beyond. Higher values should be used when peak demand is considerably higher than average demand, when there are large variations in yield, in slope and in soil conditions. PAMI (1979) has reported that most rectangular and round balers require a safety factor of 1.5 to 1.6 to make efficient use of high capacity machines in variable conditions. In some types of machines, such as tub grinders, the tractor may actually stall if the available power is not at least 50% greater than the average power demand due to large variations in peak power demand. It should be noted that PAMI and most other authors neglect power for tractor to move itself which can frequently be more than 20% of total power required for large and heavy tractors. Since the tractor-axle power is already included in the model, a safety factor of 1.4 will be used and should be fairly conservative.

The average power required from a tractor (PWR) is distributed into three parts:

$$PWR = TRPWR + DBPWR + PTO \tag{4.20}$$

where TRPWR is the tractor-axle power to move the tractor itself (W);
DBPWR is the tractor-axle power to pull the drawbar (W);
and PTO is the rotative power from the power take-off shaft to activate some implements (W).

The tractor-axle power to move the tractor itself is determined by the tractor weight, the friction force against the wheels, the tractor speed, the wheel slip and the slope of travel.

$$TRPWR = TRM * G * (RRC * \cos\theta + \sin\theta) * V * CF1 * SLF/3.6 \tag{4.21}$$

where TRM is the tractor mass (kg);
G is the earth's acceleration (9.8 m/s^2);
RRC is the rolling resistance coefficient;
θ is the angle of the slope of travel;
CF1 is a power conversion factor from axle power to PTO equivalent power (CF1=1.10);
SLF is the slip factor and is estimated as 1./(1. - SL);
SL is slip in decimal form;

and V is the tractor speed (km/h).

Rolling resistance and slip are estimated from ASAE data D230.3 (ASAE, 1981). The rolling resistance coefficient is

$$RRC = 0.04 + 1.2/CN \qquad (4.22)$$

where CN is a soil surface parameter. Typical values are 50 for hard soils, 30 for firm soils, 20 for tilled soils and 15 for soft,sandy soils.

Generally a rolling resistance coefficient of 0.08 is used during forage harvesting (firm soil). Predicted slip in decimal form is

$$SL = \left[\frac{1.}{0.3 * CN}\right] \ln\left[\frac{0.75}{0.75 - \left(\frac{RWTAN}{RWNOR} + \frac{1.2}{CN} + 0.04\right)}\right] \qquad (4.23)$$

where RWTAN is the sum of tangential forces against the rear wheels;
and RWNOR is the normal force of the rear wheels against the soil.

The ratio of tangential forces to normal forces is calculated as follows:

$$\frac{RWTAN}{RWNOR} = \frac{DBP + TRM * G * \sin\theta}{0.75 * TRM * G * \cos\theta} \qquad (4.24)$$

where DBP is the drawbar pull (N).

The coefficient 0.75 in equation 4.24 assumes that 75% of the tractor weight is distributed on the rear wheels. The drawbar pull is a function of the weight of the implement and the wagon being pulled.

$$DBP = WIM * G * (\sin\theta + RRC * \cos\theta) \qquad (4.25)$$

where WIM is the mass of the wagon or of the implement pulled by the tractor.

For power requirement calculations, the wagon will generally be considered fully loaded except for empty wagons travelling from storage to the field.

The second part of power required from a tractor is the tractor-axle power to pull the drawbar.

$$DBPWR = DBP * V * SLF * CF2/3.6 \qquad (4.26)$$

where CF2 is the power conversion factor from drawbar power to PTO equivalent power (CF2=1.20).

The third power requirement is from the power take-off shaft to activate rotating implements. Table 4.1 gives values of PTO power requirements for most harvesting operations. ASAE (1981) and PAMI (1979) have provided most estimates for power requirements. Power required for mowing is mainly a function of width while power required for conditioning is mainly a function of material throughput. Hence a mowing-conditioning operation will be a function of both width and throughput. Raking and tedding power requirements shown in table 4.1 are relatively low. All other operations have energy requirements proportional to the theoretical flow of dry matter FDM, expressed in kg of dry matter per second (kg DM/s). FDM is the same as theoretical throughput in equation 4.3 except for units.

$$FDM = TTP/3.6 \quad (4.27)$$

$$FDM = V * WW * YDM/36. \quad (4.28)$$

where FDM is the theoretical flow of dry matter (kg-DM/s);
V is operation speed (km/h);
WW is the working width (m);
and YDM is the dry matter yield (t-DM/ha).

The last equation is obtained by combining equations 4.1, 4.3 and 4.27. The PTO power required from a rotative implement (except mowers) is

$$PTO = PTOW * WW + PTOC * V * WW * YDM/36 \quad (4.29)$$

where PTO is the power take-off required for a rotating implement (W);
PTOW is the power required per unit width in the case of mowers (W/m);
and PTOC is the power required per unit throughput of dry matter (W/kg-DM/s).

For cutterbar mowers, the power requirement is simply

$$PTO = PTOW * WW \quad (4.30)$$

Table 4.1. Rotative power (PTO) requirements for forage harvesting operations

Operation	Power requiremment (Watts)
Cutterbar mower	1200 * WW
Cutterbar mower-cond.	3000 * WW + 2000 * FDM
Flail mower-cond.	3000 * WW + 8000 * FDM
Drum mower-cond.	6000 * WW + 4000 * FDM
Side-delivery rake	1000 * WW
Tedder	2000 * WW
Baler (rect., alfalfa)	5000 * FDM
Baler (rect., wheat)	6000 * FDM
Round baler (alfalfa)	7500 * FDM
Round baler (wheat)	10000 * FDM
Hay stacker	7500 * FDM
Forage harvester	
Corn silage	15000 * FDM
Alfalfa haylage pickup	15000 * FDM
Alfalfa green chopping	18000 * FDM
Blower: corn silage	EMECH = 0.08
Blower: alfalfa	EMECH = 0.06

Source: ASAE (1981) and PAMI (1979).

The blower power requirement is estimated as follows:

$$PTO = FWM * G * HEIGHT/(EMECH * 3.6) \qquad (4.31)$$

where FWM is the flow of wet material (t WM/h);
HEIGHT is the silo height (m);
and EMECH is the mechanical efficiency (table 4.1).

The field operation speed is not constant. Instead it is calculated for each operation to satisfy three criteria: the maximum desirable speed (a user defined limitation), the maximum allowable throughput and the maximum allowable tractor load. The maximum speed that satisfies all three criteria will be used for the operation.

The maximum desirable speed is a practical speed limitation to prevent excessive wear and tear or malfunction. The maximum throughput is an implement's physical ability to process material. The maximum speed and throughput are both input parameters (e.g. a baling operation may have a 10 km/h maximum speed and the baler may have a 14 t-DM/h maximum throughput). The speed that will satisfy the throughput limitation is estimated from equation 4.28. The speed that will satisfy tractor load limitations may be estimated by combining equations 4.19 and 4.20 as follows:

$$\left(\frac{XPWR}{SF}\right) = TRM*G*(RRC*\cos\Theta + \sin\Theta)*V*CF1*SLF/3.6 + DBP*V*SLF*CF2/3.6 + (PTOW*WW) + (PTOC*V*WW*YDM/36) \quad (4.32)$$

The above equation can be solved for speed only.

$$V = \frac{(XPWR/SF) - (PTOW*WW)}{\left[TRM*G*(RRC*\cos\Theta + \sin\Theta)*CF1*SLF/3.6 + DBP*SLF*CF2*3.6 + PTOC*WW*YDM/36\right]} \quad (4.33)$$

The actual operating speed will be the highest speed that will satisfy simultaneously the maximum desirable speed, the maximum allowable throughput and the maximum allowable tractor load.

4.4 Energy consumption

Three types of power sources are modeled: gasoline engines, diesel engines and electric motors. Power required from engines is estimated with equation 4.20. Load is estimated with equation 4.19. Fuel consumption equations are taken from ASAE (1981). For gasoline engines,

$$FCONS = 2.74 * LOAD + 3.15 - 0.20 * \sqrt{697 * LOAD} \qquad (4.34)$$

where FCONS is fuel consumption (L/kW.h).

For diesel engines,

$$FCONS = 2.64 * LOAD + 3.91 - 0.20 * \sqrt{738 * LOAD + 173} \qquad (4.35)$$

Actual fuel consumption rate is approximated by

$$FUEL = FCONS * PWR * (1. + FE)/2. \qquad (4.36)$$

where FUEL is actual consumption (L/h).

The last term in equation 4.36, (1.+FE)/2., is always less than 1. Fuel consumption rate is assumed to be half the normal level when the tractor is idling or turning.

The consumption of electricity is expressed in kW.h/h. It is a simple function of the power required.

$$ELECT = PWR/(ELEFF * 1000.) \qquad (4.37)$$

where ELECT is electrical power consumption (kW.h/h);
PWR is the power required to operate an electric motor (W);
and ELEFF is the efficiency of an electric motor (assumed to be generally equal to 0.85).

4.5 Labor requirements

One operator is assumed for each harvester and for each transport unit. In the case of a baling-transport-unloading operation, if no bale thrower is used, then one extra man is assumed to be stacking the bales on the wagon pulled behind the harvester. Extra labor at the unloading site must be specified. The model then adds up all the labor required for an operation (man.h/h).

4.6 Computer implementation

The previous equations have been used to write a computer program called FORHRV. It is a static machinery model that estimates the harvest rate, the energy consumption and the labor requirement for 18 different forage harvest operations at any specified yield. The model calculates harvest rates at 6 different yields in a range specified by the user and creates a matrix called RATES(108,8) that retains all the machinery information for use in a dynamic simulation.

Program FORHRV is further documented in appendix B. In the dynamic simulation, it is called only once. Information in the RATES matrix is used thereafter to interpolate harvest rates and fuel consumption at various yields generated in a complete simulation. Chapter 7 establishes the link between FORHRV and the dynamic simulation.

CHAPTER 5

FORAGE LOSSES

5.1 Introduction

Hoglund (1964) presented a useful synthesis of quantitative losses in hay, haylage and silage systems. Since then, a greater recognition has been given to qualitative losses (Waldo and Jorgensen, 1981). In fact, it is the qualitative rather than the quantitative losses that will affect how much corn and soybean meal are required in the ration and whether or not milk production can be maintained.

Both qualitative and quantitative losses must be estimated at all stages of forage conservation: harvest, storage and feeding. Losses related to alfalfa harvest are considered in greater detail than losses related to alfalfa storage and feeding or losses related to corn silage. The daily dynamic simulation is used mainly to estimate quality and quantity changes of alfalfa during growth and harvest.

Changes in storage and feeding are simulated only once per year. Average values are used to estimate storage and feeding losses for five different storage methods and seven feeding methods.

Quantitative losses of alfalfa in the field are segregated into stem and leaf losses since they are affected differently by various treatments or environmental factors. Losses are expressed as a fraction of the remaining material or nutrient.

$$RF(I) = 1. - LS(I) \tag{5.1}$$

where RF(I) is the remaining fraction of material or nutrient after treatment I is applied;
and LS(I) is the fractional loss incurred by applying treatment I.

After several treatments have been applied and after a number of environmental factors have come into play, the final remaining fraction is:

$$FRF = RF(1) * RF(2) * \ldots * RF(N) \tag{5.2}$$

where FRF is the final remaining fraction of material or nutrients;
and N is the number of treatments and environmental factors that account for losses.

Let us consider singly the more important treatments and environmental factors that affect losses.

5.2 Alfalfa harvest losses due to mechanical treatments

Mechanical treatments that produce harvest losses include mowing, conditioning, raking, tedding, baling and chopping. Some treatments are especially harsh on the alfalfa leaves at low moisture content.

Mechanical treatments produce material losses but do not generally change the chemical composition of stems and leaves. However the stem to leaf ratio may change and cause a change in the average nutritional composition of the whole plant. This indirect change in quality is estimated at the end of harvest.

5.2.1 Mowing and conditioning

Research carried out by this author (Savoie et al., 1981) showed that dry matter losses due to mowers varied between 0.25% and 1% of the yield. Losses were lowest for cutterbar mowers and highest for drum mower-conditioners. Mower-conditioners followed by heavy crimping produced up to 2% of dry matter losses under light yields. Dale et al. (1978) estimated average mowing losses as 1% of total yield for the cutterbar, 2% for the mower-conditioner and 4.6%

for mowing and heavy crimping. These values are about double the ones measured. The measured mowing losses consisted only of detached material shorter than 200 mm that would not likely be raked back in the windrow. The measured losses did not include losses from unmowed alfalfa or small particles within the windrow which might be lost in subsequent handling. In general, total losses of 1% for the cutterbar and 2% for the mower-conditioner were assumed.

Dale et al. (1978) assumed that all mowing losses consisted only of leaves and no stems. This assumption was tested in June 1981, during the first alfalfa cut at the Chatham Experiment Station in Michigan: mowing losses were separated into leaves and stems. The original data are shown in table 5.1. The average dry matter yield at cutting was 4400 kg/ha; it was split as 39% leaves and 61% stems on a total dry matter basis. Relative losses were low, between 0.025% and 0.4%. The measured losses consisted of about 75% leaves and 25% stems. If the total dry matter loss from a mower-conditioner is assumed to be 2%, then the distinct losses are 4% of the leaf mass and 1% of the stem mass.

Table 5.1. Ratio of leaves and stems lost after mowing (data collected in Chatham, Michigan in June 1981).

Previous operations(1)	Number of samples	Average losses (kg-DM/ha) Leaves	Stems	Leaves as a fraction of total loss
CB	4	2.88	1.63	0.64
MC	4	4.92	1.80	0.73
MCW	4	13.76	5.70	0.71
CB	4	0.65	0.32	0.67
MC	4	13.25	2.35	0.85
MCW	4	9.33	2.42	0.79
	Average losses	7.47	2.37	0.76

(1) Operations are: CB, cutterbar mower; MC, cutterbar mower-conditioner; MCW, cutterbar mower-conditioner-windrower. Data were collected for three operations and for two replications on different days.

5.2.2 Raking

Hundtoft (1965) published a curve relating shatter losses to moisture content during raking. It is redrawn here in figure 5.1, adjusted for a change in the abscissa from wet basis to dry basis moisture content. The statement of shatter losses would lead one to believe that most losses are leaves. Original field data in table 5.2 show that dry matter losses for raking are split almost evenly between leaves and stems. These plots were raked at dry basis moisture levels between 1 and 3. The ratio of leaf to stem losses may be different under dryer

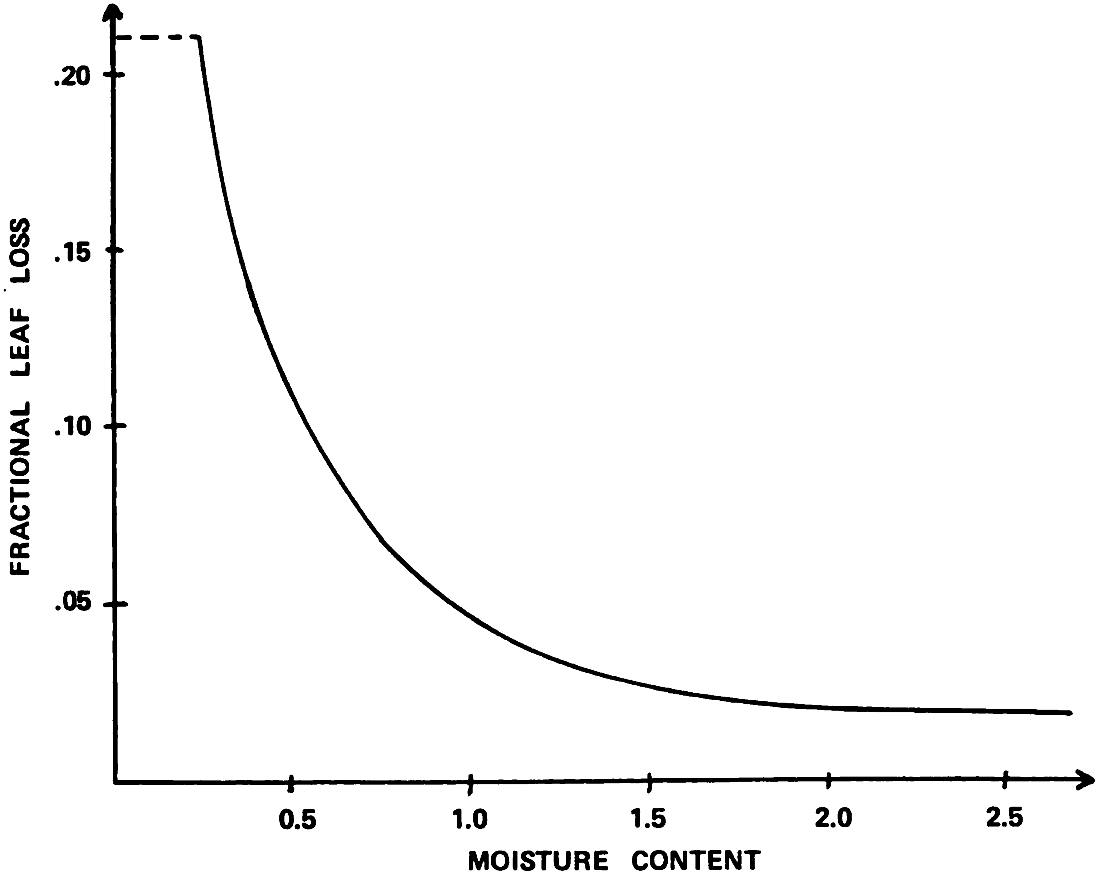

Figure 5.1. Leaf dry matter loss from raking, as a fraction of total leaf mass, versus dry basis moisture content (adapted from Hundtoft, 1965).

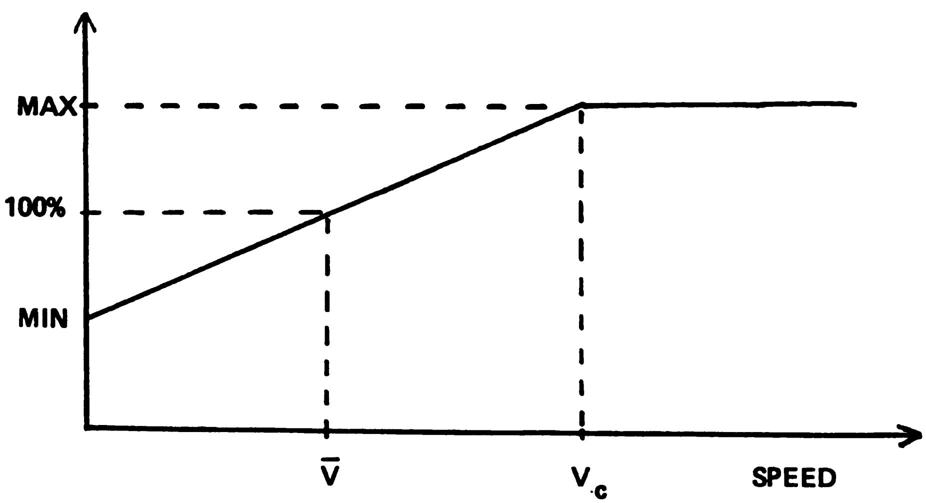

Figure 5.2. Hypothetical relationship between dry matter losses and speed of operation.

conditions. Stem losses might be expected to remain constant while leaf shatter is likely to increase considerably as the alfalfa becomes dryer. Stem loss from raking will be set constant at 2% of stem mass and leaf loss will be estimated from figure 5.1, as a fraction of the remaining leaf mass.

Table 5.2. Ratio of leaves and stems lost after raking, including mowing losses (data collected in Chatham, Michigan in June 1981).

Previous operations(1)	Number of samples	Average losses (kg-DM/ha) Leaves	Stems	Leaves as a fraction of total loss
CB-R	2	3.83	1.00	0.79
MC-R	2	3.25	0.79	0.80
MCW-R	2	2.80	0.63	0.82
CB-R	2	37.37	34.65	0.52
MC-R	2	22.44	15.53	0.59
MCW-R	2	33.59	27.49	0.55
CB-R	2	19.59	16.78	0.54
MC-R	2	26.79	29.22	0.48
MCW-R	2	15.10	16.43	0.48
	Average losses	18.31	15.84	0.54

(1) Operations are: CB, cutterbar mower; MC, cutterbar mower-conditioner; MCW, cutterbar mower-conditioner-windrower; R, parallel-bar rake. Data were collected for three operation sequences and for three replications on different days.

5.2.3 Tedding

The tedder spreads the alfalfa across the swath in a rapidly rotating and hitting motion. Dry matter losses measured in the field from tedding were between 1 and 2% of total yield per treatment (Savoie et al., 1981). Tedding was generally applied at high moisture contents (M > 2). No research has apparently estimated tedding losses at very low moisture contents. Leaves would probably shatter in a fashion similar to what can be observed during raking. Dry matter losses from tedding are assumed to be the same as raking losses: only leaves are lost in a proportion given by figure 5.1.

5.2.4 Baling

Three types of balers were considered: the conventional baler making small rectangualr bales, the large round baler and the large hay stack wagon. Alfalfa is usually baled only when the hay is dry enough for storage. Leaves are then very dry and brittle. As will be shown, leaves make up the greater part of dry matter losses during baling.

Whitney (1966) measured total dry matter losses from a conventional baler between 1.4 and 3.8% of yield, but did not distinguish stem from leaf losses. He noted that a bale ejector would increase the losses by between 0.3 and 1%. Kjelgaard (1978) used an average of 3% for baling losses from a conventional baler. Friesen (1977) compared the nutritional value of bale chamber losses with the bale itself: losses had a protein concentration of 22% while the baled hay had a protein concentration of 14%. Since alfalfa leaves and stems have a protein concentration of about 28% and 11% respectively and leaves represent initially 40% of the total dry matter at mowing time (Bert et al., 1952), a total dry matter loss of 3% would then be split as 5% of the leaf mass and 2% of the stem mass during baling. An ejector would increase leaf loss to 7.5%.

Anderson et al. (1981) and Kjelgaard (1978) have suggested 10% as an average value for dry matter losses from round balers. PAMI (1979) indicated that round baler losses can vary between 5 and 25%: very high losses are more likely to occur in light and dry alfalfa hay. Whole stems and leaves are lost at the pickup stage while mostly leaves are shattered in the bale chamber. Assuming that 10% of the total dry matter is lost, of which 75% consists of leaves, and that leaves represent initially 40% of the mass, then 19% of the leaves and 4% of the stems are lost during r

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Kjelgaard (1979) estimated average stack wagon dry matter losses at 13% of total yield. Using similar assumptions as in the case of the round baler, 24% of the leaves and 5% of the stems are lost during the formation of large hay stacks.

5.2.5 Chopping

Losses from chopping and blowing alfalfa into a wagon are estimated at 5% of total yield for wilted alfalfa and 2% for direct-cut alfalfa (Kjelgaard, 1979). Leaves are much more likely to be lost than stems in this operation where air flows are present. Assuming that 75% of the loss consists of leaves and that leaves represent initially 40% of the total dry matter, then 9% of the leaves and 2% of the stems are lost while chopping wilted alfalfa and 4% of the leaves and 1% of the stems are lost while chopping fresh alfalfa.

5.2.6 The effect of ground speed on material losses

The operation speed and the alfalfa yield have not been considered as factors affecting total material losses. Dale et al. (1978) assumed a linear relationship between raking

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raking speed and material losses: relative losses were 0% at 0 km/h and 100% at 10 km/h and above. Meanwhile, Anderson et al. (1981) measured greater baling losses at 5.6 km/h than at 8.1 km/h. They did not explain this unexpected result.

Very little else has apparently been published on the effect of ground speed on material losses. The effect might be important since the physical impact is increased at higher speeds. There is also a relationship between yield and speed: as yields become lower, machines are likely to be operated faster to make more efficient use of the throughput capacity. Low yields are conducive to higher speeds and probably higher relative material losses.

Figure 5.2 is a hypothetical relationship between losses and speed. At some average speed V, average losses are expected (100%). Above this speed up to a critical speed Vc , material losses would increase linearly to some maximum level (MAX). Below the average speed, material losses would decrease linearly to a minimum level. This minimum is not likely to be 0, especially in the case of operations using rotative power independently from ground speed. In the present simulation model no ground speed effect will be assumed in the estimation of material losses (MAX = 100% = MIN). More field research would be necessary to test this assumption.

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5.3 Alfalfa harvest losses due to environmental factors

Mechanical treatments were seen to produce important quantitative losses of alfalfa stems and leaves. However these treatments do not alter the nutrient concentration within either stems or leaves. Of course a change in the stem to leaf ratio indirectly changes the composite quality of the whole crop since leaves and stems do not have the same nutrient composition.

Environmental factors affect directly both dry matter losses and quality changes. Rainfall, plant respiration and general exposure to the weather are known to alter the digestibility of the alfalfa stems and leaves and, to a lesser extent, to change the crude protein concentration. Dry matter losses and quality changes will alternately be considered.

5.3.1 Dry matter losses from respiration

Plant cells of alfalfa remain alive and continue to respire several hours after mowing. Carbohydrates used in respiration are essentially 100% digestible and represent an important nutritional loss (Moser, 1980). Respiration of al

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of alfalfa cell tissues is maximum and relatively constant at temperatures between 30 C and 45 C. It will cease at temperatures above 55 C or at moisture contents below 35% on a wet basis (Wolf and Carson, 1973). Respiration is also practically zero below 0C (Wilkinson and Hall, 1966).

The respiration equation is given by Wood and Parker (1971) as:

$$180 \text{ g } C_6H_{12}O_6 + 192 \text{ g } O_2 \longrightarrow 264 \text{ g } CO_2 + 108 \text{ g } H_2O + 677 \text{ kcal} \tag{5.3}$$

Respiration is often measured in laboratory trials by the concentration of CO_2 in the air. Every gram of CO_2 measured corresponds to 0.68 g of carbohydrate lost from the alfalfa dry matter.

There are some discrepencies in reported values of maximum respiration rates after cutting alfalfa. Wilkinson and Hall (1966) noted a maximum heat generation rate of 36000 BTU per U.S. ton per hour at 27 C and at 80% moisture content on a wet basis. Since one lb of carbohydrate generates about 6770 BTU of heat, the respiration rate is 0.0027 kg-$C_6H_{12}O_6$/kg-DM/h. Wolf and Carson (1973) reported initial rates as high as 0.007 kg-CO_2/kg-DM/h or 0.0048 kg-$C_6H_{12}O_6$/kg-DM/h, at 30 C and at 70% moisture content on a wet basis. Wood and Parker (1971) suggested maximum

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respiration rates of 0.003 kg- CO_2/kg-DM/h for rye grass at 80% moisture (wet basis) and at 25 C. Dale et al. (1978) assumed that legumes had respiration rates 50% greater than respiration rates of grasses. The maximum respiration rate of freshly cut alfalfa is likely to be in the range of 0.003 to 0.004 kg- $C_6H_{12}O_6$/kg-DM/h.

The respiration rate increases exponentially with an increase in temperature between 0 and 30 C (Wood and Parker,1971). It increases approximately linearly with an increase of the moisture content on a dry basis (Wilkinson and Hall, 1966). A simplified relationship between respiration rate and temperature and moisture content is proposed:

$$R \propto (TDB/30)^2 * (M/4) \qquad (5.4)$$

where R is the respiration rate (kg-$C_6H_{12}O_6$/kg-DM/h);
TDB is the dry bulb temperature (C);
and M is the moisture content of alfalfa, on a decimal, dry basis (dec, d.b.).

This relationship is valid in the ranges $0 < TDB < 30C$ and $0.5 < M < 4$. For temperatures or moisture contents above these ranges, the factors in parenthesis are one. Below the ranges, the respiration rate is zero. For temperatures between 45 and 55 C, the rate actually decreases (Wolf and Carson,1973); such temperatures are not usually encountered during hay making in northern climates.

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The moisture content decreases approximately as an exponential decay function:

$$M = Mo * \exp(-k * t) \qquad (5.5)$$

where Mo is the initial moisture content (dec, d.b.);
k is the drying constant (h^{-1});
and T is time (h).

Substituting equation 5.5 in equation 5.4 yields

$$R \propto (TDB/30)^2 * (Mo/4) * \exp(-k * t) \qquad (5.6)$$

Integrating over time will give the total respiration loss. Replacing coefficient k by two empirical coefficients k1 and k2, the following equation may be used to estimate total respiration loss.

$$TRL = \left(\frac{TDB}{30}\right)^2 \left(\frac{Mo}{4}\right) * k1 * (1. - \exp(-k2 * t)) \qquad (5.7)$$

where TRL is the total respiration loss (kg-$C_6H_{12}O_6$/kg-DM).

A number of researchers agree that total respiration losses of field cured forages may amount to 10 or 15% of the original dry matter (Watson and Nash, 1960). Assuming a maximum dry matter loss due to respiration of 15% and a maximum total respiration loss of 0.4% in the first hour at 30 C and M = 4.0, values of coefficient k1 and k2 are 0.15 and 0.0291 respectively.

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Respiration losses are calculated daily (t = 24 h) and accumulated as long as alfalfa is not harvested. The total cannot however be greater than kl. The same fractional loss is assumed for both leaves and stems.

5.3.2 Dry matter losses from rainfall

Rain may increase dry matter losses in several ways: by breaking off leaves through direct impact of rain droplets, by leaching soluble nutrients, by requiring additional machinery treatments to enhance drying and by prolonging respiration of the wet alfalfa. Dry matter losses due to machinery treatments and to respiration have already been dealt with previously. Leaching loss is not likely to represent a large amount of dry matter but it might affect the digestibility. This is discussed in the next section.

In laboratory experiments, Collins (1981) estimated that 20% of the leaves were lost after two showers totaling 50 mm of rain. Since no mechanical handling was involved, this loss is presumably due only to the impact of rain. Assuming a linear relationship between leaf loss and rainfall, leaf loss due to rain is 0.4% per mm of rain.

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5.3.3 Changes in digestibility

Digestibility of alfalfa leaves and stems is affected primarily by respiration and rainfall. Respiration losses consist practically of 100% digestible nutrients. Digestibility of leaves and stems is corrected as follows at the end of the respiration process:

$$TDN(F) = (TDN(I) - TRL)/(1. - TRL) \qquad (5.8)$$

where TDN(F) is the final digestibility, at the end of field curing (dec);
TDN(I) is the initial digestibility, at the time of mowing (dec);
and TRL is the total respiration loss.

Digestibility is also affected by rainfall. Collins (1981) estimated that cell wall concentration in alfalfa increased from 32.3% to 38.4% after 50 mm of rain. A linear relationship exists between digestibility and cell wall concentration. From data given by the NRC(1977), the relationship for alfalfa is:

$$TDN = 1.06 - CW \qquad (5.9)$$

where TDN is total digestible nutrients or digestibility (dec);
and CW is the cell wall concentration (dec).

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The increase of 6.1% in the cell wall concentration is equal to a drop of the same amount in digestibility. Assuming a linear relationship and an initial digestibility level of 60%, the average relative drop in digestibility due to rain is 0.2% per mm of rain.

5.3.4 Changes in crude protein

Many contradicting statements have been published about protein losses during field curing of alfalfa. On the one hand, several authors believe that protein concentration changes very little during field drying of alfalfa (Moser, 1980; Collins, 1981; Watson and Nash, 1960). On the other hand, a number of field experiments have shown substantial drops of crude protein concentration between the time of cut and the time of baling (Bert et al., 1952; Shepherd et al., 1954) or between haylage and hay, the latter being exposed longer in the field and suffering larger protein losses (Hillman et al., 1970).

Protein concentration could decrease either through the physical fragmentation of leaves or through a degradation process within the plant tissues. At the time of cutting, the alfalfa leaves have a protein concentration of about 28% and the stems have a protein concentration of about 11% (Bert et al., 1952). If leaves are shattered,

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the protein concentration will certainly decrease. In a controlled laboratory experiment, Collins (1981) found that protein concentration actually increased slightly during alfalfa drying, even after rain. Apparently other cellular constituents, especially carbohydrates, are lost more rapidly through respiration and leaching, thus increasing the concentration of protein.

Bert el al. (1952) compared the nutrient content of field cured and barn-cured hays. The barn-cured hay contained 17% crude protein while the field-cured hay had 15.6% protein, an additional relative loss of 8.24%. At the time of cut, leaves represented 48.5% of the alfalfa dry matter. At the end of the harvest and drying processes, the barn-cured hay had 37.9% leaves and the field-cured hay had 33.3% leaves. The difference in leafiness explains about half the difference in protein concentration; the other half would be due to a weathering degradation process. The field-cured hay remained in the field between three and ten days while the barn-cured hay was removed from the field after one or two days. Assuming field-cured hay was exposed three extra days on the average (72 hours), the rate of protein concentration loss would be 0.11%/h.

Shepherd et al. (1954) also observed a consistent decrease of crude protein concentration between the time of cut and the time of baling. The relevant data are compiled in tal

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in table 5.3. The relative loss of crude protein varied between 7 and 11% for non-rained-on alfalfa and between 12 and 18% for rained-on alfalfa. The last column in the table shows the rate of crude protein loss (%/h of exposure). The rained-on hay had a larger total loss but it actually had a slightly smaller loss rate (%/h) since it was exposed longer to weather before baling. The crude protein loss appears closely related to total exposure time: about 0.15%/h , no matter whether alfalfa was rained on or not.

Table 5.3. Change in crude protein alfalfa during field drying (from Shepherd et al., 1954).

Trial no.	No. of showers	Total rain (mm)	Hours exposed in the field	CP(%) As cut	CP(%) As baled	% loss of CP Total	% loss of CP Rate (%/h)
1	0	0.	52.	19.56	18.13	7.31	.1406
2	0	0.	48.	21.57	19.26	10.71	.2231
3	0	0.	61.	18.21	16.88	7.31	.1198
			Average rate loss (1,2,3)				.1612
1a	2	17.	84.	21.58	18.91	12.37	.1473
4	3	27.	131.	20.94	17.19	17.91	.1367
			Average rate loss (1a,4)				.1420

The decrease in protein concentration is probably due to both weathering and a change in the leaf to stem ratio resulting from machinery treatments. The field experiments have not distinguished the contribution of each. Plant respiration and leaching do not decrease the protein concent

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concentration. However, other weathering factors such as bleaching, wind and "enzymatic changes" reported by Watson and Nash (1960), which have not previously been mentioned, may all contribute to substantially reduce the protein concentration. On the basis of values estimated above, the rate of protein concentration loss due to exposure only was set at 0.10%/h. This loss does not include machinery related losses. For example, alfalfa initially containing 20% crude protein would lose 24% of its concentration after 10 days (240 h) of field curing and would have a final protein concentration of 15.2%.

5.4 Alfalfa storage and feeding losses

For storage and feeding, average dry matter losses presented by Kjelgaard (1979) were used. Storage losses for dry hay are 4%, 12% and 16% for rectangular bales, round bales and hay stacks. The last two values are based on outside storage. Sheltered storage of round bales and hay stacks would probably reduce dry matter losses to the same level as rectangular bales. Storage losses of wilted alfalfa haylage and of direct cut alfalfa silage are 7% and 13% respectively.

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Feeding dry matter losses are on the average 5% for rectangular bales, 14% for round bales, 16% for hay stacks, 11% for either wilted alfalfa haylage or direct cut alfalfa silage (Kjelgaard, 1979). No published data appears to distinguish between stem and leaf losses during storage and feeding. Consequently the same loss fraction was assumed for stems and leaves.

Little quality change occurs during storage of dry hay. Weeks et al. (1975) observed that digestibility of stacked hay remained around 60% after 10 months of storage. Verma and Nelson (1981) reported that the digestibility of alfalfa in round bales actually increased by 3% after one year of outside storage. Crude protein concentration also increased by 5%. For simulation purposes, quality of alfalfa hay was assumed not to change during storage.

While dry hay is chemically stable once it reaches storage, direct-cut or wilted forages undergo substantial changes during the ensiling process. Respiration continues as long as oxygen is present. If the water content is high, considerable seepage may occur and soluble nutrients are leached. Low moisture haylage may mold if too much air is present.

Few studies have measured specifically the changes of crude protein and digestibility of alfalfa stored as a wet forage. Watson and Nash (1960) reported that ensiling red clover

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clover produced a slight increase in crude protein concentration and a decrease in digestibility. A number of feeding experiments have compared alfalfa hay with alfalfa haylage: these studies may be helpful in understanding the changes that occur during storage of wet alfalfa.

Most researchers agree that alfalfa hay contains less crude protein and more crude fiber than haylage or direct-cut alfalfa at the time of feeding (Gordon et al., 1961, 1963; Brown et al., 1963; Thomas et al., 1969). Haylage is generally more digestible than hay. One notable exception is provided by Gordon et al. (1961) who, in an early experiment with sealed silos, estimated hay to be more digestible than haylage. Excess heating during fermentation might have reduced the digestibility of haylage.

The lower crude protein and the lower digestibility of hay compared with haylage are probably accounted for mainly by the difference in field curing time and not by storage changes. Little changes in crude protein concentration and in digestibility are likely to occur during fermentation, except in the case where haylage is exposed to excess air and might result in heat-damaged, lower digestibility forage.

There are also differences in the intake of hay versus haylage: animals will in general consume more hay than haylage but, as more grain is fed, this intake difference is reduced. These nutritional aspects are left within the ration formulation model by treating hay and haylage as two distinct crops. For simulation purposes, quality of alfalfa haylage or silage was assumed not to change during storage. It should be noted that maintaining high quality throughout the storage period is likely to require more management skills with fermented forages than with dry forages.

5.5 Corn silage losses

Kjelgaard (1979) quoted average DM losses of 5% for harvesting, 6% for storage and 4% for feeding of corn silage. Quality changes are likely to occur in the silo. Watson and Nash (1960, p.401) reported that, in one experiment, crude protein concentration increased by 5% and total digestibility decreased by 9%. However no extensive data on these changes seem available. Consequently quality of corn silage was assumed unaltered during storage.

5.6 Summary of losses

Alfalfa harvest losses are estimated in greater detail than all other losses (storage, feeding, corn silage) because the dynamic simulation is intended primarily to simulate daily growth and harvest of alfalfa. Storage and feeding are simulated only once per year; average loss values are used.

Table 5.4 shows values that were used to estimate dry matter losses of alfalfa leaves and stems during harvest. Table 5.5 illustrates dry matter loss values for storage and feeding. The same fractional loss is assumed for both leaves and stems.

Quality changes are estimated according to the values given in table 5.6. Important quality changes are estimated during field curing. Quality changes during storage are practically ignored in the present model for lack of extensive data.

Table 5.4. Alfalfa dry matter losses during harvest and curing.

Factor	Leaf loss as a fraction of leaf mass	Stem loss as a fraction of stem mass
1. Mower	0.02	0.005
2. Mower-conditioner	0.04	0.01
3. Rake	(0.02-0.21)a	0.02
4. Tedder	(0.02-0.21)a	0.00
5. Baler (conventional)	0.05	0.02
6. Bale-ejector	0.075	0.02
7. Round baler	0.19	0.04
8. Stack wagon	0.24	0.05
9. Chopper (wilted)	0.09	0.02
10. Chopper (direct-cut)	0.04	0.01
11. Respiration	(0.00-0.15)b	(0.00-0.15)b
12. Rainfall	0.004/mm	0.00

(a) Rake and tedder will shatter between 2 and 21% of leaves depending on moisture content, as in figure 5.1.
(b) Respiration losses will vary between 0 and 15% depending on exposure time and environmental conditions as predicted by equation 5.7.

Table 5.5. Storage and feeding dry matter losses of alfalfa (adapted from Kjelgaard, 1979).

Storage method	Storage loss	Feeding loss
1. Small bales, stored inside	.04	.05
2. Round bales, stored inside	.04	.14
3. Hay stacks, stored inside	.04	.16
4. Round bales, stored outside	.12	.14
5. Hay stacks, stored outside	.16	.16
6. Haylage, vertical silo	.07	.11
7. Haylage, bunk silo	.13	.11

Table 5.6. Changes in the nutritional value of alfalfa during field curing (changes are shown as a fraction of the remaining value per unit mm or h).

Factor	Digestibility	Crude protein
1. Respiration	Equation 5.8	---
2. Rainfall	-0.002/mm	---
3. Exposure	---	-0.001/h

In future research, the emphasis could be shifted to refining the estimation of dry matter losses and quality changes in storage. Although no quality changes are assumed for silage and haylage, some of the literature indicates slight increases in the crude protein concentration and inconsistent changes in the digestibility of alfalfa stored as a wet forage. Better estimates of harvest dry matter losses are also needed, especially the distinction between leaves and stems and the effect of speed and moisture content.

CHAPTER 6

FIELD DRYING OF ALFALFA

A drying model is developed to be used in the dynamic simulation of forage harvesting. The model is not definitive; much research could still go into improving its predictive value. Since the main objective of the present dissertation is to simulate the whole forage system, the drying model is dealt with as much detail as was deemed necessary to provide reasonable predictions.

The section on equilibrium moisture content is based on data from the literature. The drying model itself is based on original field data collected by this author.

6.1 Literature review

Several factors affect the drying rate of mowed alfalfa in the field. Some are largely uncontrollable: air temperature, humidity, solar radiation, wind velocity, ground moisture, rainfall, dew and the plant's physiological ability to lose moisture after mowing. Other factors are more easily controlled: maturity stage at the time of mowing, machinery treatments such as conditioning, tedding, raking, the width of the windrow, maceration or chemical spraying.

A complete drying model should attempt to sort out the relative importance of each and every one of these factors. The problem may further be compounded by some unknown interaction. Before delving into the details of such a model, let us briefly survey some of the previous work.

Pedersen and Buchele (1960) and, more recently, Harris and Tullberg (1980) have presented good reviews of the physiological mechanisms involved with alfalfa drying. Neither have attempted however to predict numerically the drying rate.

Kemp et al. (1972) suggested the use of latent evaporation to predict drying rates. Latent evaporation was measured with an atmometer, a black, horizontal, porous, wet surface exposed to environmental conditions. Evaporation measurements are thus based on the integrated effects of wind, radiation, temperature and humidity. The authors tested the model only with a limited number of laboratory trials. Their model is yet incomplete for predicting field drying.

Latent evaporation is not a commonly measured quantity and therefore is difficult to use. The authors contend that it can be correlated to other environmental conditions. The drying rate is a function not only of environmental factors but also of mechanical and chemical treatments that might be applied to field curing forages. A simpler and more logical approach would be to estimate the drying constant and the drying rate directly from the basic environmental parameters and the treatment parameters.

Hill et al. (1977) proposed yet another single parameter to predict the drying rate of alfalfa: the vapor pressure deficit. The vapor pressure deficit is the difference between the vapor pressure at the plant surface, assumed saturated at the ambient dry bulb temperature, and the actual air vapor pressure. The model predicted well for large deficits and not so well for small ones. The authors noted the need to include other meteorological variables which were omitted from their study.

Tullberg and Harris (1978) presented a drying model of fully exposed alfalfa. The model predicted drying as a function of moisture content, vapor pressure deficit, leaf to stem ratio and whether the alfalfa had been immersed in a solution of potassium carbonate or not. The model is of limited use to predict field drying because it is based on laboratory trials dealing with small samples of alfalfa unlike the windrow structure found in the field.

Dale et al.(1978), and in a more detailed study Dale (1979), presented a model to predict the drying rate of alfalfa in field conditions under various mechanical treatments. The evaporation model, although presented in a different form, is in fact:

$$\frac{dM}{dt} = -k * (M - EMC) \qquad (6.1)$$

where M is the moisture content (dec, d.b.);
t is time (h);
EMC is equilibrium moisture content (dec, d.b.);
and k is the drying constant (h^{-1}).

The constant k is a function of solar radiation, wind velocity, plant density, species and type of conditioning.

Dale's conceptual model has been useful in understanding the important factors affecting drying. The numerical model however has important weaknesses. First, the model is left implicitly as a difference equation for computer implementation. This is correct, but the fact that no attention is paid to the size of the time increment can lead to fairly large errors in the estimation of moisture content. Secondly, k is simply calculated by multiplying together solar radiation, a wind velocity factor, a crop density factor and a species-conditioning factor. This assumes that doubling the solar radiation will double the drying rate - a rather unlikely outcome.

It also neglects convective evaporation due to air temperature. Thirdly, equilibrium moisture content of oats was used in the model for lack of data about alfalfa. A more realistic model of alfalfa equilibrium moisture content is presented further in this chapter.

6.2 Theoretical Model

The decreasing rate model is often proposed to simulate the drying of biological products (Brooker et al., 1974).

$$\frac{dM}{dt} = -k * (M - EMC)^{c} \tag{6.2}$$

The exponent c is often equated to one. In fact the value of c is likely to vary with M. When moisture content is very high, the moisture evaporates almost freely and at a constant rate. Then c is equal to 0. As a biological product dries, the drying rate is no longer constant but decreases as the moisture content decreases. The value of c is likely to increase as the material becomes dryer.

Since the main objective of this research is to simulate the dynamics of forage harvesting, the drying model is simplified into a single equation to predict drying in all moisture ranges. For reasons explained in the statistical analysis in section 6.4.1, c is equated to one in equation 6.2.

The constant k is tentatively defined as a linear function of environmental and operational factors.

$$k = bo + b1 * SR + b2 * TDB + b3 * WV$$
$$+ b4 * DENS + b5 * RK + b6 * CD$$
$$+ b7 * RNDW + b8 * DAY + b9 * XTR \quad (6.3)$$

where bo, b1, ... , b9 are statistical estimates of parameters affecting drying;
SR is the average solar radiation on a horizontal surface (cal/min/cm2);
TDB is the dry bulb temperature (C);
WV is the wind velocity (m/s);
DENS is the dry matter density in the windrow (kg/ha);
RK is a raking factor;
CD is a conditioning factor;
RNDW is a free water factor, affecting drying rate after rain or dew adsorption;
DAY is a factor to distinguish the first day from the subsequent days of field drying;
and XTR is an extra or additional treatment factor (e.g. chemical application, maceration).

The last five variables are actually dummy variables with values being either 0 (no treatment, no rain, first day drying) or 1 (treatments, adsorption of rain or subsequent days of drying).

The variable DENS is the alfalfa dry matter density in the windrow in kg/ha. It is estimated as follows:

$$WR = WW/WC \quad (6.4)$$

$$DENS = YDM/WR \quad (6.5)$$

where YDM is the dry matter yield of alfalfa (kg/ha);
WW is the width of the windrow (m);
WC is the width of the cut (m);
and WR is the width of windrow to width of cut ratio.

The raking dummy variable is set on (RK=1) only during the day of raking and set off (RK=0) subsequently. The reason is that raking displaces wet forages from the bottom to the top of the windrow. The beneficial drying effect is present for a limited number of hours and disappears thereafter.

With c=1, a simple analytical expression can be derived from equation 6.2.

$$\left(\frac{M - EMC}{Mo - EMC}\right) = \exp(-k * t) \tag{6.6}$$

where Mo is the initial moisture content;
and M is the moisture content at time t.

A major advantage with the use of the analytical equation 6.6 is that the time increment is not an issue. The actual moisture content of a field curing plot can be estimated at any time in the day by this single equation. Moreover the time when the plot will be ready for harvest can also be estimated by solving for t in equation 6.6. On the other hand, the use of equation 6.2, expressed as a difference equation, for estimating drying poses a serious problem with regards to the choice of a time increment. A large time increment would certainly lead to substantial inaccuracies. A very small increment could increase significantly the computation time and cost. The problem of a time increment is avoided by using an analytical equation.

The statistical estimation of the coefficients bo to b8 in section 6.4 indicates that some coefficients are not significant. Estimates of b9*XTR, for additional treatments, will be inferred from data published in the literature on various new technologies.

6.3 Equilibrium moisture content

Alfalfa left in a specific environment indefinitely will reach an equilibrium moisture content (EMC). Therefore EMC is a very important factor in alfalfa drying: it indicates whether a hay will lose or gain moisture and provides some insight as to the rate of moisture transfer.

Zink (1935) measured EMC for various hays, including alfalfa. Dexter et al. (1947) noticed a hysteresis effect in EMC of alfalfa: under the same environment, initially dry alfalfa will reach a lower EMC (through adsorption) than initially wet alfalfa (through desorption). They also observed that several samples molded before reaching EMC when they were exposed to a relative humidity above 85%.

Bakker-Arkema et al. (1962) did a systematic study of EMC of alfalfa. They measured EMC in the ranges of 4.4 to 48.9 C and 10 to 90% relative humidity. They also measured the difference between adsorption and desorption. They reported that immature alfalfa had a higher EMC than mature alfalfa.

A regression model was used to fit the adsorption data provided by Bakker-Arkema et al. (1962). The experimental data and the regression curves are plotted on figures 6.1 and 6.2. The relative humidity was split into four ranges to provide a better fit. In the range $0.10 < RH < 0.60$,

$$EMCA = 0.026850 + 0.146462 * RH + 0.045716 * RH^2 + 0.00036081 * TDB - 0.0013128 * RH * TDB \quad (6.7)$$

where EMCA is the equilibrium moisture content of alfalfa from adsorption (i.e. the alfalfa is initially drier than the environment) (dec, d.b.);
RH is the relative humidity (dec);
and TDB is the dry bulb temperature (C).

In the range $0.60 < RH < 0.90$,

$$EMCA = 0.37517 - 1.2816 * RH + 1.4283 * RH^2 + 0.0065621 * TDB - 0.010839 * RH * TDB \quad (6.8)$$

Data below 10% and above 90% relative humidity are sparse. EMC was assumed to be 0 at 0 relative humidity. In the range $0 < RH < 0.10$, simple linear interpolation is used.

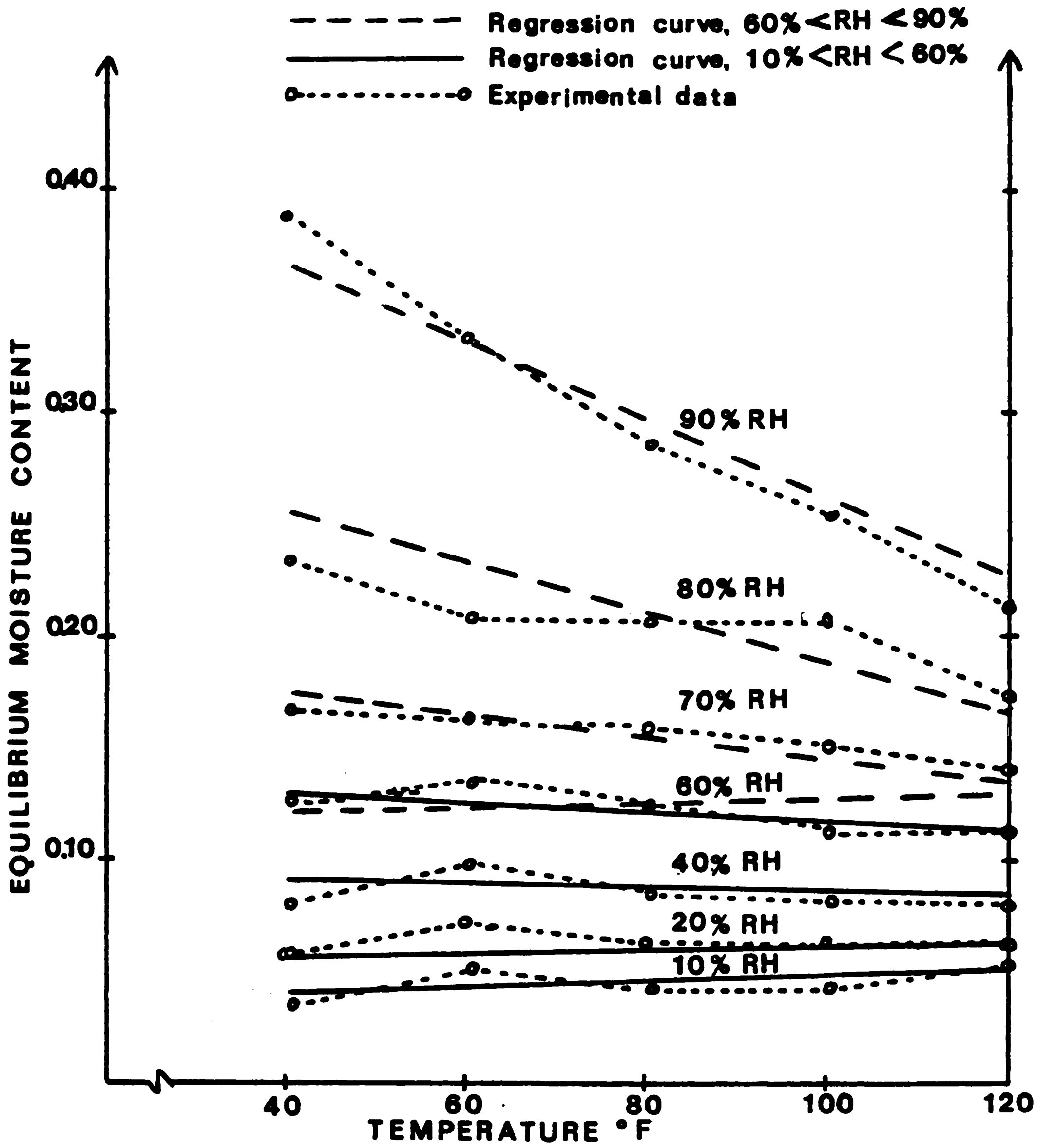

Figure 6.1. Adsorption equilibrium moisture content (dry basis) of mature alfalfa versus temperature and humidity. Experimental data are from Bakker-Arkema et al. (1962).

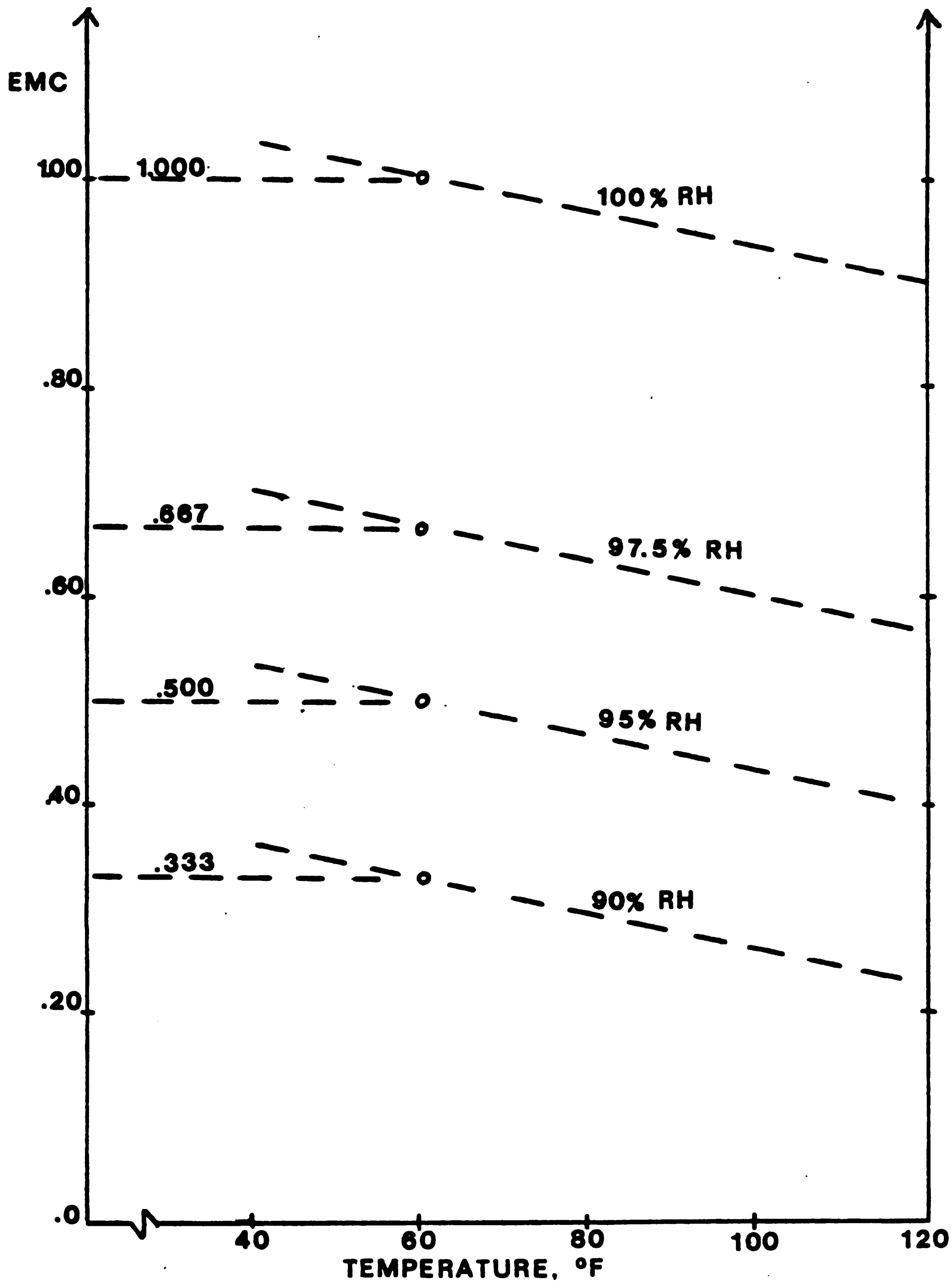

Figure 6.2. Adsorption equilibrium moisture content of mature alfalfa in the range of high relative humidities.

$$EMCA = EMCA(RH=0.10) * RH/0.10 \qquad (6.9)$$

Above 90%, three data points were obtained at a constant temperature (15.6 C) at three levels of relative humidity. The data are those on figure 6.2. Lines of constant relative humidity are assumed parallel to the 90% line. Linear interpolation is used to estimate EMC between the lines. In the range 0.90 < RH < 0.95,

$$EMCA = EMCA(RH=0.90) + (RH - 0.90)*.167/.05 \qquad (6.10)$$

In the range 0.95 < RH < 0.975,

$$EMCA = EMCA(RH=0.95) + (RH - 0.95)*.167/.025 \qquad (6.11)$$

In the range 0.975 < RH < 1.00,

$$EMCA = EMCA(RH=0.75) + (RH - 0.975)*.333/.025 \qquad (6.12)$$

All the above equations estimate EMC for adsorption of mature alfalfa. In drying we are mainly concerned with desorption. Also alfalfa is often harvested earlier than at the mature stage. Table 6.1 shows differences between desorption and adsorption. The difference is symbolized as DDA.

Bakker-Arkema et al. (1962) reported desorption EMC at only one temperature (15.6 C) for the range of relative humidities shown in table 6.1. There could be a temperature interaction in the difference between adsorption and desorption EMC at a given relative humidity. If the slopes of the desorption curves versus temperature are parallel to the slopes of the adsorption curves in figure 6.1 at the same relative humidities, then no temperature interaction would exist. For the time being no temperature interaction will be assumed until more desorption EMC data become available.

Table 6.1. Differences in EMC between adsorption and desorption at 15.6 C (from Bakker-Arkema et al., 1962)

RH	EMC		Difference
	Adsorption	Desorption	
.10	.050	.070	.020
.20	.074	.093	.019
.40	.099	.115	.016
.60	.134	.164	.030
.70	.163	.235	.072
.80	.208	.385	.177
.90	.333	.727	.394
.95	.499	1.212	.713
.975	.667	1.558	.891
1.000	1.000	2.215	1.215

A quadratic equation was used to estimate the difference, except in the range $0 < RH < 0.10$ where the difference is considered constant and equal to 0.01. In the range $0.10 < RH < 0.60$,

$$DDA = 0.028221 - 0.085842*RH + 0.14686*RH^2 \quad (6.13)$$

In the range $0.60 < RH < 0.90$,

$$DDA = 1.67675 - 5.3655*RH + 4.3765*RH^2 \qquad (6.14)$$

In the range $0.90 < RH < 1.00$,

$$DDA = 32.6417 - 75.3285*RH + 43.8909*RH^2 \qquad (6.15)$$

The difference in EMC due to maturity is defined as DMM. Experimental data from Bakker-Arkema et al. (1962) are shown in table 6.2.

Table 6.2. Differences in EMC between prebloom and mature alfalfa at 15.6 C (from Bakker-Arkema et al., 1962).

RH	EMC Mature	EMC Prebloom	Difference
.10	.043	.060	.017
.20	.064	.080	.016
.40	.087	.109	.022
.60	.122	.161	.039
.70	.157	.207	.050
.80	.205	.263	.058
.90	.284	.452	.168

In the range $0 < RH < 0.10$, the difference in EMC between prebloom and mature alfalfa is considered constant and equal to 0.01. In the range $0.10 < RH < 0.60$,

$$DMM = 0.019236 - 0.043229*RH + 0.12676*RH^2 \qquad (6.16)$$

In the range $0.60 < RH < 0.90$,

$$DMM = 0.002210 * \exp(4.5396 * RH) \qquad (6.17)$$

The exponential model was used here because it provided a more reasonable trend than the quadratic model which suggested a minimum at RH=0.67. Above 90% relative humidity, the difference due to maturity is assumed constant and equal to DMM at RH=0.90 for lack of data (DMM=0.131).

For maturities between prebloom and mature alfalfa, a linear interpolation is proposed. The actual difference is calculated as follows:

$$ADMM = DMM * (DM - D)/DM \qquad (6.18)$$

where ADMM is the actual difference in equilibrium moisture content between mature alfalfa and the present crop (dec, d.b.);
DMM is the maximum difference in EMC between prebloom alfalfa and mature alfalfa;
DM is the number of calendar days between prebloom and mature stages;
and D is the number of days since prebloom stage.

The actual equilibrium moisture content of alfalfa is corrected for maturity stage and desorption-adsorption differences as follows:

$$EMC = EMCA + DDA + ADMM \qquad (6.19)$$

where EMC is the desorption EMC.

Figure 6.3 shows typical curves of EMC versus relative humidity. Temperature is an important variable mainly at high relative humidities. The present model fits well the data between 10 and 90% relative humidities.

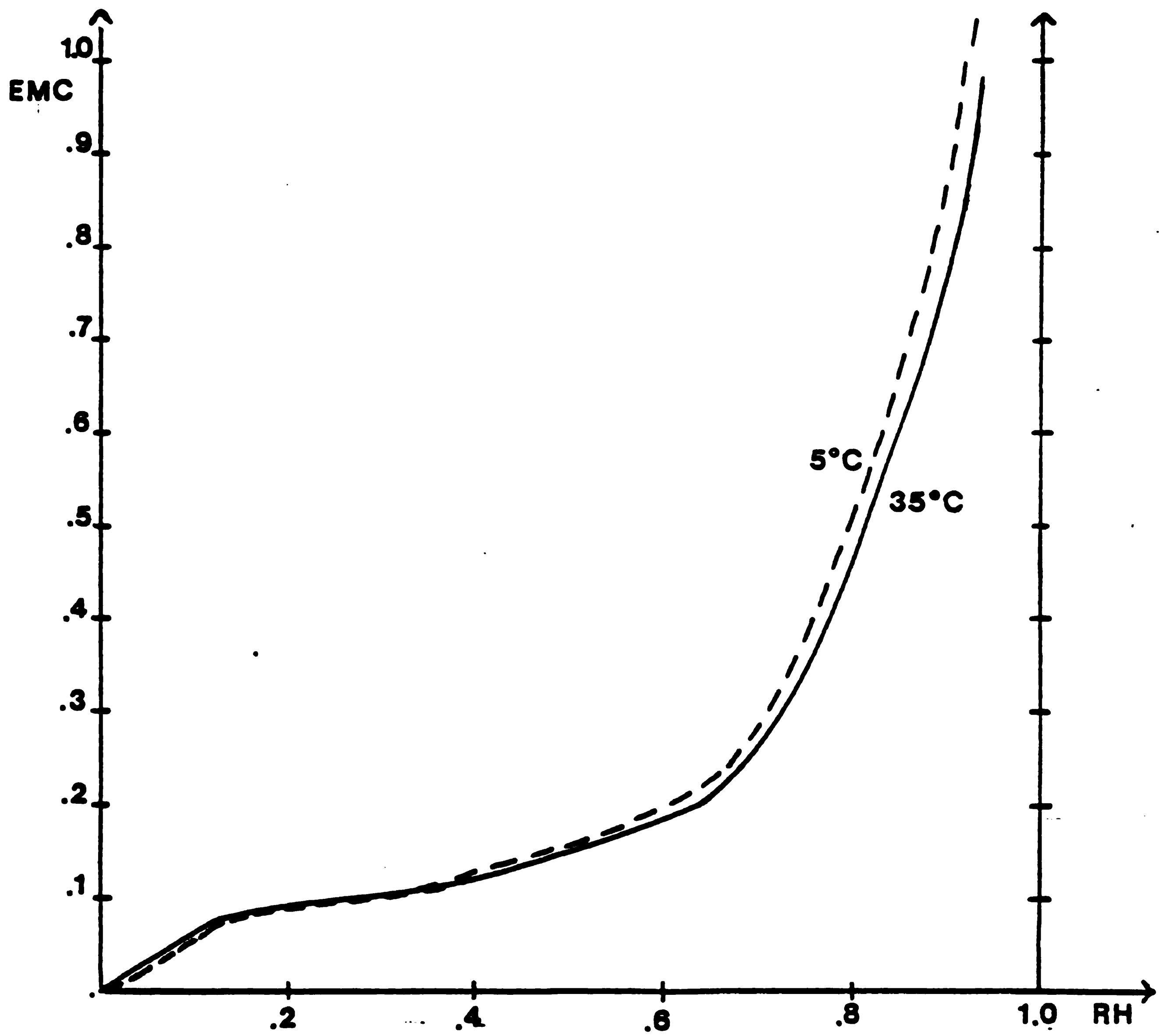

Figure 6.3. Predicted equilibrium moisture content (dry basis) versus relative humidity for desorption of prebloom alfalfa at 5 C and 35 C.

There is some evidence that at 0% relative humidity the EMC is not exactly 0 as was assumed here (see Zink (1935)). Above 90% relative humidity, EMC may sometimes be higher than what is predicted here. Further research may be useful in ascertaining more accurate values of equilibrium moisture content, especially under high relative humidities and specifically for desorption.

6.4 Estimating coefficients for the drying model

In this section, experimental data are analyzed to obtain a prediction equation for alfalfa drying in the field. Two simple models are also proposed to estimate the moisture content change of alfalfa exposed to rainfall and dew.

6.4.1 Experimental results

Field drying experiments were carried out during the first and the second alfalfa cuts in 1980 and again during the first cut in 1981 at the Upper Peninsula Experiment Station in Chatham, Michigan. Various machinery sequences were used to compare drying rate differences. The methodology has been explained in a published paper (Savoie et al., 1981). The reduced data are presented in appendix D. Each of the 189 observations was obtained from an average of between two and eight samples.

6.4.2 Statistical analysis

A multiple regression routine was used to analyze the data. The dependent variable k was calculated as follows:

$$k = \frac{(dM/dt)}{(M - EMC)^c} \qquad (6.20)$$

where M is equal to (Mo+Mf)/2;
Mo is the initial moisture content;
Mf is the final moisture content;
and (dM/dt) is the drying rate observed (g water/g DM/h).

The variable k was fitted to the model in equation 6.3 for values of c between 1 and 4. The R square value increased as c was decreased. The fit with c=1 yielded the highest value R square=0.3630. The latter value of c was prefered partly because a simpler mathematical expression resulted and also because all the signs of the coefficients were reasonable (b1 ... b8).

The complete model was fitted by least squares and the following expression was found.

$$\begin{aligned} k = & -0.021572 + 0.072605 * SR + 0.0054228 * TDB \\ & + 0.0022264 * WV + 0.021293 * RK \\ & + 0.029745 * CD + 0.00064916 * RNDW \\ & + 0.0077584 * DAY - 0.00000766 * DENS \end{aligned} \qquad (6.21)$$

A number of coefficients were non-significant. A step-wise regression was used to delete the non-significant terms at the 0.10 level of significance. The following simpler expression resulted.

$$k = -\ 0.016409 + 0.073064 * SR + 0.0055486 * TDB - 0.00000734 * DENS + 0.019722 * RK + 0.029649 * CD \qquad (6.22)$$

The R square value decreased from 0.3630 to 0.3577 with the deletion of the non-significant variables.

The regression analysis tells us a great deal about the relative importance of the various factors in predicting drying. It is noteworthy that wind velocity was dropped as a non-significant variable, in apparent contradiction with work done by Shepherd (1965). Shepherd showed a significant effect of wind speed up to a critical point while maintaining other variables relatively fixed. The present results do not necessarily deny a certain windspeed effect on drying rate under certain conditions; they point however that wind effect is overshadowed by solar radiation and dry bulb temperature.

Somewhat unexpectedly dew and rain water absorbed by the alfalfa did not evaporate significantly faster than water initially in the plant. The hypothesis may be that a large fraction of water left on the alfalfa surface is absorbed by the plant before it evaporates, and therefore evaporates at a rate similar to water initially in the plan

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The analysis also suggests there is no reason to believe that the drying constant in subsequent days will be any different from the drying constant on the first day of cut, under the same environmental conditions.

All signs in equation 6.22 are of a reasonable nature. Particularly as density increases, the drying constant and the drying rate will decrease.

The relative humidity was not considered as an independent variable to estimate the drying constant k because EMC in equation 6.20 already accounts for the relative humidity. The constant k was in fact positively correlated with relative humidity. This unexpected result suggests that the EMC model predicts values too high under high relative humidities. Future research should provide more extensive data on the desorption equilibrium moisture content of alfalfa.

The equation was developed from data shown in appendix D. Given the reasonable nature of the signs, slight extrapolations should still provide reasonable results. Of course further data outside the present range will yield greater confidence in the estimations. Data were especially scarce in the lower moisture range. The model may be less accurate to predict drying for low moisture contents. Probably the best way to improve the prediction would be to break down the estimating equation into several rang

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ranges for moisture contents between 0 and 5.5, the observed upper limit of alfalfa moisture content. Using different values of coefficient c in equation 6.20 for the different ranges would increase the precision of the estimation. Since the main purpose of this dissertation is to model the dynamics of forage harvesting, the present single equation model was felt adequate.

6.4.3 Rain adsorption

During the field trials, a few occurences of rain were observed. The data are shown in appendix D.

No statistical analysis was done because of the limited number of observations. Conditioned alfalfa absorbed about 40% more rain than the non-conditioned alfalfa. The fraction absorbed was greater for a light rainfall than for a heavy rainfall. The change in moisture content was apparently not affected by the density or the width of the windrow. In fact, tight windrows which had a lesser area exposed to rainfall than wide swathes absorbed a higher fraction of the rain. In the end both wide and narrow windrows had a similar moisture content increase. Freshly mowed alfalfa rewetted more easily than alfalfa mowed in previous days. The following simple model, in FORTRAN language, is proposed:

```
IF(RAIN.LE.5.)  DMR=0.25*RAIN*FCR
IF (RAIN.GT.5.)  DMR=(1.25+0.03*(RAIN-5.))*FCR
IF (DMR.GT.3.)  DMR=3.
IF (EXDAY.GT.0.)  DMR=DMR*(2./3.)
M=M+DMR
IF (M.GT.5.5) M=5.5
```

where RAIN is actual rainfall (mm);
DMR is the increase in moisture content due to rain adsorption;
FCR is a conditioning factor for rain adsorption (1 for no conditioning, 1.4 for conditioned alfalfa);
EXDAY is the number of days alfalfa has been exposed for field curing;
and M is the actual moisture content before and after the rainfall (dec, d.b.).

The model states that for rainfall below 5 mm a greater fraction of the rain is adsorbed than for heavier rainfalls. The increase in moisture content, on a dry decimal basis, can never be greater than 3.00 for freshly mowed alfalfa. Alfalfa exposed more than one day will adsorb only two thirds of the rain adsorbed by freshly mowed alfalfa. The final moisture content of rewetted alfalfa can never exceed 5.5, the apparent physiological limit of alfalfa for holding water.

The model is admittedly approximate and would benefit from further investigation. At this time. it was felt adequate for simulation purposes.

6.4.4 Dew adsorption

Data for dew adsorption during the night is also shown in appendix D. Conditioned alfalfa generally adsorbed about 20% more dew than non-conditioned alfalfa. Tight windrows reduced dew adsorption, compared with wide swathes. More dew was picked up when the evening air was very humid. The drop of non-rain moisture in the previous day appeared as an important factor in the ability of alfalfa to pick up dew. The following model is proposed:

```
DMDEW=DMPV*WR*(RH-0.5)*FCD
IF (RH.LT.0.5) DMDEW=0.
```

where DMDEW is the increase of moisture content from dew adsorption;
DMPV is the previous day's change of non-rain moisture content (moisture at 8:00 minus moisture at 20:00, before nightly dew adsorption);
WR is the windrow width to the mower cut width ratio;
RH is the relative humidity of air at 20:00 the evening before dew start settling on the alfalfa;
and FCD is a conditioning factor for dew adsorption (FCD=1 for non-conditioned alfalfa, FCD=1.2 for conditioned alfalfa).

6.5 Additional treatments

The term XTR in equation 6.3 was meant to include any other treatment which might affect the drying constant and the drying rate of alfalfa. Of current interest are treatments like tedding, maceration and chemical spraying.

6.5.1 Tedding

Tedding has a double drying effect. It reduces the windrow density by spreading the forages and it moves the wet bottom layer closer to the top for faster drying.

Dernedde (1979) used a tedder with two different conditioning treatments: crushing and abrasion. In combination with tedding, both conditioners had similar drying performances. Without tedding, the abrasion treatment was superior to the crushing treatment. Clearly there is interaction in the sequence of machinery used. Moreover the effect of an additional treatment may be very strong during midday and could diminish as the sun radiation and air temperature decrease. Such interactions between treatments and the environment are likely. They have seldom been measured by researchers looking into new treatments. The last term in equation 6.3 should be expanded at least to include:

$$b9 * XTR + b10 * (XTR * SR) + b11 * (XTR * TDB)$$

Coefficients b10 and b11 would account for the interaction between the treatment and the drying environment.

Because of the limited information, tedding will be implemented simply as having the turning effect of raking (RK=1) during a single day and as providing a lesser density (WR=1). The drying constant in equation 6.3 will increase accordingly.

6.5.2 Maceration

Maceration shreds the alfalfa tissues and creates a highly transpiring surface. Krutz et al. (1979) have presented some data for maceration. Under favorable drying conditions, the drying rate of macerated alfalfa was initially almost double that of cutterbar mowed alfalfa. After four hours of drying, the drying rates became almost equal as the macerated alfalfa approached balable moisture (<0.25). On the average the macerator produced a drying rate 1.6 times greater than the mower alone. Under those conditions, the drying constant estimated from equation 6.22 was about 0.166 for the mower alone and 0.266 for the macerator. Based on these limited observations, the value of b9*XTR would be 0.10 during the first four hours of drying. Generally complete drying for baling will require more than four hours. After this four hour period, maceration is likely to still show some benefit though to an unknown and probably lesser extent. The average effect of maceration for curing periods extending beyond four hours will be assumed to be half the initial effect, b9*XTR=0.05.

6.5.3 Chemical treatment

Spraying chemical solutins has been used to accelerate the drying of forage crops (Wieghart et al., 1980). The advantage of chemical spraying is very apparent initially but is largely lost as drying proceeds to balable moisture. From unpublished data, the first day increase of the drying constant due to chemical spraying appears to be in the order of b9*XTR=0.04 and in subsequent days is close to zero or even negative as the untreated material catches up with the treated one. In the simulation model, chemical spraying will be assumed to have an average continuous effect of b9*XTR=0.02.

6.6 Conclusions

The exponential decaying function is used to predict moisture content of alfalfa drying under field conditions. A single equation is used to predict moisture content at any time, or to predict the time when an alfalfa plot may be dry enough for harvest. Statistical analysis of two years of field data has shown the drying constant to be mainly a function of solar radiation, dry bulb temperature, material density and machinery treatments. A linear additive model is used to relate the drying constant to environmental and management factors. Simple models for dew and rain adsorption are also proposed.

The effect of additional treatments such as tedding, maceration or chemical spraying on the drying rate are estimated from data available in the literature. The efficiency of some mechanical or chemical treatments is probably linked to weather conditions. More research would be useful to determine the importance of such interactions.

A more precise drying model should be broken down into several moisture ranges. Presently a single equation is used to estimate drying rate over the entire moisture range of alfalfa. This is felt adequate for the present purpose of simulating forage harvesting on a daily basis. In the future a more precise drying model could be developed by generating prediction equations for several moisture ranges.

For the present simulation model, the available historical weather data included dry bulb temperature, solar radiation and precipitation on a daily basis, but did not include relative humidity. Consequently the equilibrium moisture content could not be estimated on a daily basis. EMC was simply fixed at 0.15 for the first and fourth alfalfa cuts and at 0.10 for the second and third cuts. In the future more complete weather data should include relative humidity because of its importance in the drying model.

CHAPTER 7

THE DYNAMIC SIMULATION

Alfalfa harvest is simulated on a daily basis. Decision algorithms specify whether alfalfa may be mowed or harvested on any given day. In addition a storage policy separartes high quality from low quality alfalfa.

The present chapter describes these algorithms. Alfalfa harvest may be done in three ways: either as direct-cut alfalfa, as field-cured wilted alfalfa for haylage or as field-cured dry hay. Each is described in detail. The chapter concludes by illustrating how alfalfa harvest, corn harvest (as silage or corn grain) and feeding the cows are linked together in the dynamic simulation.

Many management defined criteria are used to make decisions. Appendix C describes how these criteria are read in as input data. This chapter describes the effects the criteria may have on the sequence of events as weather, yield and other related stochastic variables change.

7.1 The commanding subroutine: ALHARV

All alfalfa harvest operations are controlled by a subroutine called ALHARV. A flow chart in figure 7.1 illustrates the interactions between the growth simulator and the harvest operations controlled by ALHARV.

Several management parameters are required for alfalfa harvest: total area harvested, the sequence of operations which implicitly include the size of each machine and a number of decision criteria (e.g. the maturity at which alfalfa mowing may begin, the moisture content at which the crop may be harvested, whether mowing can be simultaneous or not with harvest, etc.). These management parameters are read as input and are described in appendix C.

The alfalfa growth simulator, written by Parsch (1982), predicts dry matter yield and quality of both leaves and stems on a daily basis. A 26-year series of historical weather data from East Lansing is used for growth and harvest simulation.

When alfalfa is ready for harvest, either after a specific calendar date or after alfalfa has reached a suitable maturity stage, subroutine ALHARV is called. On the first day of harvest, an initialization subroutine is called to estimate the work rates as a function of the

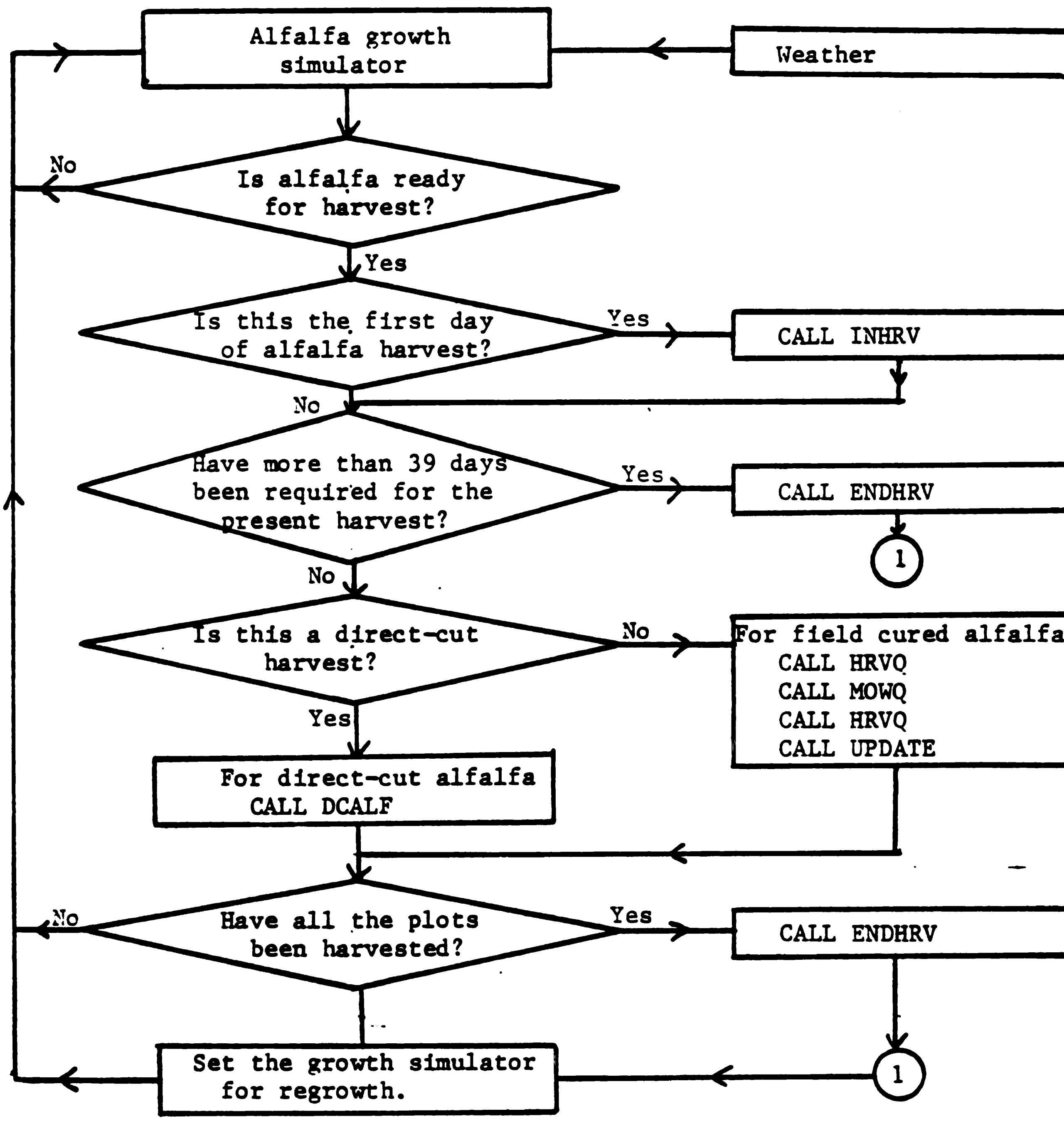

Figure 7.1. Interactions between the growth simulator and the alfalfa harvest.

alfalfa yield. The whole area is also divided into discrete plots. One plot is defined as the area that can be harvested in half a day of continuous field work. A half day is presently defined as a five hour period.

The choice of a half day as a harvest time increment was felt more practical and flexible than either a 1-hour time increment which is too small (farmers would not go out and harvest for only one hour) or a full day time increment which would not allow the option of doing other chores besides harvesting.

For direct cut alfalfa, only one subroutine (DCALF) is called daily. If weather conditions are suitable for field operations, two plots will usually be harvested as direct-cut alfalfa per day.

For field-cured alfalfa, three subroutines are called daily in the following sequence: HRVQ, MOWQ, HRVQ and UPDATE. Subroutine HRVQ checks whether any field-curing plot may be harvested today. It is called twice, once before MOWQ, because first priority is given to harvest over all other field operations such as mowing or raking, and again after MOWQ, in case some plots mowed in the morning could be ready to harvest before the end of the day. A moisture content criterion must be satisfied for a plot to be harvested (i.e. alfalfa must be dry enough either as hay or haylage). Not more than two plots may be harvested in a single day.

Second priority is given to mowing. If mowing can be simultaneous with harvest or if no harvest occurs today, then MOWQ estimates the number of plots that may be mowed today. Subroutine HRVQ is called again in case some plots mowed in the morning may be harvested the same day. Finally subroutine UPDATE examines all the plots that are still curing at the end of the day (i.e. mowed but not harvested). It updates the moisture content until the next morning including day time drying and rainfall or dew adsorption. It also estimates dry matter losses from environmental factors and recalculates the remaining alfalfa yield in each plot.

Once all the plots are harvested, subroutine ENDHRV will aggregate the dry matter and feeding value of the harvested alfalfa. Expected losses in storage and from feeding are already accounted for at this point. Subroutine ENDHRV will also be activated if the harvest period extends beyond 39 calendar days because of dimensional constraints in the growth model. In this case all the remaining unharvested plots are destroyed.

At the end of an alfalfa harvest, the growth simulator is set for regrowth at a date midway between the first and the last mowing dates. The next harvest will not begin until the alfalfa satisfies again the maturity criterion or a new date constraint for the subsequent harvest.

The following sections describe in greater detail the decision criteria involved with direct-cut alfalfa, field-cured alfalfa and storage policy.

7.2 Direct-cut alfalfa

Since direct-cut alfalfa involves no field-curing delays, it is much simpler than hay or haylage operations. Direct-cut harvest is simulated in subroutine DCALF.

Harvesting will proceed on a given day as long as machinery can get on the field. In the present model a single condition must be met to allow direct-cut of alfalfa: the current day's rainfall must be less than 2 mm. When this condition is satisfied, plots are harvested and put into storage immediately. Harvest losses and expected losses in storage and from feeding are all accounted for in subroutine DCALF. The final output is metric tons of dry matter, crude protein and digestibility of alfalfa available as feed.

The maximum field working time for either direct-cut or field-cured harvest is set at 10 hours in the present model, because a plot was defined as the area harvested in half a day (5 hours) and a maximum of two plots may be harvested per day. One may change the available field time by simply changing the definition of a half day: a 12-hour day could be implemented by defining a plot as the area harvested in 6 hours. Minor changes in INHRV and in MOWQ would be required.

7.3 Field-cured alfalfa

Two important decision algorithms are discussed in this section: MOWQ and HRVQ. Each subroutine contains a number of conditional checks that will specify how many plots may be mowed or harvested in a given day. These subroutines are used to simulate the harvest of field-cured alfalfa.

7.3.1 MOWQ: How many plots can be mowed?

Subroutine MOWQ basically determines how many plots may be mowed in a given day. It also initializes a matrix called HARMAT which keeps track of important characteristics (moisture content, total dry matter, leaf fraction,stem fraction, crude protein, digestibility) of each field-curing alfalfa plot.

The algorithm is illustrated in figure 7.2. In practice the area to be mowed is a complex function of weather expectations, the area already mowed, the stage of maturity of the crop and some management choices. In the

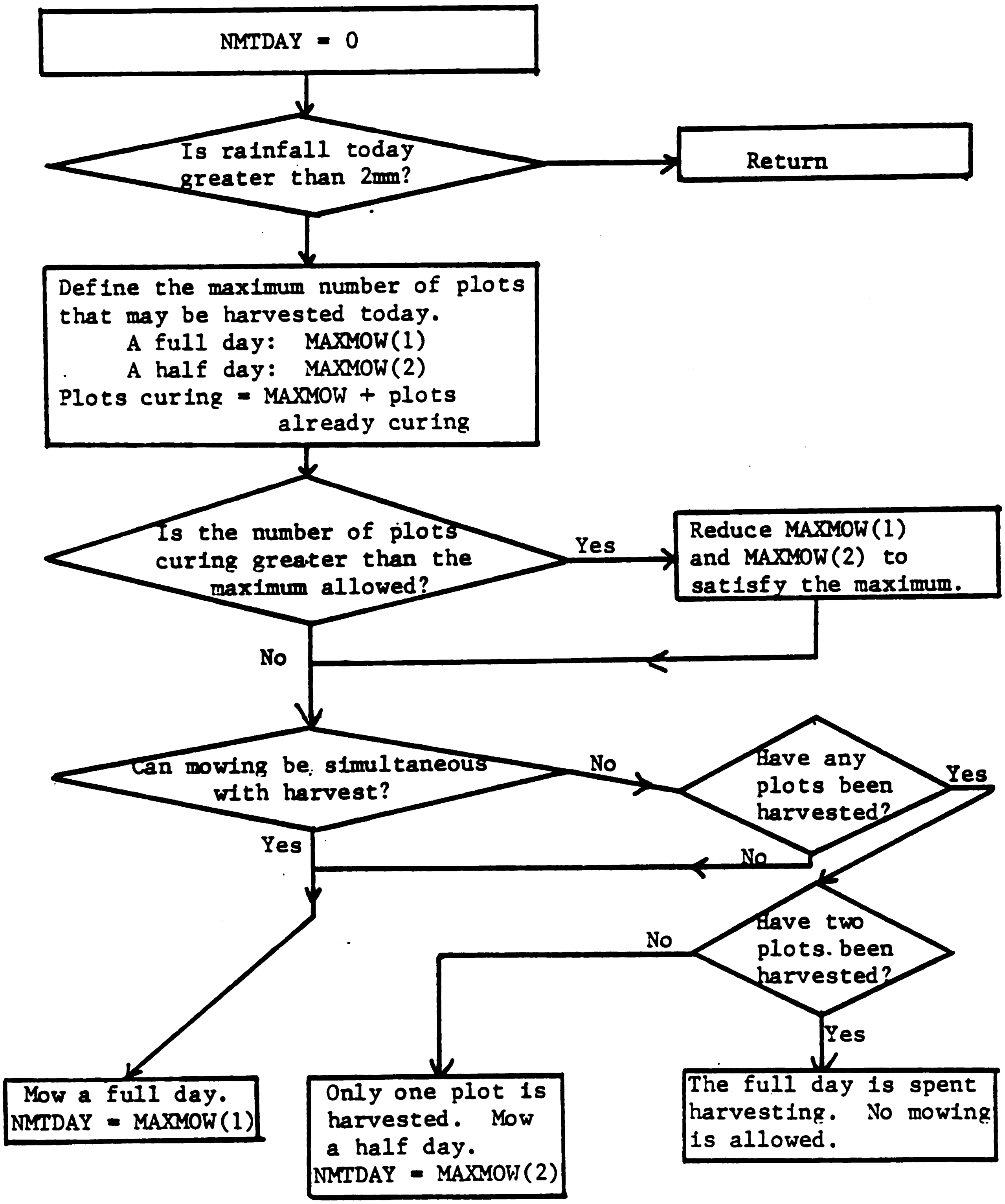

Figure 7.2. The basic algorithm to decide how many plots may be mowed today.

present model, the only weather variable considered is rain: if rain in the current day is greater than 2 mm, no mowing will be done. When mowing is possible, the maximum number of plots that may be harvested in a half day and in a full day are both calculated. A half day represents 5 hours of mowing time and a full day is 10 hours. (These time lengths can be changed in MOWQ as explained in section 7.2.) Meanwhile the total number of plots curing cannot be greater than some management defined criterion. Thus a manager can specify that mowing should not outdistance harvest by, say, more than three days (i.e. the total mowed area should not represent more than three full days of harvesting or a maximum of 6 plots). This mowing limitation criterion is an input parameter (see Appendix C).

The maximum number of plots that may be mowed in a full day is estimated by the following FORTRAN statements:

```
NM10 = IFIX (10.  * RTMOW/AREAPL)
MAXMOW(1) = MAX0 (1,NM10)
```

where NM10 is an integer number of plots mowed in ten hours (the decimal fraction is truncated by the function IFIX);
RTMOW is the mowing rate (ha/h);
AREAPL is the area per plot (ha);
and MAXMOW(1) is the maximum number of plots that may be mowed in a full day. The function MAX0 insures that at least one plot will be mowed.

Similar statements are used to estimate the number of plots mowed in half a day. These maximum numbers will be reduced if they result in too many plots left curing in the field.

A full day of mowing will occur in two cases: when mowing can be simultaneous with harvest or when no plots are harvested today. Mowing will be limited to a half day when it cannot be simultaneous with harvest and when one plot is being harvested today. No mowing will be done if the whole day is spent harvesting two plots and mowing cannot be simultaneous with harvest.

7.3.2 HRVQ: How many plots may be harvested?

For field-cured alfalfa, harvesting has the restricted meaning of either baling or chopping material after it has reached an adequate moisture content. Harvesting has a higher priority than mowing: if field curing plots are dry enough, they will be harvested before additional alfalfa is mowed.

Figure 7.3 shows the basic algorithm that determines how many plots will be harvested in a given day. Of course when no plots are curing, no harvest is possible. If a curing plot is dry enough by 4pm, then it may be harvested. For a second plot to be harvested, one of the plots must be

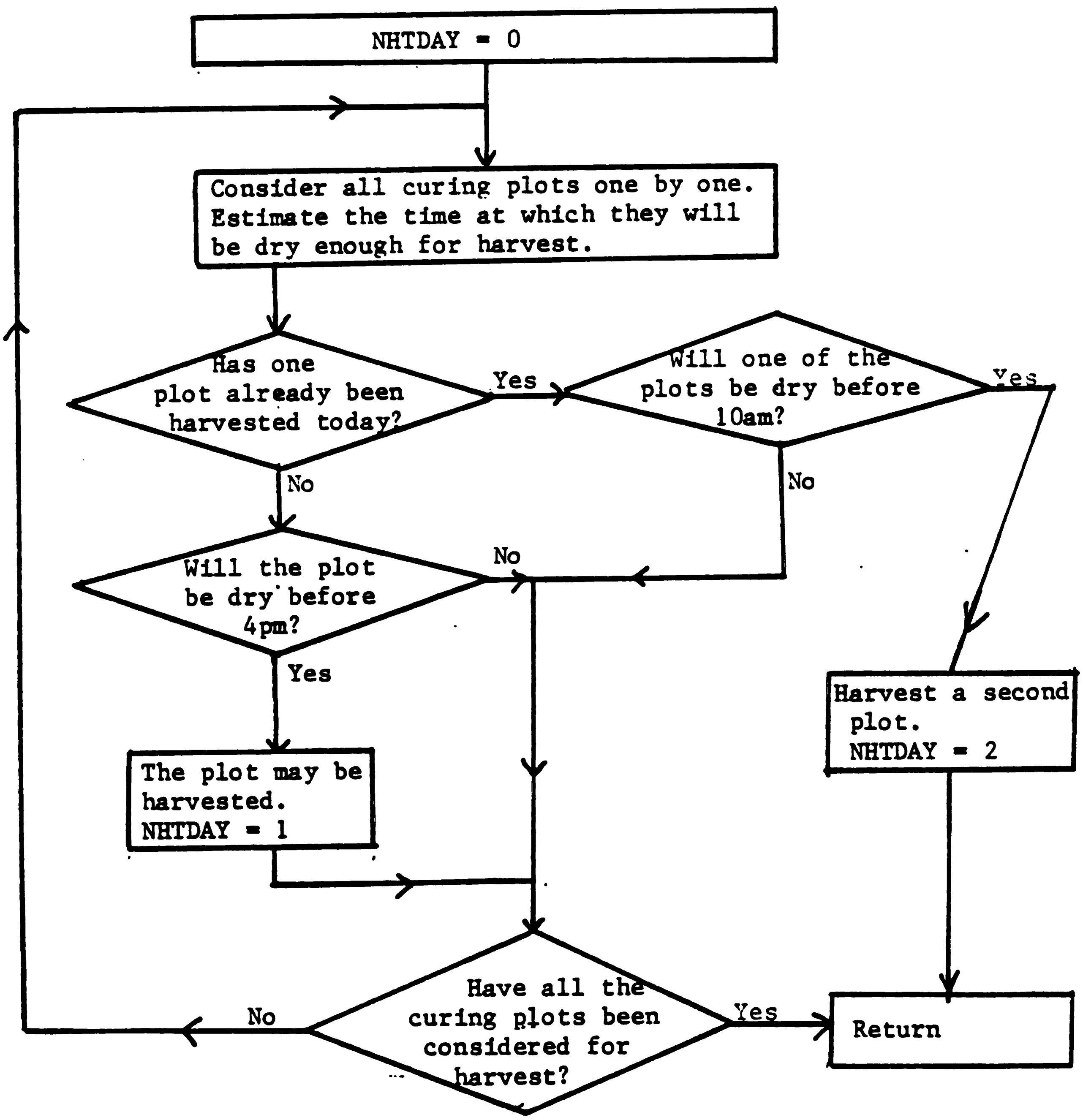

Figure 7.3. Basic algorithm to decide how many plots will be harvested today (NHTDAY).

ready for harvest before 10am since the harvest crew would be working at least 10 hours continuously. The maximum number of plots that may be harvested in a day is two.

7.3.3 Other field-curing operations

Besides mowing or mowing-conditioning, a few other field-curing operations are sometimes required: extra conditioning after mowing, tedding, raking or treatment after rainfall. Appendic C explains in greater detail how these other field-curing operations may be included in the harvesting sequence.

These additional field-curing operations are optional and may be omitted. When extra conditioning after mowing is specified (e.g. tedding), it is assumed to be applied immediately after mowing. When raking is specified, its main purpose is to bring a wide swath into a narrow windrow. Such raking treatments are assumed to be applied early in the morning on the day a plot is harvested. Raking or tedding may also be used to disturb a plot that has been rained on. In such a case, the treatment is applied once, immediately after rainfall.

7.4 Storage policy

From a nutritional point of view, it is important to separate high quality from low quality forages. The high quality material is fed to lactating cows whereas the lower quality feed is given to the dry cows and heifers.

A storage allocation algorithm was written to separate alfalfa plots of different quality into different storage areas. Five storage locations are defined as: high quality wet alfalfa, low quality wet alfalfa, high quality dry alfalfa, low quality dry alfalfa and destroyed alfalfa plots because of overexposure. In the last location, alfalfa plots are destroyed after they have been curing beyond a "critical number of days". This criterion is a manager defined input. It is set at 14 days in most simulations.

Another criterion, "critical crude protein", is used to separate high from low quality alfalfa. When the average crude protein within an alfalfa plot goes below the criterion, the plot is stored in the lower quality location.

Wet alfalfa includes both direct-cut alfalfa silage and field-cured haylage. One or two silos of fixed capacity may be specified for wet alfalfa storage. The first silo is for high quality forages, the second is for lower quality forages. When the first silo is filled, all the remaining alfalfa is forced into the second silo no matter what the quality is. If a very high "critical crude protein" criterion is used, it is possible that the second silo will be filled before the first one. In such a case, the remaining alfalfa is forced into the first silo. When both silos are filled, all the remaining alfalfa must be harvested as dry hay since no emergency wet alfalfa storage is allowed.

Dry hay is also separated into two storage locations, a high quality one and a low quality one. An initial storage capacity is specified. But extra emergency space is always available to store dry hay at some marginal cost ($/ton-DM/yr). Storage space is not a constraint for hay but it is for wet alfalfa.

At the end of each simulation year, the total dry matter available as feed, the average crude protein and the average digestibility are estimated at each of the four useful storage locations: high quality wet alfalfa, low quality wet alfalfa, high quality dry alfalfa and low quality dry alfalfa. The standard deviations for crude protein and digestibility are also estimated from all the single plots that are accumulated in each storage location.

Total storage and feeding losses are estimated from coefficients presented in chapter 5. The resource requirements for feeding, namely labor and energy, are estimated from coefficients presented in table 7.1. The resource requirements are given per unit of forage wet matter.

Table 7.1. Labor and energy requirements for feeding (from Kjelgaard, 1979).

	Feeding method	Labor (man.h/tWM)	Fuel (L/tWM)
1.	Rect. bales, hand fed	1.00	0.00
2.	Round bales, self fed	0.25	0.50
3.	Round or rect. bales, ground	0.50	1.50
4.	Hay stacks, self fed	0.20	0.50
5.	Hay stacks, shredded	0.40	1.50
6.	Vertical silo unloader	0.50	0.15
7.	Bunk silo and scoop	0.15	0.10

7.5 Linking all the subsystems

The dynamic simulation model estimates the performance of a forage system for a whole year. Alfalfa growth and harvest are simulated daily. Corn planting and harvest are simulated by 10-day periods. At the end of the year, all the feed harvested is allocated to a dairy herd. Excess forages are sold on the market and supplemental feeds are purchased. The yearly profit is total income from milk and excess forages sold on the market minus the total cost for machinery, storage structures, labor, energy and supplemental feeds. The yearly simulation is repeated generally 26 times using 26 years of historical weather data. These 26 samples of yearly profit provide the data to estimate the standard deviation and the frequency curve of yearly profits.

The program begins by reading some user defined inputs. The machinery information and the alfalfa information input files are documented in appendices B and C of the present dissertation. The alfalfa growth, corn crop and weather data files are documented in Parsch (1982). The program then calls FORHRV to set up a machinery operation matrix. This matrix contains harvest rates, fuel and labor consumptions for all field operations over a wide range of yields. These calculated rates will be used throughout the simulation at the beginning of each new alfalfa harvest.

At the beginning of each year, an initialization subroutine (YRINIT) is called to set all the aggregation variables to 0. Each day alfalfa growth is simulated by ALSIM. When alfalfa is ready for harvest, ALHARV is called. At the end of each harvest, the alfalfa crop is aggregated into various storage locations (subroutine ENDHRV). At the end of each year, corn silage and corn grain harvests are simulated per 10-day intervals in subroutine CRNHRV (Parsch, 1982). All the feed is then allocated for feeding dairy cows and the amounts of purchased supplements are estimated (subroutine COWFD). Finally the yearly profit is estimated. The yearly simulation can be repeated for several years (usually 26) to gain information about the distribution of the annual net return.

CHAPTER 8

COST ESTIMATES

The objective function for evaluating forage systems was presented in chapter 3. It is reproduced here for convenience.

$$PR = I(1) + I(2) - C(1) - C(2) - C(3) \qquad (8.1)$$

where PR is the total yearly profit;
I(1) is income from milk production;
I(2) is income from the sale of excess forages;
C(1) is the annual cost of labor, energy, repair and maintenance for harvest, storage and feeding;
C(2) is the cost of purchased supplemental feeds;
and C(3) is the annualized cost of fixed assets (machinery, silos, land).

The income from milk production I(1) and from the sale of excess forages I(2) and the cost of supplemental feeds C(2) are three interdependent terms. Their estimation is dealt with simultaneously in section 8.1. The annualized cost of fixed assets is discussed in section 8.2. Finally parameters for the estimation of variable costs are presented in section 8.3.

8.1 Balancing the dairy ration

The simulation model allows for alfalfa to be stored in up to four distinct locations: in a first silo (usually as high quality wet alfalfa), in a second silo (usually as lower quality wet alfalfa), as high quality dry hay and as low quality dry hay. The storage policy is presented in section 7.4.

A dairy ration formulation model was written to allocate in some optimal way all the harvested feeds to the animals. The model is based largely on information published by the NRC (1978).

A brief review of the literature in section 5.4 showed that intake of wet alfalfa was slightly less than intake of dry alfalfa. Since haylage generally has a higher quality than hay, the reduced intake can offset the quality advantage. To simplify things, the crude protein and the digestibility of wet alfalfa are reduced by 5% to account for the lesser intake compared with dry alfalfa hay.

The four alfalfa storage locations are ranked according to crude protein. A fifth alfalfa source included in the analysis is purchased alfalfa hay in case the farm does not produce enough roughage in a bad year.

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The crude protein and the digestibility will vary from year to year depending on weather and other factors. The digestibility is converted into net energy of lactation of alfalfa by the following linear relationship (from data in NRC, 1978).

$$NEL = 1.15 + (TDN - 0.52) * 2.5 \qquad (8.2)$$

where NEL is net energy of lactation in alfalfa (Mcal/kg); and TDN is the total digestible nutrients (dec).

Equation 8.2 is used for values of TDN between 0.52 and 0.74. The NRC (1978) does not indicate any alfalfa samples with a digestibility outside this range. When TDN is below 0.52, NEL will be assumed constant and equal to 1.15. When TDN is above 0.74, NEL will be assumed equal to 1.70.

All the alfalfa, corn silage and high-moisture corn harvested on the farm are fed at such a rate that all will be depleted at the same time. The proportion of each in the ration is estimated as follows:

$$TDM = TALF + TCS + THMC \qquad (8.3)$$

$$FR(1) = TALF/TDM \qquad (8.4)$$

$$FR(2) = TCS/TDM \qquad (8.5)$$

$$FR(3) = THMC/TDM \qquad (8.6)$$

where TDM is the total dry matter of roughages and high-moisture corn harvested on the farm in a given year (t-DM);

TALF is the total alfalfa harvested (t-DM);
TCS is the total corn silage harvested (t-DM);
THMC is the total high-moisture corn harvested (t-DM);
FR(1) is the initial fraction of alfalfa in the ration;
FR(2) is the initial fraction of corn silage in the ration;
and FR(3) is the initial fraction of high-moisture corn in the ration.

Initially the ration is assumed to be composed only of farm grown crops in proportions estimated by equations 8.4, 8.5 and 8.6. The average crude protein and the average net energy of lactation are calculated for the five feed mixes, i.e. the five alfalfa sources with corn silage and high-moisture corn. No qualtiy variation is assumed in the corn crop.

These five feed sources are balanced with six groups of dairy animals defined as follows:

1. High yield lactating cows (35 kg of milk per day or 23500 lb per year);
2. Medium yield lactating cows (30 kg of milk per day or 20100 lb per year);
3. Medium-low yield lactating cows (25 kg of milk per day or 16800 lb per year);
4. Low yield lactating cows (20 kg of milk per day or 13400 lb per year);
5. Dry cows;

6. Heifers.

The feed requirements for each type of cow are shown in table 8.1. The requirements are based on 650 kg cows producing milk with 3.5% fat. Heifers are assumed to weigh an average of 300 kg. Rations are balanced by insuring that the minimum concentration of NEL (net energy of lactation) and CP (crude protein) are met. Initially only farm grown feeds are assumed in the ration in proportions given by equations 8.4, 8.5 and 8.6. If the minimum required level of NEL is not satisfied, corn grain is added until the requirement is met. If the minimum level of CP is not satisfied, soybean meal is added until the requirement is met.

The total number of lactating cows and the herd composition (i.e. what proportion of animals are in each of the six groups defined previously) are input parameters. Appendix C explains how they are read into the model.

The total number of cows in the herd allows estimation of the total yearly intake (tons DM) for each cow group. Starting with the high yield lactating cows and the highest quality alfalfa feed mix, the farm grown crops are fed to the cows until their group requirement is met.

Total purchased feeds (soybean meal, corn grain) and unused farm grown crops (alfalfa, corn silage, high-moisture corn, corn grain) are given a buying or se

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selling market value. By including the value of the total milk production, an estimate of the net return can be obtained.

Table 8.1. Daily feed requirements for six types of dairy cows (from NRC, 1978).

Milk production level (kg/day)	Max. intake % Body weight	Max. intake kg-DM	Daily need NEL (Mcal)	Daily need CP (kg)	Min. concentr. NEL (Mcal/kg)	Min. concentr. CP (kg/kg)
35.	3.2	20.80	34.45	3.385	1.656	0.163
30.	3.0	19.50	31.00	2.975	1.590	0.153
25.	2.8	18.19	27.55	2.565	1.514	0.141
20.	2.6	16.90	24.10	2.155	1.426	0.128
Dry cows	---	---	13.39	0.984	1.35	0.11
Heifers	---	---	7.25	0.746	1.35	0.12

8.2 Fixed costs

Two important types of durable assests are involved in forage systems: machinery and storage structures. Some of these assets may have a useful life of ten to thirty years. It is necessary to convert their initial cost into an annualized cost to estimate yearly profits in equation 8.1.

The annual cost of durable assets that depreciate with time can be estimated by the capital recovery formula.

$$ANC = \left[IC - \left(\frac{SV}{(1+i)^n}\right)\right] \left[\frac{i * (1+i)^n}{(1+i)^n - 1}\right] \qquad (8.7)$$

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where ANC is the annualized cost of durable, depreciable assets;
IC is the initial cost;
SV is the salvage value at the end of the accounting life;
i is the interest rate;
and n is the accounting life (years).

In the present model the effects of income tax and differential inflation rates are not considered. The reader is referred to Bartholemew (1981) and Rotz et al. (1981) for more discussion on the topic of cost estimation.

The accounting life will generally be set at 10 years for machinery and 30 years for storage structures. The salvage value is set at 10% of the initial cost for machinery and at 0 for storage structures.

8.3 Variable costs

Variable costs include labor and energy for harvest and feeding, and repair and maintenance of machinery.

Harvest labor is estimated by assuming one operator per tractor. Total labor requirement is the sum of all the tractor use. Feeding labor is proportional to the total amount of forages to be fed. Coefficients in table 7.1 are used to estimate the total feeding labor. Labor cost is generally set at $5.00 per hour.

Energy use for field machinery are estimated in model FORHRV according to equations presented in section 4.4. All energy requirements are converted into liters of diesel fuel. Energy for feeding is estimated from coefficients in table 7.1. The cost of fuel is generally set at $0.31 per liter.

Repair and maintenace costs of machinery are proportional to use. A simple model is used.

$$RM = IC * COEFRM * USE \tag{8.8}$$

where RM is the annual repair and maintenace cost of a machine ($/yr);
IC is the initial cost of the machine ($);
COEFRM is a coefficient of repair and maintenace cost (h^{-1});
and USE is the annual machine use (h/yr).

Hunt (1973) has presented some values of COEFRM for various farm machinery. A selected number of coefficients is presented in table 8.2.

Table 8.2. Repair and maintenance cost coefficients (from Hunt, 1973).

Machines	COEFRM (h^{-1})
Tractor	0.00012
Mower	0.00120
Rake, tedder	0.00070
Forage harvester	0.00029
Wagon	0.00018
Blower	0.00025

8.4 Economic parameters used in the model

The choice of values for economic parameters such as prices, discounting rates and depreciation life is very important because it might influence the comparison of various systems. These parameters are often uncertain and can be the object of considerable economic analysis.

The main focus of the dissertation is to compare forage systems technologies and management strategies. It is not to carry out extensive analysis of price levels, various discount rates or depreciation lives. The economic parameters used in the analysis are generally fixed. For the record, the values chosen are presented below. The machinery prices are fully described in appendix A. They are average prices based on the list prices available in fall 1981. The following subsections deal with the cost of storage structures, the price of feed and discounting rates.

8.4.1 Storage structures

The initial cost of storage structures is estimated from quotes of local manufacturers (spring 1982). Prediction equations are developed alternately for the cost of

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of vertical concrete silos and for the cost of clear span hay barns.

8.4.1.1 The cost of vertical silos

Table 8.3 shows the prices of six vertical concrete silos of various sizes. Dry matter capacities were estimated from the Midwest Plan Service (1980). Since unloaders are a necessary part of a silo, their cost is also included in the overall silo cost.

Table 8.3. Prices of vertical concrete silos.
(quoted from Tristate Silo Inc., Eaton Rapid, MI)

Silo size (diameter x height)	Storage capacity (tDM)	Silo cost ($)	Unloader cost ($)	Total cost ($)	Cost per unit storage ($/tDM)
20' x 50'	111.	14300.	6300.	20600.	186.
20' x 80'	214.	22700.	6300.	29000.	136.
24' x 60'	207.	21700.	8500.	30200.	146.
24' x 80'	308.	28300.	8500.	36800.	119.
30' x 60'	325.	28800.	9300.	38100.	117.
30' x 80'	480.	36700.	9300.	46000.	96.

When costs are estimated on a per ton basis, a clear trend appears between cost and capacity. McIsaac and Lovering (1980) have actually proposed an equation relating silo cost to volume under Canadian conditions. Their equation predicts current Michigan prices closely for capacities below 300 tons DM. Above this capacity however, the eqution generates unreasonably high prices.

The actual silo prices are plotted on figure 8.1 versus dry matter capacity. The slope is high for low capacities and decreases as the capacity increases. For very low capacities, the marginal cost is about $200./t-DM. The slope becomes apparently constant above 300 t-DM where the marginal cost becomes $50./t-DM. The total cost of a 300 t-DM silo is $37000. Assuming that a zero ton silo will cost nothing, there are now four boundary conditions that can be used to fit a cubic equation. The initial cost of a silo smaller than 300 t-DM is predicted as

$$SC = 200. * CAP - 0.2667 * CAP^2 + 0.00003704 * CAP^3 \qquad (8.9)$$

where SC is the predicted initial cost of a vertical silo, including an unloader ($);
and CAP is the silo capacity (t-DM).

For silo capacities above 300 tons DM, the initial cost is predicted as

$$SC = 37000. + 50. * (CAP - 300.) \qquad (8.10)$$

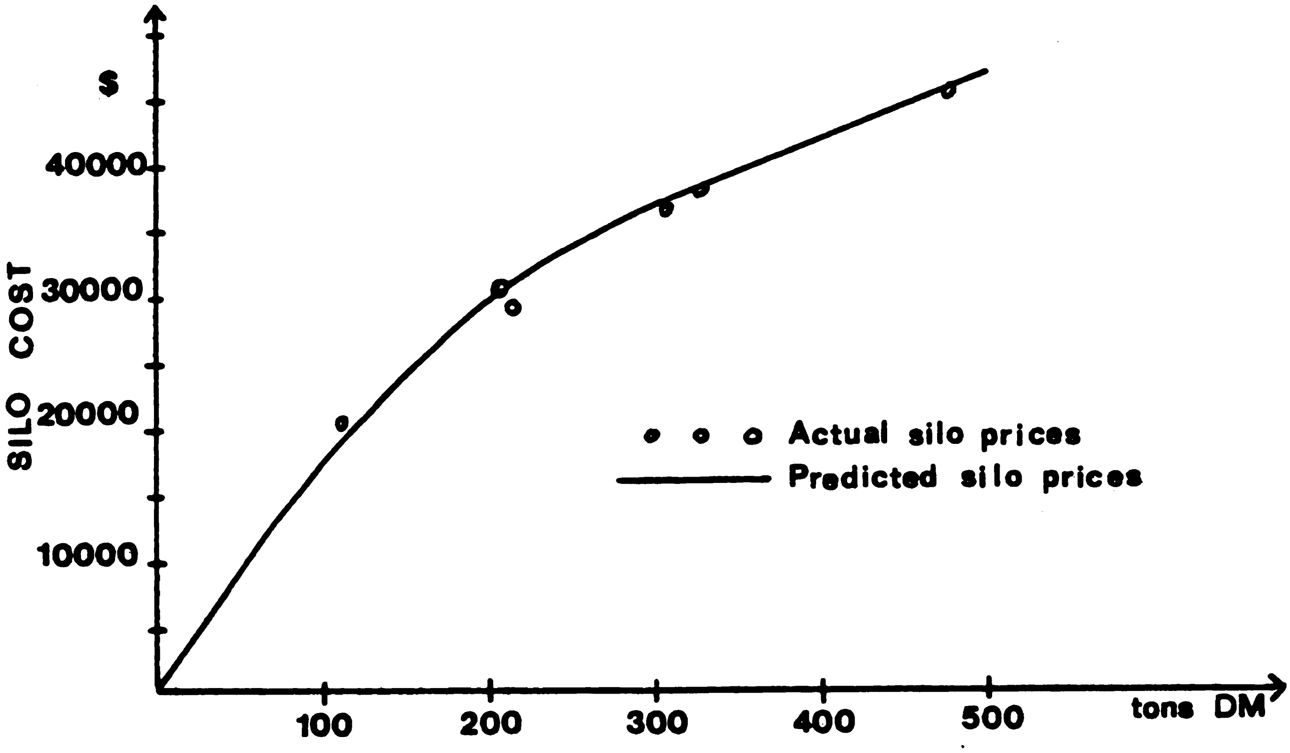

Figure 8.1. The initial cost of vertical concrete silos versus silage capacity.

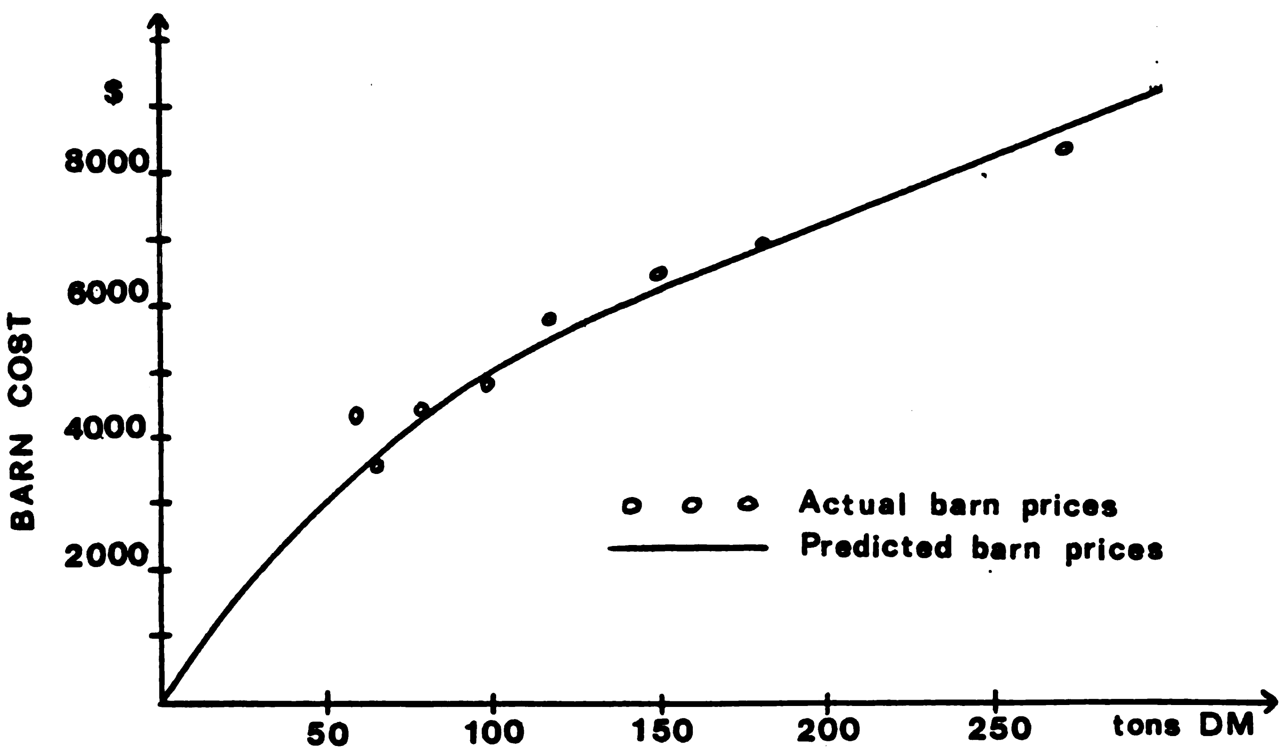

Figure 8.2. The initial cost of clear span barns for the storage of hay versus storage capacity.

8.4.1.2 The cost of hay barns

Table 8.4 shows prices and sizes of clear span buildings that may be used for the storage of dry hay. The storage capacity is estimated by substracting 12' from the width for moving in the building, by substracting 1' from the height for clearance and by assuming a hay density of 157 kg/m^3. As with silos, a trend exists between cost and capacity.

Table 8.4. Prices of clear span buildings (quoted from Detroit Steel, Charlevoix, MI and from Lane Clear Span Building, Adrian, MI).

Building size (width x length x height)	Useful capacity (t-DM)	Cost ($)	Cost per unit storage ($/t-DM)
40' x 42' x 12'	58.	4290.	74.
50' x 98' x 12'	182.	6995.	38.
60' x 98' x 14'	272.	8590.	32.
40' x 40' x 14'	65.	3777.	58.
40' x 48' x 14'	78.	4495.	58.
40' x 60' x 14'	97.	4888.	50.
40' x 72' x 14'	117.	5795.	50.
48' x 78' x 14'	150.	6495.	43.

The actual barn prices are plotted on figure 8.2 versus storage capacity. For low capacities, the marginal cost is about $75. per ton of dry matter. For capacities above 150 tons DM, the slope becomes practically constant at $20./t-DM. The total cost of a 150 ton barn is $6200.

Assuming that zero capacity will cost nothing, the four boundary conditions are used to fit a cubic equation. For capacities below 150 tons DM, the initial cost of a hay barn is predicted as

$$BC = 75. * CAP - 0.30667 * CAP^2 + 0.000548 * CAP^3 \qquad (8.11)$$

where BC is the predicted initial cost of a clear-span hay barn ($);
and CAP is the useful storage capacity of the barn (t-DM).

For barn capacities above 150 tons DM, the initial cost is predicted as

$$BC = 6200. + 20. * (CAP - 150.) \qquad (8.12)$$

8.4.2 Prices of feed

Table 8.5 shows the prices used for the purchase of supplemental feeds and for the sale of excess forages. Prices are based on recent prices published by Nott et al. (1981) and by the Michigan Agricultural Reporting Service. To convert U.S. units into metric tons of dry matter, moisture contents of 20% and 15% on a wet basis are assumed for alfalfa hay and corn grain respectively.

Table 8.5. Prices of inputs and outputs used in the ration formulation model.

Item	Price (U.S. units)	Price (metric units) ($/t-DM)
Milk	$13./cwt	286.
Soybean meal	$225./ton	248.
Buying alfalfa hay	$60./ton	83.
Selling alfalfa hay	$50./ton	69.
Buying corn grain	$3.00/bu	139.
Selling high-moisture corn	---	90.
Selling corn silage	---	70.

Market prices are usually not published for high-moisture corn and corn silage. High-moisture corn has practically the same feeding value as dry corn. However it has a very short life once it is taken out of storage so its marketing is difficult. Corn silage has a lower nutritional value than corn grain and spoils rapidly after it is taken out of storage. Selling prices are set arbitrarily at about 35% below the purchase price of equivalent feeds because of the short preservation period once these fermented feeds are taken out of storage.

8.4.3 Interest rates

Interest or discounting rates are required to estimate the annualized cost of durable assets such as machinery or storage structures. Table 8.6 shows the discount rates and accounting lives that are generally assumed in the analysis.

Table 8.6. Discount rates and accounting life to estimate yearly cost of durable assets.

Item	Discount rate	Accounting life (years)
Machinery	0.15	10.
Storage structures	0.13	30.

The discount rates in table 8.6 are actually nominal rates because they include the effect of inflation. Real interest rates are closer to 0.04. When comparing alternatives of different capital cost, it may be more appropriate to use real rates. The real and nominal rates will be used alternately to compare hay and haylage systems in chapter 9. In general, nominal rates from table 8.6 will be used.

CHAPTER 9

SIMULATION RESULTS

The models described in the previous chapters along with those described by Parsch (1982) are linked together to simulate forage harvest, storage and feeding. The simulation model is used to test how various management or technological changes might affect the forage system's performance.

Simulation results in this chapter are based on 26 years (1953-1978) of historical weather data from East Lansing, Michigan. Results are generally shown as an average of 26 samples. The results may not be wholly applicable to other geographical locations because of different climatic patterns. similar climate. The forage model could actually be used with weather data from other locations. In this sense, the model still has largely unexplored capabilities to analyze forage systems under a wide variety of climates.

9.1 Crop management decisions

Two major crop management decisions are considered in the following discussion: the alfalfa maturity stage at which mowing should start and the value of a fourth alfalfa cut in late fall.

9.1.1 Maturity at the time of mowing

The alfalfa growth model does not directly predict maturity, but does predict the crude protein of the whole plant. Crude protein is set at a maximum value of 0.231 as long as the ratio of leaves to stems is greater than one (in the early vegetative stage). As the plant matures, the ratio of leaves to stems decreases and so does the crude protein concentration.

The dates on which alfalfa mowing may start are defined in the array BGNCUT(NTHCUT). The number of cuts per year is usually set at 3 or 4; NTHCUT identifies the specific cut (1 to 4). Subroutine ALHARV can interpret BGNCUT (NTHCUT) as the first day to check for alfalfa maturity rather than the first mowing day. Crude protein is used as a measure of plant maturity. When a "mowing crude protein criterion" (appendix C) is specified in the range 0.15 to 0.23, it is compared daily with the standing crop crude protein. If the plant's crude protein is greater than the criterion, the plant is considered immature and mowing is postponed. To prevent overlap with the subsequent mowing dates, postponement is limited to 10 days. Ten days after BGNCUT(NTHCUT), mowing is forced to start even if the crude protein is above the criterion level.

Table 9.1 shows the date ranges within which mowing will start for the harvest of alfalfa at three maturity levels. The three maturity levels are identified by the crude protein concentration below which mowing may start: 0.230, 0.200 and 0.170.

Table 9.1. Date ranges of the first mowing day for harvesting alfalfa at three maturity levels under a three cut system. Dates are shown in Julian days.

CP at	Harvest 1		Harvest 2		Harvest 3	
mowing	Earliest	Latest	Earliest	Latest	Earliest	Latest
.230	136	145	181	190	226	235
.200	146	155	201	210	256	265
.170	156	165	221	230	286	295

The date ranges were chosen after testing the growth model over 26 years of weather data and observing when each harvest would most likely reach the specified crude protein. Since growth usually starts on day 91 (April 1), the time intervals between cuts are seen to be about 45 days, 55 days and 65 days for each maturity level. The objective of such a comparison is to measure whether the additional growth and yield of more mature crops can compensate the quality loss.

Table 9.2 illustrates the wide year-to-year variation in the date at which alfalfa reaches the same maturity. For example, the first harvest of early maturity alfalfa (CP=0.23) began at the earliest date (May 16 or day 136) in six years, began at the latest date (May 25 or day 145) in eight years and started between these two dates in 12 years out of 26.

Table 9.2. Number of years out of 26 when mowing started at the limiting date.

CP at	Harvest 1		Harvest 2		Harvest 3	
mowing	Earliest	Latest	Earliest	Latest	Earliest	Latest
.230	6	8	4	10	1	16
.200	13	2	6	14	8	13
.170	9	5	4	18	4	15

Table 9.3 shows the potential alfalfa yield that was available on the earliest mowing date. Mowing could be postponed up to 10 days after this earliest date if alfalfa was still immature (i.e. the crude protein was still very high). In most cases mowing started later than the earliest date and the actual yield was higher than the potential yield in table 9.3. As expected, the later growth system (CP=0.170) had the greatest potential yield.

Table 9.3. Potential alfalfa yield (tDM/ha) and crude protein at the earliest mowing date.

CP at	Harvest 1		Harvest 2		Harvest 3		Total	
mowing	DM	CP	DM	CP	DM	CP	DM	CP
.230	3.42	.23	3.36	.23	2.56	.23	9.35	.23
.200	4.56	.21	4.25	.22	2.36	.21	11.17	.21
.170	5.52	.18	4.02	.21	2.27	.20	11.81	.19

Table 9.4 shows actual harvested alfalfa available as feed after accounting for harvest, storage and feeding losses. The total average crude protein decreases steadily as alfalfa is harvested at a more mature stage. Surprisingly the total harvested feed does not increase steadily with maturity. It is maximum for an intermediate maturity (CP=0.20). Although the more mature alfalfa had the greatest potential yield, it incurred greater harvest losses probably due to the fact that the last harvest was in late October, early November during more adverse weather conditions.

Table 9.4 Harvested alfalfa (tDM/ha) available as feed after accounting for harvest, storage and feeding losses.

CP at	Harvest 1		Harvest 2		Harvest 3		Total	
mowing	DM	CP	DM	CP	DM	CP	DM	CP
.230	3.43	.177	3.24	.186	2.00	.182	8.67	.180
.200	4.01	.157	3.39	.172	1.65	.152	9.05	.160
.170	4.68	.144	2.85	.159	1.25	.140	8.77	.146

Tables 9.5 and 9.6 show how the harvested alfalfa would be used by a herd of 128 lactating cows producing either 20 or 35 kg of milk per cow per day. The low milk producing herd consumed mostly alfalfa and little corn or soybean meal. Some extra alfalfa had to be bought for the low milking herd. The high milk producing herd required more energy in its ration and consumed a large quantity of corn and also some soybean meal. Consequently some alfalfa was left over and sold as excess forage. Tables 9.5 and 9.6 point out the higher energy need of high production cows compared with low production cows. In the present simulation, only alfalfa is farm grown and all the corn is purchased. With high milk production, it would probably be desirable to reduce the area grown as alfalfa and increase the area grown as corn.

Table 9.5. Feed utilization (tDM/yr) on an 80 ha farm with 128 low yield lactating cows (20 kg milk/cow/day) when alfalfa is harvested at three maturity levels.

CP at mowing	Alfalfa produced	Alfalfa sold	Soy meal purchased	Corn grain purchased
.230	693.79	-173.24	1.63	123.61
.200	723.87	-100.42	1.86	166.12
.170	701.81	-54.31	5.29	230.86

Table 9.6. Feed utilization (tDM/yr) on an 80 ha farm with 128 high yield lactating cows (35 kg milk/cow/day) when alfalfa is harvested at three maturity levels.

CP at mowing	Alfalfa produced	Alfalfa sold	Soy meal purchased	Corn grain purchased
.230	693.79	67.54	67.93	482.43
.200	723.87	171.28	94.65	527.36
.170	701.81	214.36	112.82	574.34

Table 9.7 shows the non feed costs, i.e. mainly the machinery, storage, labor and energy costs. The fuel, repair and maintenance (RM) and labor costs are proportional to the potential yield and increase with maturity. The storage cost is usually constant except when the hay storage structure is filled and emergency hay storage is required (assumed at $10. per ton DM per year). The greatest amount of feed was harvested under the intermediate maaturity (CP=0.200) and explains the higher storage cost.

Table 9.7. Comparing non-feed production costs ($/yr) for harvesting alfalfa at three maturity levels on an 80 ha alfalfa farm.

CP at mowing	Mach.	Storage	Fuel	RM	Labor	Fert.	Total
.230	26545.	11155.	2421.	4302.	5917.	15508.	65849.
.200	26545.	11399.	2549.	4500.	6154.	15508.	66655.
.170	26545.	11321.	2584.	4587.	6159.	15508.	66705.

Tables 9.8 and 9.9 illustrate the average net return from harvesting alfalfa at three maturity levels and at two milk production levels. With either low yield milking cows or high yield milking cows, the greatest return is obtained when alfalfa is harvested at the least mature stage (CP=0.230). The benefit of harvesting early is more noticeable with high yield milking cows that use more efficiently high quality feed.

Table 9.8. Economic comparison ($/yr) of alfalfa harvest at three maturity levels on an 80 ha farm with 128 lactating cows (20 kg milk/cow/day).

CP at mowing	Non-feed costs	Net feed costs	Milk returns	Net returns
.230	65849.	31966.	267238.	169423.
.200	66655.	31986.	267238.	168597.
.170	66705.	38220.	267238.	162313.

Table 9.9. Economic comparison ($/yr) of alfalfa harvest at three maturity levels on an 80 ha farm with 128 lactating cows (35 kg milk/cow/day).

CP at mowing	Non-feed costs	Net feed costs	Milk returns	Net returns
.230	65849.	78840.	467667.	322978.
.200	66655.	84974.	467667.	316038.
.170	66705.	93021.	467667.	307941.

The cumulative probability curves of net yearly return are plotted in figures 9.1 and 9.2 from the 26 samples of yearly simulation. For low yield cows the expected net return is largest when alfalfa is harvested early (CP=0.230). However, in a number of years, the greater

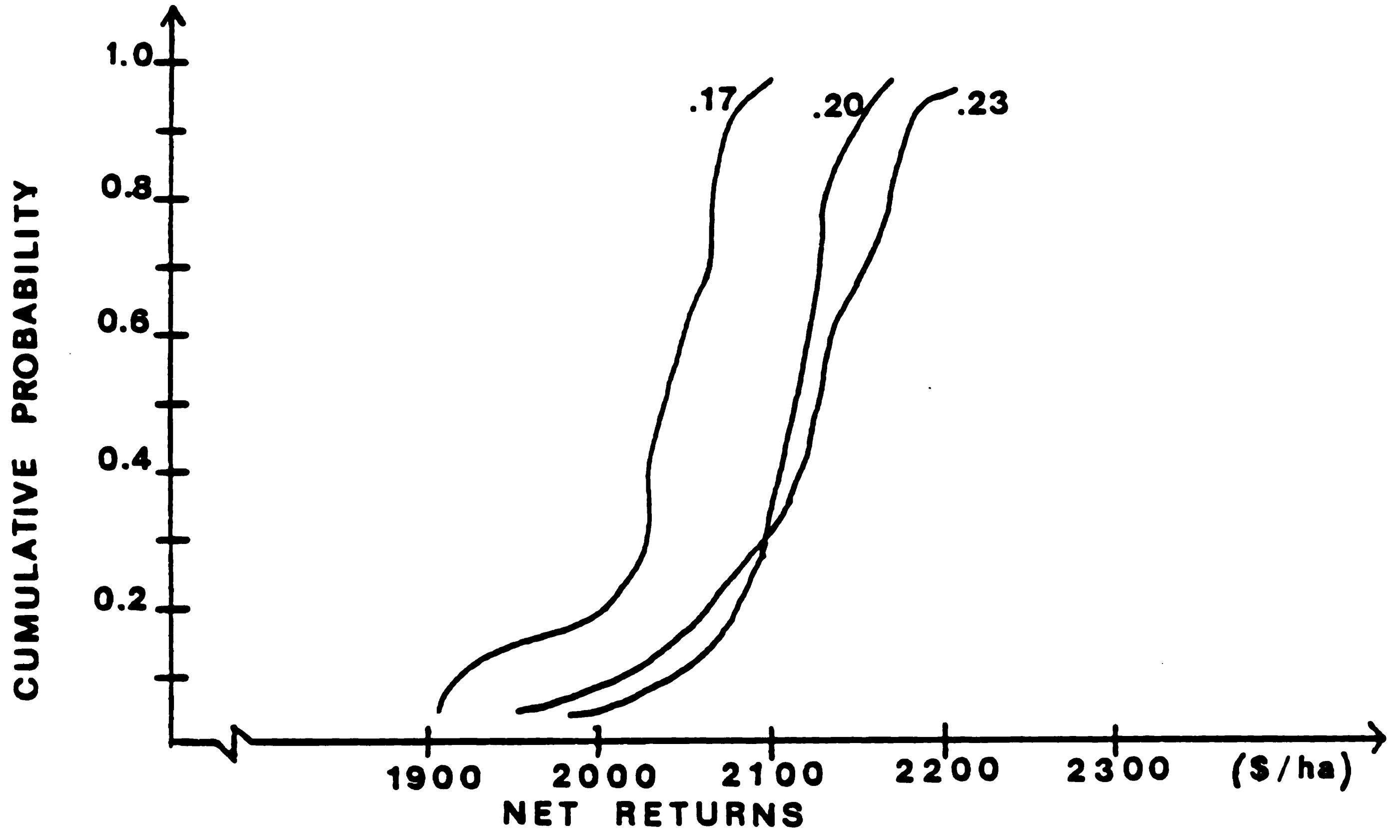

Figure 9.1. The cumulative probability of net return per ha for mowing at three maturity levels, identified by the alfalfa crude protein on the first mowing day, with low milk producing cows (20 kg/day/cow).

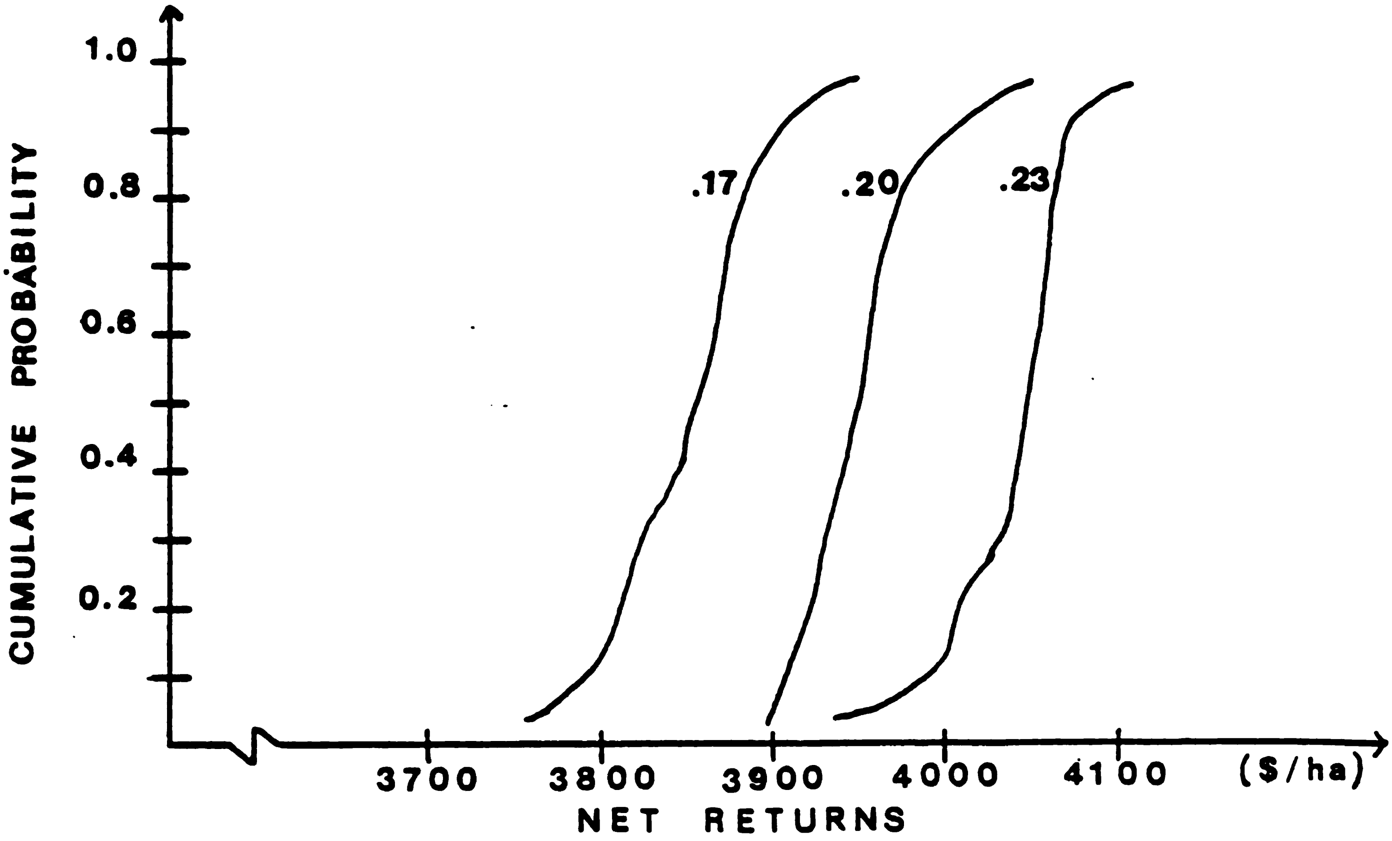

Figure 9.2. The cumulative probability of net return per ha for mowing at three maturity levels, identified by the alfalfa crude protein on the first mowing day, with high milk producing cows (35 kg/day/cow).

yield provided by harvesting later (CP=0.200) would compensate the quality loss. Indeed a profit may sometimes be made by substituting quantity for quality with a low yield milking herd that does not require a very high quality feed.

In the case of a high milk producing herd, the advantage of harvesting early is unambiguous (figure 9.2). In general alfalfa harvest should begin early, when the crude protein is between 20 and 23%, to provide the highest quality feed.

9.1.2 Three versus four alfalfa harvests

In the preceding section it was observed that alfalfa should be harvested as early as possible to get a high quality feed and a maximum net return to the farm. Under an early harvest system the third cut will start between Julian days 226 and 235 (August 14 and August 23). A fair amount of regrowth is usually expected between the end of the third cut and late October. A comparison was made between the 3-cut early harvest system (CP=0.230) described in the previous section and a 4-cut early harvest system. The fourth cut is scheduled to start between Julian days 286 and 295 (October 13 and October 22).

Table 9.10 shows the production (non-feed) costs to harvest 3 or 4 cuts of alfalfa per year. The extra fuel, repair and labor costs to harvest a fourth cut represent $2547. or $31.84 per ha. An additional storage cost of $1061. was also required since the storage structures were already filled after three cuts. The fourth cut was harvested as hay and stored at a temporary storage cost of $10. per tDM per year. In all it costs about $45./ha to harvest and store the fourth cut.

Table 9.10. Production costs ($/yr) of a 3-cut alfalfa system and of a 4-cut alfalfa system over 80 ha.

System	Mach.	Storage	Fuel	RM	Labor	Fert.	Total
3 cuts	26545.	11155.	2421.	4302.	5917.	15508.	65840.
4 cuts	26545.	12216.	2998.	5201.	6988.	15508.	69456.

The average feed available from a 3-cut early harvest system is 8.67 tDM/ha with a crude protein of 0.180. The average feed available from a fourth cut harvested as hay after October 13 is 1.32 tDM/ha with a crude protein of 0.141. Hence the yearly total harvested feed under the 4-cut system is 9.99 tDM/ha with an average crude protein of 0.175.

Table 9.11 compares the net returns of a 3-cut and a 4-cut system at four milk production levels. In all cases the 4-cut system yields a larger net return. The difference is greatest for low milk producing levels since the fourth alfalfa cut will actually be used in the ration and reduce the purchase of alfalfa hay at $83. per tDM. In the case of a high milk production level the extra alfalfa harvested will not be fed to the herd due to its low quality (CP=0.141) but it will be sold as excess forages at $69. per tDM. In both cases the expected harvested feed (1.32 tDM/ha) and the reduced expense or the increased income cover the additional production cost ($45./ha).

Table 9.11. Economic comparison ($/yr) of a 3-cut and of a 4-cut alfalfa system over 80 ha at four milk production levels.

Milk level kg/day	Number of cuts	Non-feed costs	Net feed costs	Milk returns	Net returns	Diff.
20.	3	65849.	31965.	267238.	169424.	6894.
	4	69456.	21464.	267238.	176318.	
25.	3	65849.	43795.	334048.	224404.	6615.
	4	69456.	33573.	334048.	231019.	
30.	3	65849.	59046.	400858.	275963.	5623.
	4	69456.	49816.	400858.	281586.	
35.	3	65849.	78840.	467667.	322978.	4745.
	4	69456.	70488.	467667.	327723.	

Figures 9.3 and 9.4 illustrate how the net return from a 4-cut system is generally superior, or said to be stochasticly dominant, over a 3-cut system with either a low milk producing or high milk producing herd.

By comparing the net return on a year by year basis for 26 years, there were actually 2 or 3 years when the 3-cut system would have been more profitable. Table 9.12

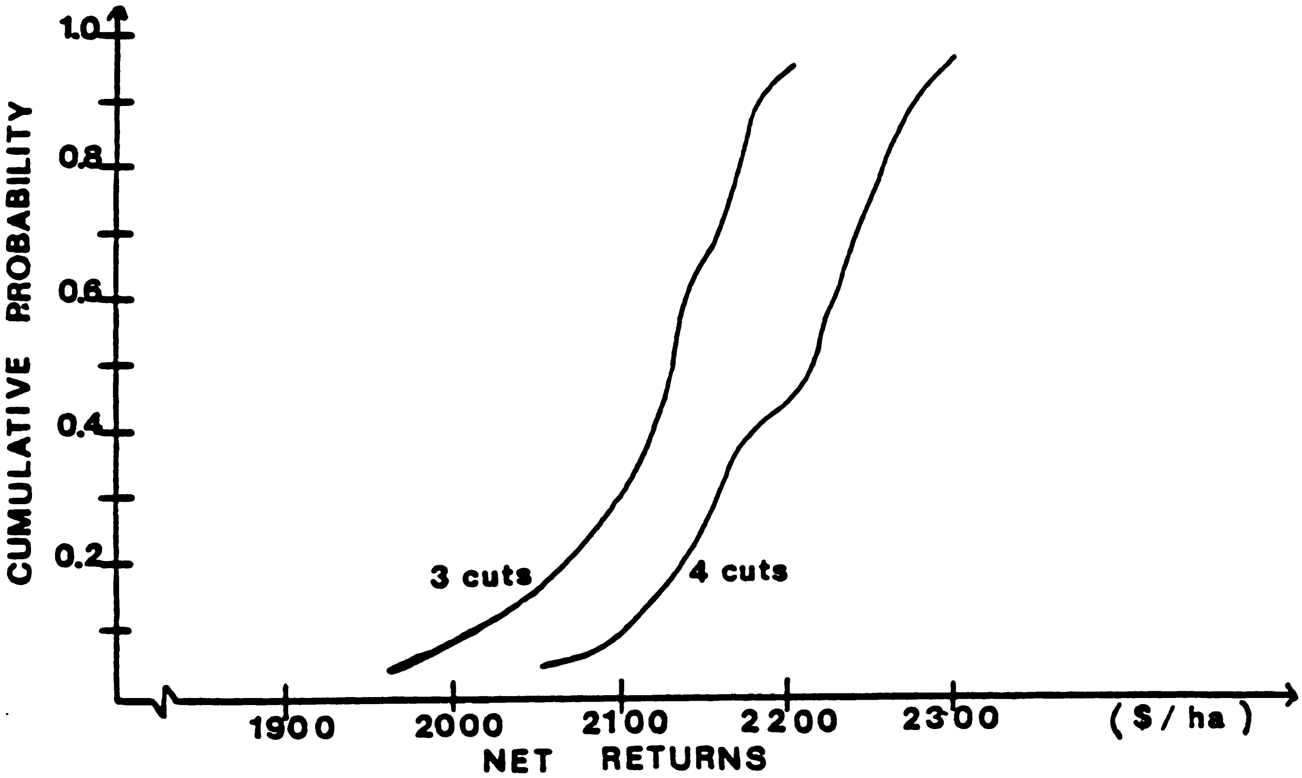

Figure 9.3. The cumulative probability of net return per ha for a 3-cut and for a 4-cut alfalfa harvest systems with low milk producing cows (20 kg/day/cow).

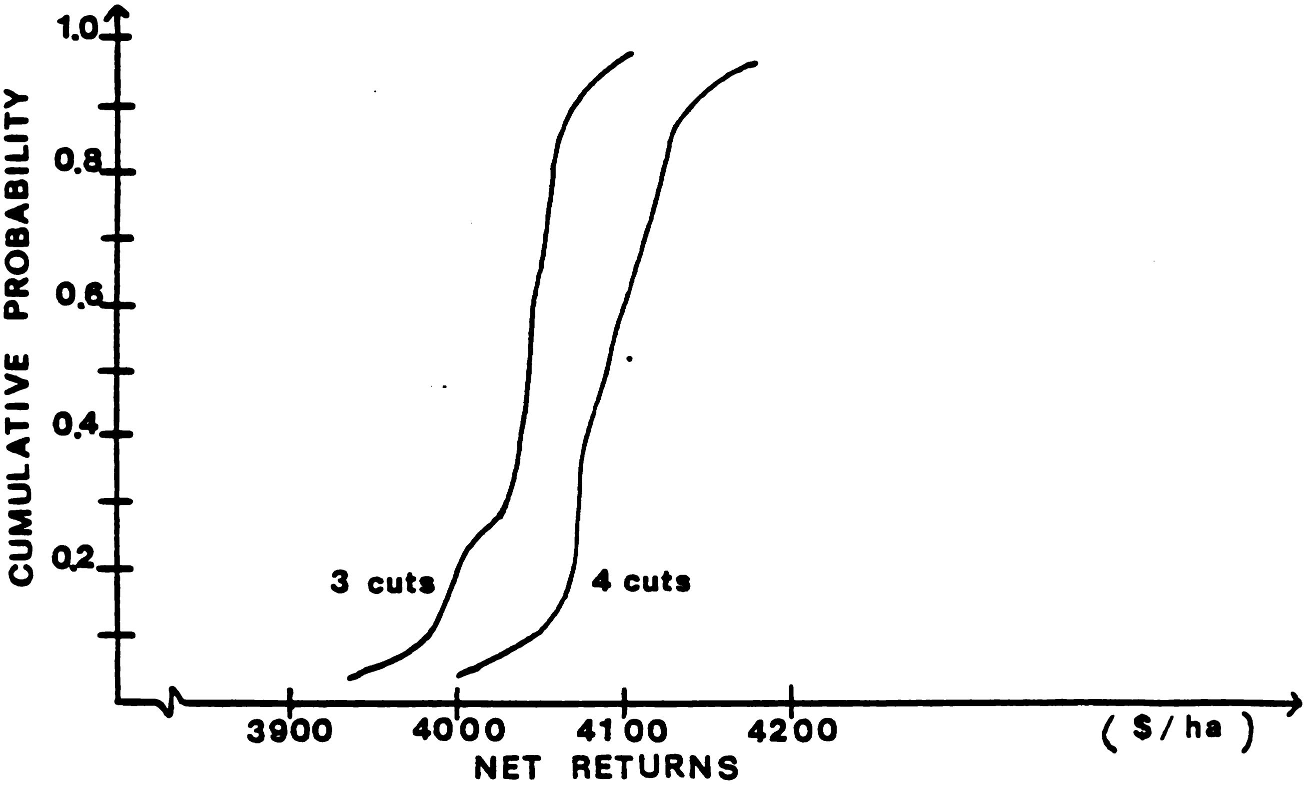

Figure 9.4. The cumulative probability of net return per ha for a 3-cut and for a 4-cut alfalfa harvest systems with high milk producing cows (35 kg/day/cow).

shows the yields in three years when the fourth cut was not profitable. Figures 9.5 and 9.6 illustrate the cumulative probability of the difference of net returns between a 4-cut and a 3-cut system. In one year out of ten, the 3-cut system would appear more profitable. But the level of increased profits in the other nine years out of ten amply justify the 4-cut system.

Table 9.12. Potential yield and actual harvest of the fourth alfalfa cut in specific years when the fourth cut was not profitable.

Year	Potential yield (tDM/ha)	Harvested feed (tDM/ha)	Net return ($/ha)
1957	2.92	0.50	2.21
1962	1.62	0.15	-3.45
1976	2.12	0.00	-20.14

A farmer may wish to avoid these losses by defining a minimum yield below which he will not harvest the fourth cut. Since the harvest and storage costs were estimated at $45./ha, the farmer would on the average hope to harvest at least 0.65 tDM/ha valued at $69./tDM. The average potential yield of the fourth cut for a 26-year period was 2.44 tDM/ha. Since the average harvested alfalfa available as feed was 1.32 tDM/ha, the average dry matter loss was 46%. On the basis of average values, a farmer should not harvest a fourth cut unless the potential yield is at least 1.21 tDM/ha. In fact the potential yield was always greater than this minimum value throughout 26 years of

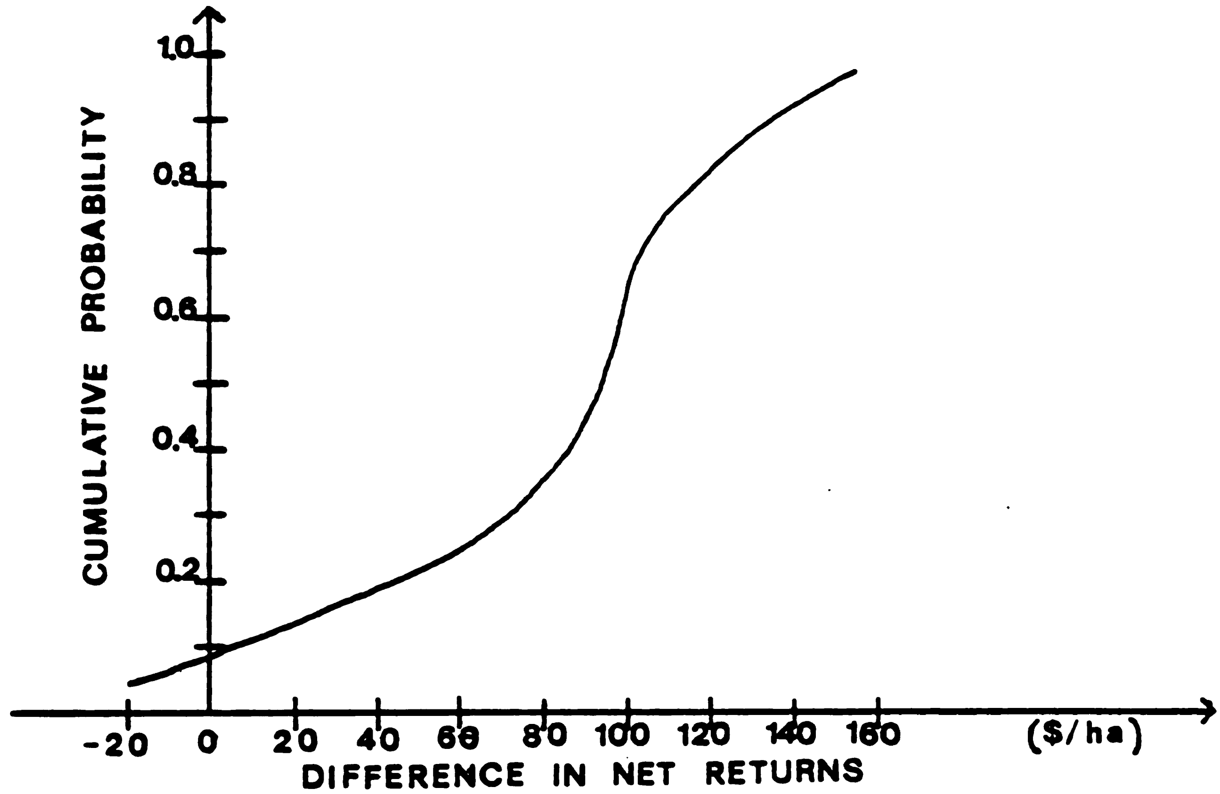

Figure 9.5. The cumulative probability of the difference in net returns in favor of a 4-cut system versus a 3-cut system with low yield cows (20 kg/day/cow).

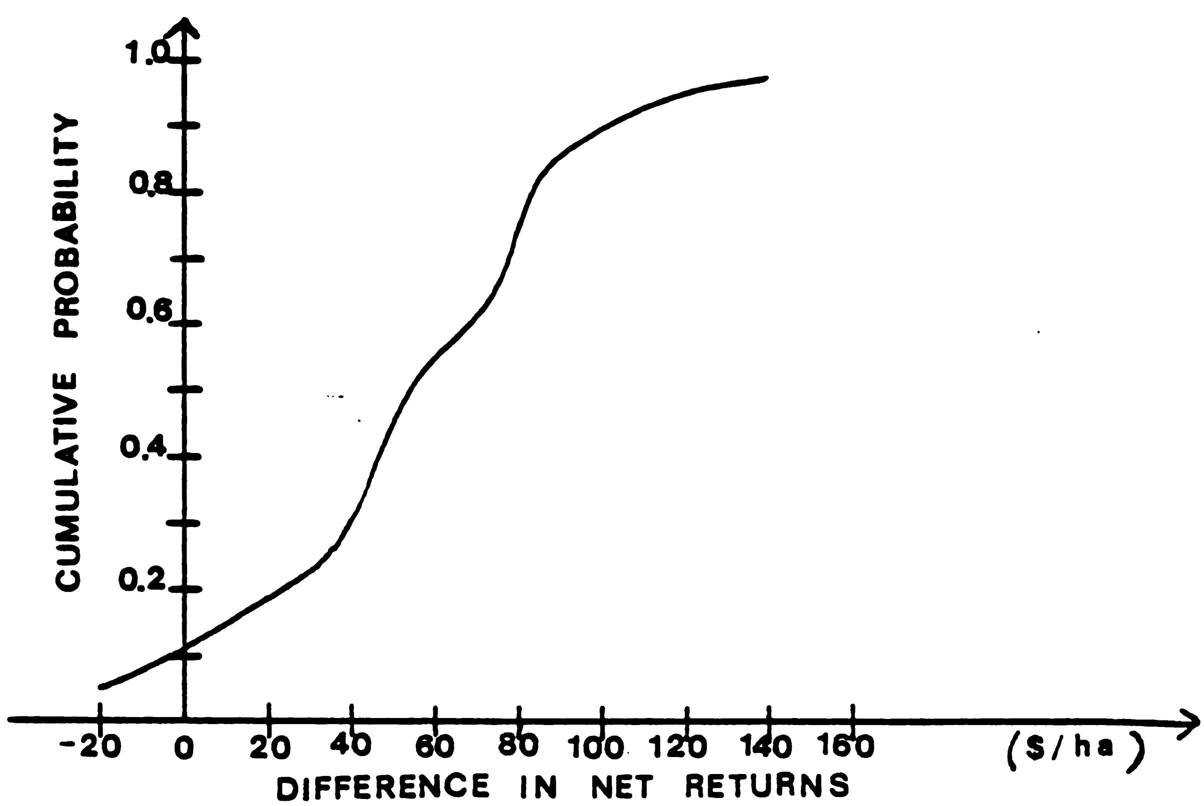

Figure 9.6. The cumulative probability of the difference in net returns in favor of a 4-cut system versus a 3-cut system with high yield cows (35 kg/day/cow).

simulation. The two or three years out of 26 when a fourth cut was unprofitable were not due to low yield but rather to exceptionally bad weather conditions during harvest.

In the simulation example, the fourth alfalfa cut was harvested as hay and additional temporary storage had to be provided. If unused fixed storage space is available at the time of the fourth cutting, then no additional storage cost would be incurred. Moreover, if the fourth cut can be harvested as haylage instead of hay, less losses are likely to occur. If other crops must also be harvested in the fall, the profitability of the fourth alfalfa cut may become questionable because of possible time conflicts. A fourth alfalfa cutting is generally profitable although there is about a 10% chance of a negative return in exceptionally bad years as long as there is no time conflict with the harvest of other crops.

9.2 The rate of harvest and forage value

The value of a crop is often affected by the harvest rate. In the case of cash crops such as grains, an extended harvest period usually increases dry matter losses and reduces the overall quality. The decrease in the crop value is called timeliness cost.

Alfalfa does not fit well into this simple definition of timeliness cost. Indeed the total alfalfa yield increases almost continuously so that a slower harvest rate will actually produce a greater yield. However quality will decrease. There may sometimes be a tradeoff between quality and quantity as was shown in section 9.1.1. Alfalfa is also different from other crops because of its regrowth mechanisms within the same year. The rate of harvest will affect the yield and quality of subsequent harvests.

A fixed machinery set (medium size chopper and round baler, about 75% haylage and 25% hay) was analyzed over a range of areas. If a timeliness cost is associated with alfalfa harvest, it should appear in the form of higher feed costs per cow or per unit area as more time is used to complete the harvest. The size of the storage structures and the number of cows are scaled to the area. Fixed storage capacity is set as 7.5 tDM/ha for silos and as 2.5 tDM/ha for a hay barn. Extra storage is available for hay at a marginal cost of $10. per tDM per year. The ratio between cows and area is set as 1.6 lactating cows per hectare.

Table 9.13 shows the potential yield at the earliest mowing dates and the actual harvested feed. All the beginning harvest dates were the same for all areas. The potential yield is greatest for low areas because the crop was harvested quickly and more time was available for regrowth. The actual harvest is also greatest for small areas. The differences in actual harvest are smaller than the differences in potential yield. Indeed over large areas the alfalfa continued to grow for a longer time because the harvest was extended over a longer period.

Table 9.13. Potential alfalfa yield and actual harvest (tDM/ha) from a 4-cut system using the same machinery complement (chopper-round baler) over a wide range of areas.

Area (ha)	Potential yield	Potential CP	Actual harvest	Actual CP
20	13.76	.21	10.25	.181
40	13.04	.21	10.15	.178
60	12.42	.22	10.04	.177
80	11.79	.22	10.00	.175
100	11.19	.22	9.95	.174
120	10.59	.22	9.93	.172

Table 9.14 shows in greater detail how the yearly yield was distributed into four harvests. Clearly in the first harvest, a longer harvest period results in higher yields and lower quality. In the second harvest, dry matter and qualtiy are practically the same over all areas. The regrowth has adjusted to the slower harvest rates and adapted itself to a longer harvest period. In the third cut, a longer regrowth period produced slightly higher yields for smaller areas. The fourth cut illustrates two trends opposite to those in the first cut: as the area

harvested as alfalfa increases, the fourth cut yield decreases and the qualtity increases. This is due to the shorter regrowth period. Actually the date of harvest for the fourth cut was probably not optimal. The fourth harvest could have started earlier to get a higher quality at the cost of a lesser yield.

Table 9.14. Actual harvested feed (tDM/ha) during each of the four alfalfa cuts.

Area	Harvest 1		Harvest 2		Harvest 3		Harvest 4	
(ha)	DM	CP	DM	CP	DM	CP	DM	CP
20	2.91	.199	3.12	.191	2.42	.189	1.79	.127
40	3.13	.190	3.17	.189	2.20	.185	1.65	.134
60	3.29	.183	3.23	.189	2.08	.183	1.43	.141
80	3.43	.177	3.24	.186	2.00	.182	1.32	.141
100	3.56	.172	3.24	.185	1.89	.183	1.25	.140
120	3.69	.167	3.18	.186	1.82	.183	1.24	.148

Tables 9.15 and 9.16 show how the feed costs and net returns vary as a fixed machinery set is used over a larger area. In all cases the decrease in the fixed machinery costs overshadows the increase in the feed costs. For areas above 140 or 150 ha, the system becomes infeasible as the harvest period in some years extends beyond the earliest mowing dates of subsequent harvests. Production costs decrease slightly with area because these costs are proportional to yield. As the machinery set is used over a larger area, more calendar days are required to complete the harvest and less time is available for regrowth. Hence the potential yield is lower and the variable costs related

to harvest (labor, energy, repairs) are also lower.

Table 9.15. Costs and net returns ($/ha) of a haylage machinery system used over a wide range of areas with a low yield dairy herd (20 kg milk/cow/day).

Area (ha)	Mach. costs	Other prod. costs	Feed costs	Milk returns	Net returns
20	1327.	545.	249.	3340.	1219.
40	664.	544.	252.	3340.	1881.
60	442.	539.	261.	3340.	2098.
80	332.	536.	268.	3340.	2204.
100	265.	534.	277.	3340.	2264.
120	221.	532.	282.	3340.	2305.

Table 9.16. Costs and net returns ($/ha) of a haylage machinery system used over a wide range of areas with a high yield dairy herd (35 kg milk/cow/day).

Area (ha)	Mach. costs	Other prod. costs	Feed costs	Milk returns	Net returns
20	1327.	545.	838.	5846.	3136.
40	664.	544.	859.	5846.	3780.
60	442.	539.	870.	5846.	3994.
80	332.	536.	881.	5846.	4097.
100	265.	534.	891.	5846.	4156.
120	221.	532.	898.	5846.	4195.

Table 9.17 shows the average number of calendar days required to complete each harvest. The feed costs were seen to increase from $249./ha to $298./ha for low milk yield between a 20 ha farm and a 120 ha farm. The average yearly number of harvest days required for each farm is 17 and 81 respectively. The timeliness loss would be about $0.50/ha/day. Since the average yield is 10 tDM/ha and the value of alfalfa feed can be approximated by $80./tDM, the

timeliness coefficient would be about 0.0006/day for low milk production. In the case of high yield cows, the increase of feed cost was about twice as much as for low yield cows. The timeliness coefficient would be 0.0012/day for high milk production.

Table 9.17. The average number of calendar days required to harvest each alfalfa cut with a constant size machinery system.

Area	Cut 1	Cut 2	Cut 3	Cut 4	Total
20	3.35	3.50	3.73	6.54	17.12
40	8.00	7.23	6.65	8.92	30.80
60	11.42	11.00	9.08	11.54	43.04
80	15.19	14.35	11.46	14.35	55.35
100	18.96	18.38	13.62	17.31	68.27
120	23.65	21.50	15.65	20.69	81.49

A similar analysis was done with a 100% hay system. The average harvest rate of the hay system was slightly (less than 10%) larger than the haylage system described previously. The medium size conventional baler was simulated over the same area range. From the data in table 9.18, the timeliness coefficients would be about 0.0012/day for low milk yield and 0.0024/day for high milk yield. These timeliness coefficients are relatively low. ASAE (1981) suggests 0.0180 for haymaking in Michigan in June in data D230.3. The estimated timeliness coefficients would indicate that a low harvest rate does not really affect the overall value of an alfalfa crop especially when four cuts are made yearly. A slow harvest rate will produce a low quality first cut but the subsequent cuts will be of higher because the regrowth will have adjusted to the harvest rate.

Table 9.18. Feed costs ($/ha) for low and high milk producing cows with a 4-cut completely hay fixed machinery system over a wide range of areas.

Area (ha)	Feed costs (20 kg/cow)	Feed costs (35 kg/cow)	Total calendar days to harvest
20	285.	806.	24.57
40	295.	844.	33.95
60	296.	861.	45.28
80	330.	885.	55.92
100	330.	904.	68.58
120	339.	920.	81.66

From a practical point of view, the farmer should not worry about taking three or four weeks to harvest the first cut. The subsequent cuts will compensate for the lower quality first cut. Reducing the harvest period to one or two weeks is not worthwhile since this will increase the machinery cost more than it will reduce the feed costs. If the number of cuts per year is reduced from four to three or even two, then the timeliness cost would become more important and so would the machinery size. The effect of rate of fill on haylage quality in not presently considered. If slow filling rates cause considerable oxidation, then the timeliness cost for haylage systems would be greater than the one predicted.

9.3 Field-curing delay

The previous two sections have shown that the time at which harvest of alfalfa begins is more important than the rate at which it proceeds. Another important parameter in forage systems is the field-curing delay. Quality and value of a forage crop will generally decrease with a longer exposure time.

The forage harvest technologies presently available provide a number of alternatives to decrease the field curing delay:

1. Increasing the drying rate by additional treatments at mowing or during curing;
2. Baling hay at a higher moisture content and treating the hay against spoilage;
3. Shifting from hay to haylage;
4. Shifting to direct-cut alfalfa harvest and conservation.

Hay usually cannot be baled before its moisture content is below 20% (wet basis). The treatment of wet hay could allow harvest at 30% moisture. A haylage system can provide good conservation of alfalfa with moisture as high as 60%. A direct-cut system would require no field curing at all but the technology is not yet feasible because of important seepage losses in storage.

This section will consider the relative advantages and disadvantages of the four technologies outlined above.

9.3.1 Increasing the drying rate

New treatments are being proposed to increase the drying rate of forages to decrease the total field curing time. Section 6.5 dealt with some of these treatments (spraying a chemical solution and maceration) and their impact on the drying rate.

There are tradeoffs associated with these additional treatments. The reduced field exposure time must be weighed against either higher leaf loss or higher production cost or both. More information is required (especially with regards to leaf loss and production costs) to completely assess some of these new technologies. The impact of an increased drying rate can nonetheless be assessed without all the other technological data.

A 100% hay system was simulated under three conditions: with a regular mower-conditioner (control), with an additional treatment that would increase the drying constant by an average of 0.02 similar to the spraying of a chemical solution and with another type of treatment that would increase the constant by 0.05 similar to maceration. (Section 6.5 gives a justification for these numerical values.) No consideration is given to extra dry matter losses or to extra production costs.

Table 9.19 shows the actual harvest and the average number of days hay was exposed under the three curing conditions: a control (mower-conditioner), spraying a chemical solution and maceration. As the drying rate is increased, the total dry matter harvested and the quality both increase. The results show a reduction of the average exposure time by as much as 1.5 days.

Table 9.19. Actual harvested yield (tDM/ha) and average field-curing time using extra treatments to increase the drying rate of baled hay.

Extra treatment	Assumed value of b9*XTR (eq. 6.3)	Harvest DM	Harvest CP	Average exposure days High qual.	Average exposure days Low qual.
Control	0.00	9.27	.167	4.15	6.63
Chemical	0.02	9.72	.169	3.82	5.87
Maceration*	0.05	10.10	.171	3.42	5.19

(*) The extra dry matter losses for maceration are not accounted.

The increased quality of the alfalfa is translated into feed cost savings in table 9.20. The feed cost savings are about $40./ha/yr with an increased drying coefficient of 0.02 and $80./ha/yr with an increased drying coefficient of 0.05. The treatment is assumed to be applied over 80 ha for all four cuts.

Table 9.20. The annual feed cost ($/ha) as influenced by faster drying treatments for an 80 ha alfalfa farm with 128 lactating cows at four milk production levels.

Extra treatment	20 kg/day	25 kg/day	30 kg/day	35 kg/day
Control	330.	469.	663.	885.
Chemical	284.	422.	622.	845.
Maceration	246.	381.	577.	797.

The cost of spraying a chemical solution on alfalfa would have to be less than $10. per ha per cut or $4. per ton DM to be profitable. This is unlikely given the types of chemical solutions and their concentrations suggested by Wieghart et al. (1980). Indeed the most promising chemical solution represented an application cost of about $4.50 per ton DM. When the extra labor and equipment costs are added, the cost of spraying a chemical solution would vary between $5. and $10. per ton DM depending on farm size.

A new mechanical hay conditioner such as the macerator suggested by Krutz et al. (1979) appears more promising. It does not have the high variable costs associated with chemical application. If it could actually save $80./ha/yr, a farmer with 80 ha of alfalfa could certainly afford to pay even double the price of an actual mower-conditioner. However the analysis does not include any estimate of extra dry matter losses or of extra fuel requirement of such a machine. A complete analysis should include these technical considerations.

9.3.2 Baling at a higher moisture content

The total exposure time of alfalfa during field curing can be reduced either by increasing the drying rate or by harvesting at a higher moisture content. Haylage is one way to harvest at a higher moisture content and is considered in section 9.3.3. Baled hay can be harvested at a higher than normal moisture content, provided some treatment is applied to prevent spoilage.

In the 1950's and 1960's, barn drying of wet hay was a common practice but energy and labor requirements have outdated such a process. More recently the application of proprionic acid has been suggested to conserve hay baled at a high moisture content (Nehrir et al., 1978).

Three simulations were done to compare the effect of being able to harvest hay at a higher moisture content. Table 9.21 shows how a greater amount of yield and quality would be retained if hay could be harvested and stored safely at a higher moisture content. The number of days required for field curing may be reduced by between one half and two full days.

Table 9.21. Actual harvested feed (tDM/ha) and average field-curing time when hay may be baled at a higher moisture content.

Moisture content at baling		Harvested feed		Average exposure days	
Wet basis	Dry basis	DM	CP	High qual.	Low qual.
20%	.25	9.27	.167	4.15	6.63
30%	.43	10.16	.173	3.50	5.27
40%	.67	10.69	.176	2.97	4.37

The improved quality and quantity represent substantial feed cost savings (table 9.22). About $100./ha/yr may be saved by baling hay at 30% moisture on a wet basis instead of 20%. For such a system to be profitable, the preservative should cost less than $10. per ton of alfalfa DM preserved.

Table 9.22. The annual feed cost ($/ha) when hay may be baled at a higher moisture content for an 80 ha farm with 128 lactating cows at four milk production levels.

Moisture at baling (w.b.)	20 kg/day	25 kg/day	30 kg/day	35 kg/day
20%	330.	469.	663.	885.
30%	238.	368.	560.	778.
40%	187.	312.	497.	713.

9.3.3 Haylage versus hay

Alfalfa haylage can be harvested and stored safely with a moisture content between 50% and 60% (wet basis) whereas hay must be dried down to 20% moisture content. Consequently haylage will be subject to weather risk a shorter time than hay. Haylage technology however is more capital intensive than hay technology for both machinery and storage facilities.

A 100% hay system is compared to a 100% haylage system with four alfalfa cuts per year under mid-Michigan climate. The hay machinery system consists of three tractors (60 kW, 40 kW and 20 kW), a large baler (maximum throughput of 14 tDM/h), three bale wagons, a bale elevator, a 2.7 m mower-conditioner, a rake and three men working full-time during hay harvest. Mowing, raking and baling operations are those defined in the example in appendix B (operations 22, 40 and 170).

The haylage machinery system uses three tractors (80 kW, 60 kW and 40 kW), a medium size forage chopper (maximum throughput of 11 tDM/h), two forage wagons, a forage blower, a 2.7 m mower-conditioner and two men working full-time during haylage harvest. Mowing and chopping operations are identical to operations 22 and 150 in the example in appendix B. Since there is no raking in the haylage operation, the mower leaves the alfalfa in a narrow windrow 1.35 m wide compared with a wider windrow of 2.16 m for hay making.

Table 9.23 shows that the haylage was on the average exposed between 2.4 and 3.2 days for the first and second silos while hay was exposed on the average 4.2 days for high quality hay (CP > 0.17) and 6.6 days for low quality hay (CP < 0.17).

Table 9.23. Average number of field-curing days of alfalfa before going into storage (80 ha farm).

	Silo 1		Silo 2		High quality hay		Low quality hay	
System	Days	CP	Days	CP	Days	CP	Days	CP
Hay	NA	NA	NA	NA	4.15	.189	6.63	.148
Haylage	2.44	.195	3.24	.169	NA	NA	NA	NA

Table 9.24 shows the actual feed available after accounting for harvest, storage and feeding losses and its quality for the hay and haylage systems over a range of areas.

Table 9.24. Alfalfa available as feed (tDM/ha/yr) from fixed machinery systems for hay and haylage harvest over a range of areas.

Area (ha)	Hay		Haylage	
	Harvested feed	CP	Harvested feed	CP
20	9.83	.172	11.13	.186
40	9.68	.169	11.17	.183
60	9.61	.167	11.15	.182
80	9.27	.167	11.05	.180
100	9.27	.165	11.08	.179
120	9.21	.163	11.04	.177

For both systems, the storage and the herd size were scaled to area. The storage capacity was set at 12.5 tDM/ha for hay and 15 tDM/ha for haylage. These capacities are larger than the average harvested feed because storage and feeding losses must be accounted and some extra storage space should be provided for exceptional years. The actual size of storage structures is two thirds of the annual storage capacity requirements since harvest extends between late May and late October and the same storage space can be used twice during at least four months per year. Table 9.25 shows the storage capacities required and the storage investment cost for both systems under a range of areas.

Table 9.25. Storage capacity (tDM) and investment cost ($) for a hay system (one hay barn) and for a haylage system (two equal size silos).

Area (ha)	Hay			Haylage		
	Annual cap. (tDM)	Storage cap. (tDM)	Cost of barn ($)	Annual cap. (tDM)	Storage cap. (tDM)	Cost of silos ($)
20	250.	167.	6500.	300.	200.	34700.
40	500.	333.	9900.	600.	400.	58000.
60	750.	500.	13200.	900.	600.	74000.
80	1000.	667.	16500.	1200.	800.	84000.
100	1250.	833.	19900.	1500.	1000.	94000.
120	1500.	1000.	23200.	1800.	1200.	104000.

The hay and haylage systems can be compared on the basis of resource requirements. The hay system requires much less capital investment but usually requires more labor (table 9.26). The hay system also requires less fuel than the haylage system.

Table 9.26. The resources required to operate three harvest systems for an 80 ha alfalfa farm.

System	Machinery investment	Storage investment	Fuel (L/yr)	Labor (man.h/yr)
Hay	$79800.	$16500.	5339.	1831.
Haylage	$110100.	$84000.	9387.	1553.
Direct-cut*	$103900.	$102000.	10415.	1223.

(*) Equipment and energy necessary for dewatering direct-cut alfalfa are not included.

The main advantages of the haylage system over a hay system are a lesser labor requirement, a higher harvested yield and a higher quality (which may however be offset by a lower animal intake). Two disadvantages with the haylage system are the high investment costs and the relatively higher fuel consumption.

Figures 9.7 and 9.8 show the expected net costs of haylage and hay systems versus area. The costs include the storage and machinery annualized fixed costs, the cost of labor and energy and repair and maintenance for harvest and feeding, the cost of fertilizers for maintaining alfalfa yields and the net cost of feeds for the specified milk production and herd size. Herd size is set at 1.6 lactating cows per hectare of alfalfa.

When comparing systems of largely different investment levels, the discount rate used in the analysis becomes very important. The fixed costs of both systems are estimated using a real discount rate of 4% (i=0.04). This is more appropriate than the use of nominal rates because real rates provide an adjustment for inflation. A 10-year accounting life is used for machinery, with a 10% salvage value; a 20-year accounting life is used for storage structures with no salvage value.

The upper and lower bounds in figures 9.7 and 9.8 are obtained from the lowest and highest costs in a 26-year simulation. The hay system has wider bounds and more variable costs than the haylage system. In this sense, the hay system is generally riskier than the haylage system.

The curves in figures 9.7 and 9.8 are superimposed in figure 9.9 to compare the expected cost of each system. The haylage system is generally more expensive than the hay

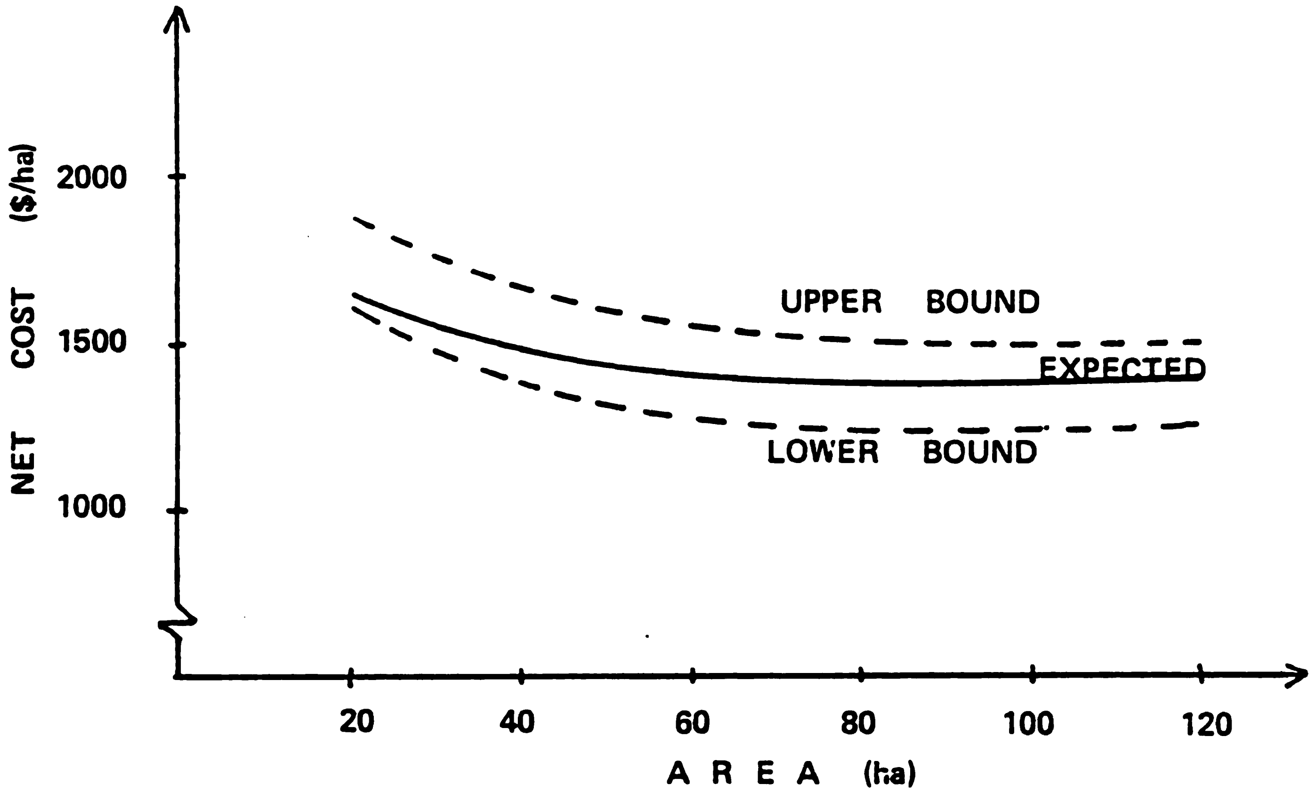

Figure 9.7. Net cost of a hay system versus area for high milk production (35 kg/day/cow) and real interest rates (i=0.04).

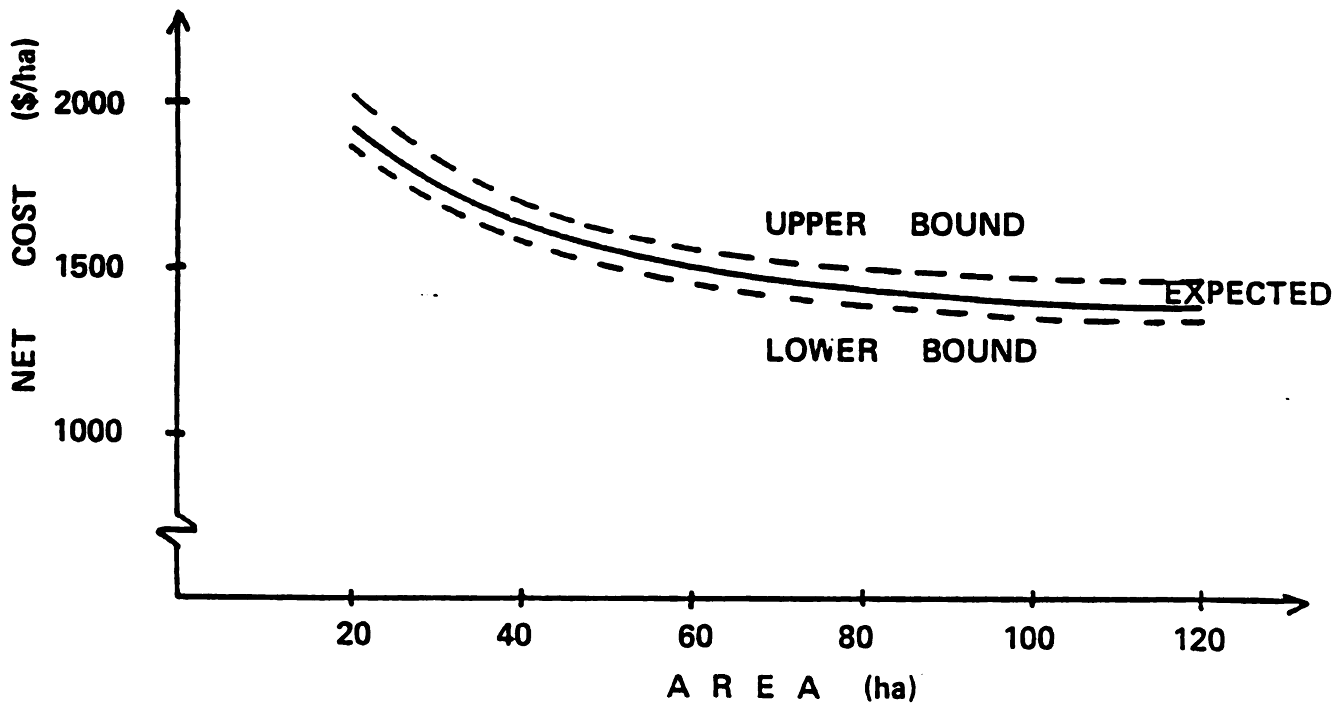

Figure 9.8. Net cost of a haylage system versus area for high milk production (35 kg/day/cow) and real interest rates (i=0.04).

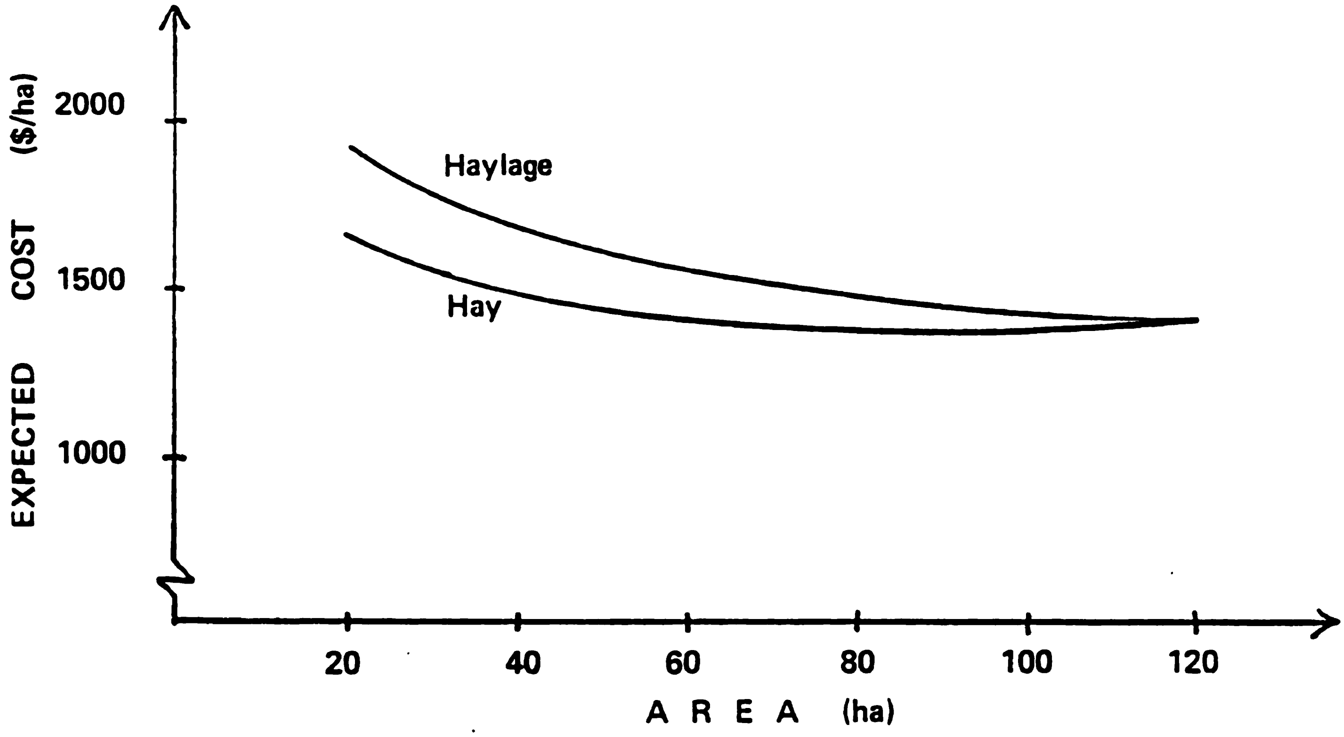

Figure 9.9. Expected cost of a haylage system and a hay system versus area for high milk production (35 kg/day/cow) and real interest rates (i=0.04).

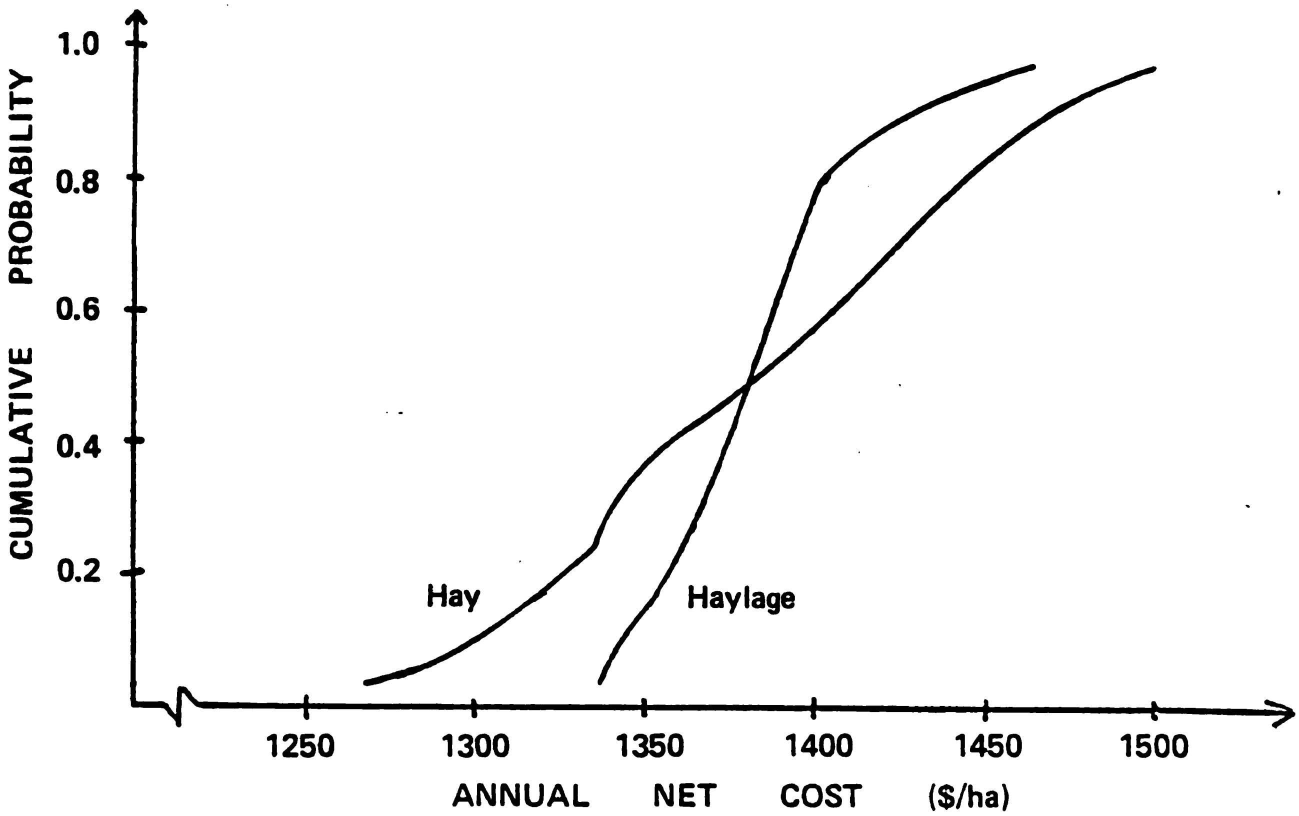

Figure 9.10. The cumulative probability of annual net cost of a hay system versus a haylage system under 120 ha of alfalfa with high milk production (35 kg/day/cow) and real interest rates (i=0.04).

system with a high yield milk producing herd (35 kg/day/cow). At 120 ha, both systems cost approximately the same. Figure 9.10 shows that the hay system is more variable than the haylage system at 120 ha. Since they both have the same expected return, a risk adverse farmer would choose the haylage system rather than the hay system at 120 ha. For smaller areas, the hay system is more profitable but more variable than the haylage system. Some farmers may be willing to forfeit some profit in order to reduce the year to year variation in cost and could then prefer the haylage system to the hay system.

Figure 9.11 compares the haylage system and the hay system with a low milk producing herd (20 kg/day/cow). The haylage system becomes less expensive than the hay system for areas above 60 ha. It becomes more profitable more quickly with a low milk producing herd than with a high milk producing herd because the advantage of haylage over hay is more quantitative than qualitative. Tables 9.27 and 9.28 show the alfalfa feed production and utilization with high yield and low yield dairy herds.

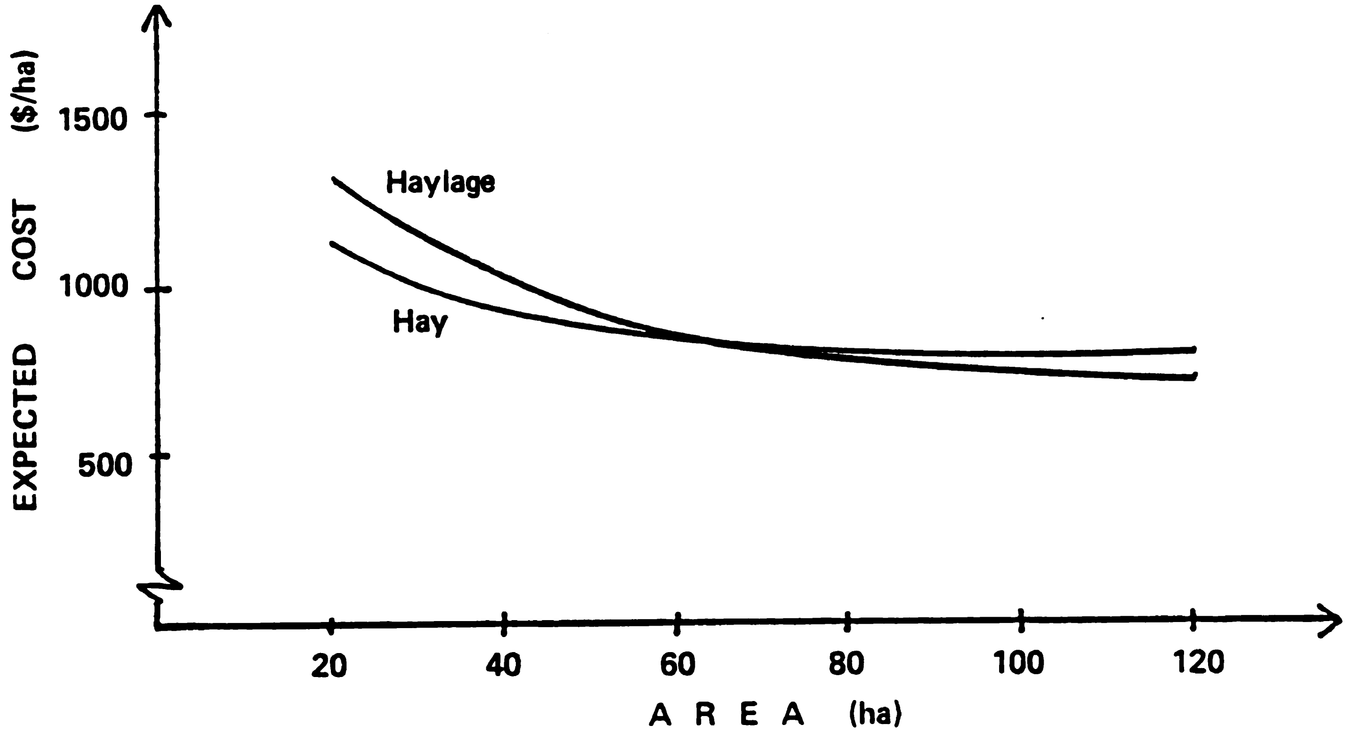

Figure 9.11. Expected costs of a haylage system and a hay system versus area for low milk production (20 kg/day/cow).

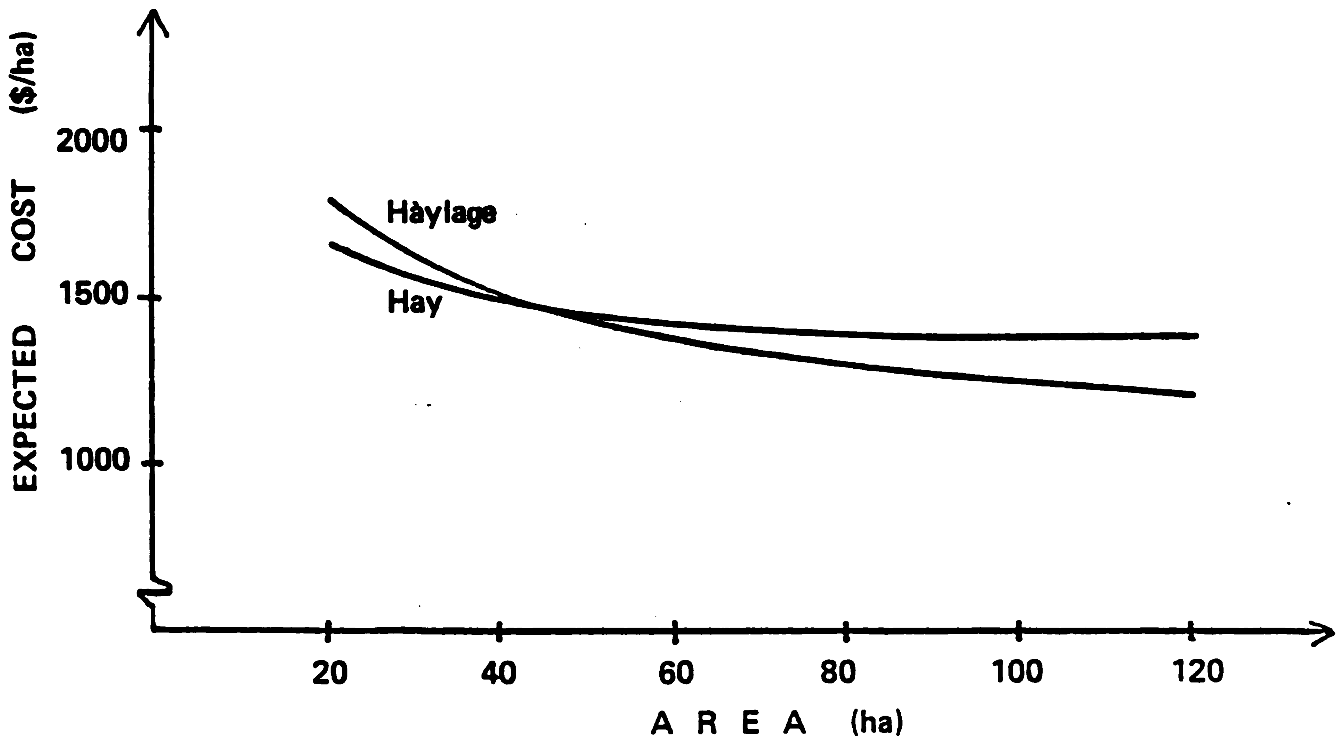

Figure 9.12. Expected costs of a haylage system and a hay system versus area assuming haylage dry matter intake is the same as hay intake (high milk production).

Table 9.27. Feed production and utilization (tDM) under four harvest and conservation systems on an 80 ha farm with 128 high milk producing lactating cows (35 kg/cow/day).

System	Alfalfa harvested DM	CP	Alfalfa sold	Soy meal purchased	Corn grain purchased
Hay	741.4	.167	56.0	59.8	429.5
Haylage	884.2	.180	263.1	63.1	490.4
Direct-cut	978.3	.195	346.7	55.7	487.3
Direct-cut + formic acid	978.3	.195	236.1	25.2	407.2

Table 9.28. Feed production and utilization (tDM) under four harvest and conservation systems on an 80 ha farm with 128 low milk producing lactating cows (20 kg/cow/day).

System	Alfalfa harvested DM	CP	Alfalfa sold	Soy meal purchased	Corn grain purchased
Hay	741.4	.167	-154.7	1.48	94.8
Haylage	884.2	.180	-31.5	0.41	76.2
Direct-cut	978.3	.195	22.6	0.00	36.6
Direct-cut + formic acid	978.3	.195	-1.3	0.00	12.7

The haylage system conserves about 20% more yield and 10% more crude protein than the hay system. The quality advantage of haylage is however offset by a lower intake potential compared with hay. With high milk producing cows, the haylage system indeed requires slightly more soybean meal and corn grain than the hay system to balance the ration. Low milk producing cows require a lower nutrient concentration than high milk producing cows and consume more alfalfa and less soybean meal or corn grain (table 9.28).

A large fraction of the haylage cannot be used by the high milk producing herd because the nutrient concentration is not high enough. In the model, excess haylage is sold at $69. per tDM. In practice, a farmer could use about 16% less land with a haylage system than with a hay system to produce the same quantity of feed.

A review of literature in section 5.4 showed that dairy cows will generally intake less haylage than hay on a dry basis. This is modelled by decreasing crude protein and digestibility of haylage by 5% in the ration formulation model. The sensitivity of this assumption was tested by assuming that haylage had the same dry matter intake potential as hay. Figure 9.12 shows that the feed value of haylage would increase significantly and the break-even point for the haylage system with high yield lactating cows would be 40 ha instead of 120 ha.

A real interest rate of 4% has been used to compare the haylage and hay systems. Some businesses use a real rate of return of 10% for investment comparisons. If such a high rate were used, the hay system would appear even more advantageous than the haylage system because of its lower investment cost for both machinery and storage. Farmers often do not expect such a high rate of return. In some cases, their loans may be subsidized to a level that is close to a 0% real discount rate. Between 1975 and 1980, the inflation rate was higher than the interest rates of the Federal Reserve Bank (U.S.D.A., 1981). The average real interest rate was -0.9% during that period. Under those circumstances, the real cost of capital was low because loans were available at a very low real cost. Figure 9.13 shows that the break-even point of a haylage system would shift down to 100 ha with a real interest rate of 0% instead of 120 ha with a real rate of 4%.

9.3.4 Direct-cut alfalfa

The ultimate way to reduce the field curing time of alfalfa is by direct cut. The main problem with direct-cut alfalfa is its high moisture content and the large seepage losses that are likely to occur during storage. Bruhn and Koegel (1977) have suggested mechanical dewatering of alfalfa by pressing out up to half the initial water. The dewatered alfalfa may be conserved as haylage without field curing.

Table 9.26 compares the resources required to operate a direct-cut system, a hay system and a haylage system. The machinery investment for the direct-cut system is smaller than the one for the haylage system, but the cost of equipment for dewatering and processing the freshly

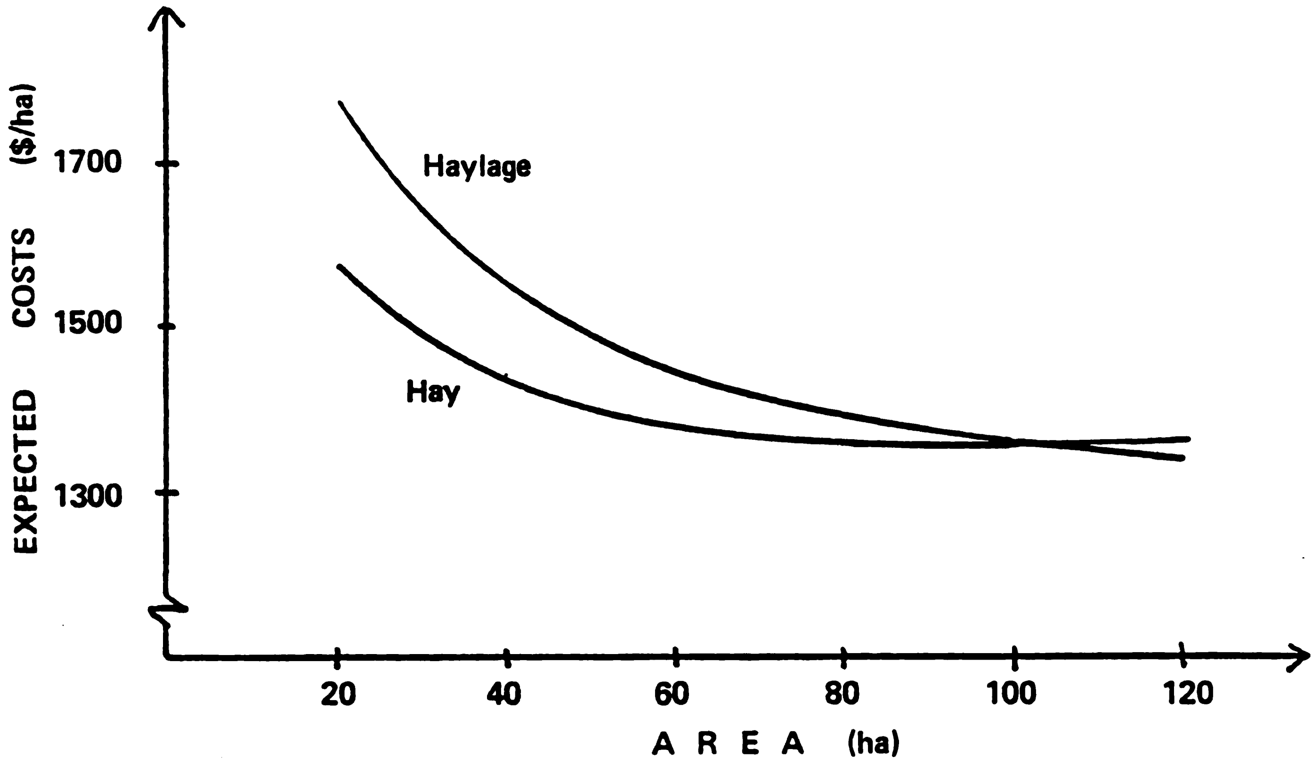

Figure 9.13. Expected costs of a haylage system and a hay system versus area assuming a low real interest rate (i=0.00) and high milk production.

mowed alfalfa is not included.

Simulation over 26 years showed that more quantity and quality would be retained with a direct-cut system. Table 9.27 shows that it retains 11% more yield than the haylage system and 32% more than the hay system. Storage losses for direct-cut are assumed to be the same as for haylage. In practice it is difficult to avoid important seepage losses with direct-cut alfalfa.

The quantities of soybean meal and corn grain purchased indicate that hay, despite its lower crude protein concentration, has a very good intake level compared with haylage and direct-cut alfalfa. Waldo and Jorgensen (1981) have suggested the use of formic acid to increase the intake potential of haylage to almost the same level as dry hay. Assuming that the addition of formic acid to wet alfalfa increases its intake to the same level as hay, the more efficient use of direct-cut alfalfa results in substantial savings of soybean meal and corn grain purchases (table 9.27).

Table 9.29 compares the net feed costs under the four harvest and conservation systems. The benefit of haylage versus hay increases with lower milk producing cows. The advantage of haylage would hence be more quantitative than qualitative since low yield cows make better use of low quality feed. Similarly the benefit of direct-cut alfalfa increases with lower producing cows. In the case of haylage and direct-cut alfalfa, the decrease in net feed cost is due largely to the increased production of alfalfa (and increased sale of excess forages) and not to the lesser purchase of supplements.

Table 9.29. Net feed costs ($/ha) on an 80 ha alfalfa farm with 128 lactating cows at four milk production levels.

System	20 kg/day	25 kg/day	30 kg/day	35 kg/day
Hay	330.	469.	663.	885.
Haylage	268.	420.	623.	881.
Direct-cut	48.	219.	436.	720.
Direct-cut + formic acid	28.	128.	317.	582.

The addition of formic acid to direct-cut alfalfa would decrease the purchase of supplemental feeds. The advantage is greatest with high milk producing cows. In fact, the increased dry matter intake assumed for wet alfalfa would allow 110 more tons of alfalfa to be consumed by the herd and would reduce purchases of soybean meal by 30 tons and of corn grain by 80 tons (table 9.27).

The benefit of increasing the dry matter intake of wet alfalfa is about $140. per ha per year or about $10. per ton DM with high milk producing cows. The benefit decreases rapidly with lower milk producing cows.

In summary, haylage and direct-cut alfalfa do not reduce substantially the amounts of supplements required in the ration compared with good quality hay. Although they have a higher crude protein concentration than hay, their lower intake potential makes the overall quality similar to that of hay. Haylage and direct-cut alfalfa do have a quantitative advantage over hay by providing more feed per unit area. Increasing the intake potential of wet alfalfa (with formic acid or any other mean) would be valuable mainly for high milk producing cows. The analysis showed a reduction in feed cost of the order of $10. per ton of alfalfa dry matter harvested. Any haylage treatment to increase animal feed intake would have to cost less than the estimated benefit.

9.4 Storage policy

The simulation model includes four possible storage locations for alfalfa: silo one (usually high quality wet alfalfa), silo two, high quality hay and low quality hay. These four locations allow flexibility and greater efficiency in the allocation of forages. Indeed the higher quality alfalfa may be fed to high yield lactating cows and the lower quality alfalfa can be fed to dry cows and heifers.

Two smaller silos usually cost more than one large silo with the same total capacity. The two smaller silos however provide more flexibility in the allocation of forages. They also ensure a faster filling rate which may reduce oxidation losses in the silo. The present storage model does not simulate varying storage losses. Nonetheless the storage policy may be assesed from the feed allocation point of view.

Table 9.30 relates the distribution of harvested alfalfa when one or two silos are used. In addition to the harvested haylage, each system include between 280 and 290 tons of alfalfa baled as hay.

Table 9.30. Average haylage quality and standard deviation when one or two silos are used.

Policy	Silo 1			Silo 2		
	DM	CP	S(CP)	DM	CP	S(CP)
1 silo	507.7	.183	.017	0.0	.000	.000
2 silos	258.4	.194	.012	259.9	.171	.011

Tables 9.31 and 9.32 show how the feed would be utilized with a high milk yield herd and with a low milk yield herd. More soybean meal and more corn had to be purchased with the high milk herd under the one-silo policy. The feed purchases with the low quality herd were curiously lower under the one-silo policy. Apparently under the two-silo policy, alfalfa with CP=0.194 would be too high in quality to be used efficiently with a low milk yield herd and alfalfa with CP=0.171 would require the purchase of some supplements. A pooled average CP=0.183 proves to be the most efficient quality level for use by low production cows.

Table 9.31. Feed utilization under two storage policies with high yield cows (35 kg/day).

Policy	Alfalfa produced (tDM)	Soy meal purchased (tDM)	Corn grain purchased (tDM)	Alfalfa sold (tDM)
1 silo	798.42	70.84	482.30	176.95
2 silos	799.62	63.51	474.94	163.46

Table 9.32. Feed utilization under two storage policies with low yield cows (20 kg/day).

Policy	Alfalfa produced (tDM)	Soy meal purchased (tDM)	Corn grain purchased (tDM)	Alfalfa sold (tDM)
1 silo	798.42	0.92	87.55	-105.38
2 silos	799.62	0.82	94.50	-97.33

This points out a weakness in the ration formulation model. Mixing high quality alfalfa with low quality alfalfa gives numerically an intermediate average quality. But the cows might respond more as if they were fed only low quality instead of an average quality feed. Table 9.30 did in fact show a larger standard deviation in quality with the one-silo policy. The feed model could be improved by taking the variation into account.

Table 9.33 shows the difference in feed costs between storage in one large silo and storage in two smaller silos. With high milk producing cows a two-silo policy allows better allocation of feed and an estimated saving of $1910. per year (for 128 cows). The feed cost savings become negative under low milk production levels for reasons explained in the above paragraph. In reality we would expect a greater segregation of feed to always reduce feed costs.

Table 9.33. The feed costs ($/yr) under two storage policies at four milk production levels with a herd of 128 lactating cows.

Policy	20 kg/day	25kg/day	30 kg/day	35 kg/day
1 silo	21178.	33474.	50196.	72398.
2 silos	21464.	33578.	49816.	70488.
Diff.	-286.	-98.	380.	1910.

Table 9.34 shows the difference in investment costs between the one-silo and the two-silo policies. The difference of $22000 is large and would be minimally compensated only with a high production herd. (The return of $1910. per year represents a negative return over 10 years and a 6% return over 20 years.) At any milk production level lower than 30 kg/cow/day, the two-silo policy is not worthwhile.

Table 9.34. The storage investment required under two storage policies.

Policy	Storage capacity of each silo (tDM)	Total investment ($)
1 silo	600.	52000.
2 silos	300.	74000.

As mentioned above however, at least two advantages of the two-silo policy are not accounted for in the model: the lower oxidation of haylage due to a faster filling rate and the lower variation in feed quality within each silo. These two factors should be included in a future more refined storage-feeding model.

CHAPTER 10

CONCLUSIONS

A systems approach was used to evaluate the production and utilization of forages on dairy farms. The boundaries included crop growth, harvest, storage and feeding to the dairy herd. A computer simulation model was developed to simulate the growth and harvest of alfalfa on a daily basis and the allocation of feed on a yearly basis. Historical weather data from East Lansing, Michigan were used to repeat the simulation over 26 years.

10.1 General conclusions

After having worked over the past two years on a multidisciplinary research project and having completed the present dissertation, two major conclusions predominate:

1. The systems approach, by considering simultaneously several interdependent components (namely crop growth, harvest, storage and ration formulation) provides a broader understanding of the relative importance of each component than if one were to consider each component separately;
2. Numerical simulation can be used along with field research to analyze the long term impact of new technologies and their adaptability to a wide range of management conditions.

The simulation results showed some interactions between technological choices or management practices and the level of milk production. For example, a hay system was generally less expensive than a haylage system for alfalfa areas below 40 ha. As the area under cultivation increased, the haylage system became profitable more quickly with low milk producing cows than with high milk producing cows because the advantage of haylage over hay is more quantitative than qualitative. Another example is that early harvest of alfalfa is more profitable with high milk producing cows than with low milk producing cows. Simulation provides the researcher and the extension specialist a broad perspective that a few field or nutritional experiments might not give.

Experiments explain physical and biological behavior and are the basis for the simulation model. They can never be replaced by simulation. However simulation may allow the researcher to expand rapidly and at a lesser cost his conclusions to other climatic conditions or to other types of farms. Simulation may also point to promising changes and areas where research priority should be given.

10.2 The sensitivity of model assumptions

With the exception of the alfalfa drying model, the simulation model is largely based on research published in the literature. Some technological coeffiecients are more accurate than others. The following section discusses the relative accuracy of those coefficients and the effect of erroneous values. Five aspects of the model are considered: the machinery model, the dry matter loss estimates, the quality loss estimates, the drying rate model and the feed model.

The machinery model should be the most accurate one since it is largely based on physical principles while the other models must incorporate biological or physiological principles that are more difficult to quantify. Some aspects of the machinery model such as time for loading and unloading material and the energy to convey material are only approximate. These approximations should not however have much impact on the overall model.

Dry matter losses can vary considerably during harvest, storage and feeding. Losses from mowing and conditioning are generally low; any inaccuracy should be of little consequence. Losses from raking and baling can be considerably high especially with dry and leafy material, and for round balers and hay stack wagons. Some of the loss estimates in the literature may be outdated because harvest technology has been changing rapidly. Dry matter losses due to environmental factors, such as respiration and rainfall, are not large and their estimation is relatively adequate. Material losses in the silo and during feeding may be considerable; their estimation would benefit from more detailed modelling compared with the use of a fixed percentage loss in the present model.

Quality losses are well modelled during harvest as long as accurate values of leaf and stem losses are available. The model does not deal however with the appearance of mold when alfalfa is left curing for several days under rainy conditions. Quality losses in storage, especially with haylage, is undoubtedly affected by the rate of fill, the silo size and environmental conditions. Modelling quality changes during storage is likely to be the most significant improvement in the analysis of haylage systems.

The drying model predicts the average drying over a whole day. It does not predict accurately the instantaneous drying rate; this was not an objective of the simulation model. The drying model may suffer from the fact that a single equation was used to estimate drying over the whole range of moisture contents. The parameters in the drying equation may be biased because their estimation is based on data mostly in the higher moisture range. Only a few drying data were obtained for low moisture content alfalfa.

The feed model assumes that intake potential is lower for haylage than for hay. The simulation results showed that if the assumption were changed and haylage intake were assumed to be the same as hay intake, the value of haylage would be increased by $150./ha. The haylage system would become more profitable than the hay system at 40 ha instead of 120 ha. The notion of an intake difference between hay and haylage is very crucial and should be further investigated.

The feed model does not deal with quality variability within the storage structure as it would affect animal response. Simulation results show that some storage policies can provide higher and more uniform quality, but no premium value is given to uniformity versus heterogeneity within the storage structure with equal average quality.

10.3 Managing the alfalfa crop

The simulations in chapter 9 dealt essentially with the alfalfa crop and how management or technological changes could improve the performance of the forage system. On the basis of historical weather from East Lansing, a number of specific conclusions may be drawn:

1. Alfalfa harvest should start early when quality is still high. The greater yield obtained by postponing the harvest does not generally compensate the quality loss. One exception occurs with low quality demanding animals that can more efficiently use a greater quantity of lesser quality feed provided by late harvest than the smaller quantity of high quality feed provided by early harvest.
2. The simulation model indicates that a fourth cut is generally profitable if the three previous cuts start early (around May 20th, July 5th and August 20th). In one year out of ten the fourth cut has a negative return not on account of low yield but because of bad harvesting conditions. If other crops must also be harvested at the same time, the

profitability of the fourth alfalfa cut may be more questionable because of the time conflict.

3. A slow harvest rate will result in lower conserved yield and quality than a fast harvest rate, but the differences are small between an instantaneous harvest and a harvest extended over four weeks. An extended first cut will have a relatively high yield and low quality. The subsequent regrowths will adapt themselves to the harvest rate and compensate the low first cut quality with a higher more uniform quality in the subsequent harvests. For haylage systems, a slow harvest rate may cause more damage at storage than in the field because of excessive oxidation during silo filling. For hay harvest, a farmer should not worry about taking three or four weeks for the first cut. The decrease of crop value is relatively small and does not justify the purchase of large machinery to reduce the average harvest period to less than three weeks. For both hay and haylage systems, the rate of harvest and the timeliness costs will become more important as the number of yearly harvests decreases.
4. The field-curing time and weathering of alfalfa can be reduced either by increasing the drying rate or by harvesting at a higher moisture

content. A reduction of the field-curing time always results in more yield and crude protein conserved for feed. Conventional hay making with a mower-conditioner for all four alfalfa cuts required an average of 4.2 days for curing to 20% moisture (wet basis) and conserved 9.3 tDM/ha with a crude protein concentration of 16.7%. Increasing the drying rate by about 20%, through additional treatments such as maceration or spraying a chemical solution at mowing, would decrease curing time for hay to 3.4 days and increase harvested yield to 10.1 tDM/ha and 17.1% crude protein. Additional dry matter losses due to the extra mechanical treatment are however not accounted. Baling hay at 30% moisture and treating it against spoilage could conserve 10.2 tDM/ha at 17.3% crude protein after 3.5 days of curing on the average. Conserving alfalfa as haylage allows harvesting at moisture contents as high as 60%. The average curing time for hayalge is decreased to 2.4 days; 11.1 tDM/ha of alfalfa at 18.0% crude protein are available as feed. Direct-cut alfalfa reuires no field-curing at all and could conserve 12.2 tDM/ha at 19.5% crude protein. Seepage losses and other handling losses are, however, not included for the direct-cut system.

5. Technologies that conserve more yield and a higher crude protein concentration will result in lower feed costs. Increasing the drying rate for hay making or baling at a higher moisture content can represent a saving of $8. to $10. per ton of dry matter harvested, or a premium value for hay of 10 to 15%. The higher crude protein concentration of haylage compared to hay does not however translate itself into a higher per unit feed value because haylage has a lower dry matter intake potential than hay. The higher nominal quality of haylage is offset by a lower dry matter intake compared with hay. Increasing the potential intake of haylage or direct-cut alfalfa with the use of formic acid or other treatments could reduce feed costs by $10./tDM of alfalfa harvested, which is equivalent to a premium value to haylage of about 15%.

10.4 Comparing hay and haylage systems

Hay and haylage systems represent different investment levels, different use of energy and labor, different conservation and feeding characteristics. Many factors come into play in the comparison of these two systems.

In general, a haylage system requires more investment and more energy but less labor than a hay system. It also retains more yield and more crude protein than the hay system. The nominal quality advantage of haylage is however offset by a lower dry matter intake compared with dry hay. The main advantage of haylage over hay is more quantitative than qualitative.

Under mid-Michigan conditions, the haylage system becomes more profitable than the hay system for areas above 120 ha of alfalfa with high yield lactating cows and above 60 ha with low yield lactating cows when a ratio of 1.6 is used for lactating cows to land (cows/ha). Low milk producing cows can consume more haylage than high milk producing cows because the former require relatively low nutrient concentrations that can largely be met by the haylage whereas the latter require high nutrient concentrations that can only be met by the addition of substantial quantities of corn grain and soybean meal.

An assumption in the feed model states that intake of haylage is lower than intake of hay. If the assumption is changed and haylage is assumed to have the same intake potential as hay, the haylage system becomes more profitable than the hay system with high yield cows at 40 ha instead of 120 ha. The difference in feed cost is about $150. per ha between the two assumptions. It is important to evaluate more accurately the difference in animal response between alfalfa hay and alfalfa haylage.

Interest rates used when comparing hay and haylage systems can be important. A high real interest rate will favor the hay system because of its lower investment cost. Subsidized loans may make the haylage system more attractive than the hay system.

Under mid-Michigan conditions, a 100% hay system is generally less expensive than a 100% haylage system for farms growing less than 40 ha of alfalfa. Between 40 ha and 120 ha, haylage may become more profitable than hay depending on a number of assumptions. Low milk producing cows or low interest rates will favor the haylage system. If haylage intake is closer to hay intake than would indicate the few feeding trials published, the feed value of haylage could be significantly higher than the one estimated in the model.

The farmer's attitude toward risk will also affect his choice. A risk adverse individual may be willing to forfeit some profit in order to reduce the year-to-year variation. He could thus choose the haylage system which, although more expenxive than the hay system, offers less variability. The hay system requires more total labor than the haylage system and three men instead of two during harvest.

Farmers may view hiring and managing temporary labor as representing a higher cost than the $5. per hour assumed in the model. The haylage system does offer this intangible advantage compared with the hay system.

Under more humid conditions, haylage might become more profitable than hay under smaller areas. The analysis did not consider corn production at all. Introducing corn silage along with haylage may be a more efficient way to use both machinery and storage structures in the context of the whole farm.

A haylage system can produce the same quantity of feed of similar quality as a hay system on about 16% less land. All comparisons were based on equal areas of alfalfa for haylage and hay systems. The excess haylage was given a value of $69. per tDM. In practice, a farmer may have better land use opportunities than producing excess forages. A more realistic comparison between haylage and hay should consider the production of other crops on the land that is freed from forage production when shifting from hay to haylage. Ideally the boundaries of the system should be expanded to cover the whole farm.

CHAPTER 11

RECOMMENDATIONS FOR FUTURE RESEARCH

The simulation model still has a largely unexplored potential for analyzing forage systems under various climates. In addition the simulation results have pointed out some model weaknesses and areas where more experimental research would be helpful.

In the short term, the simulation model can be used with minimal changes to expand the analysis of forage systems as follows:

1. Use weather data from other locations besides mid-Michigan to specify under what general conditions various technologies might become preferable (e.g. under what rainfall pattern and for what alfalfa areas would haylage become more profitable than hay). Try to include historical values of relative humidity to get better estimates of the drying rate.

Hay systems appeared to be more profitable than haylage systems in mid-Michigan for farms growing less than 40 ha of alfalfa, and up to 120 ha under certain conditions. For this reason research efforts should continue to improve hay systems. Some short term research priorities could be:

2. The development of improved field curing treatments that would increase the alfalfa drying rate and would not increase dry matter losses.
3. The investigation of treatments to conserve high moisture hay. Early baling can substantially reduce dry matter and nutrient losses.

The simulation model dealt with growth and harvest in greater detail than it did with storage and feeding. Consequently more research is needed to model storage and feeding more accurately. Some long term research priorities should include:

4. Experimental measurement of oxidation of alfalfa haylage as affected by the rate of fill, the silo size and the rate of removal. Little is known about the quality changes within the silo under various filling rates, environmental conditions and rates of removal.

5. More precise knowledge on the animal intake difference between alfalfa hay and alfalfa haylage and how to model it.
6. Research and development of new physical or chemical means to increase the intake potential of alfalfa haylage.
7. A ration formulation model that deals explicitly with cow response to feeds of variable quality.
8. Validation of the crop model under a wide range of climatic conditions. The prediction of leaf and stem quality is critical for crop valuation and should be further investigated.
9. Validation of the dry matter loss parameters under a wide range of climatic and operational conditions (e.g. rainfall, speed of operation, crop density). A distinction between leaf loss and stem loss should always be made.
10. Measurement of alfalfa field drying especially at low moisture contents. More data to predict the desorption equilibrium moisture content of alfalfa are also required. The drying model should be broken into several ranges for greater predicting accuracy.

In general, when assessing a new technology, field experiments should be done to estimate field losses (distinguishing leaf and stem losses), labor and energy requirements, any change in the drying rate and, ideally, feeding trials. A relatively small number of experiments over a short time can provide values for most parameters needed in a simulation model. The simulation model can then be used to assess the long term value and adaptability of the new technology.

APPENDICES

APPENDIX A

A SURVEY OF FORAGE HARVEST MACHINERY

Appendix A

A SURVEY OF FORAGE HARVEST MACHINERY

A generic summary of forage harvest machinery is presented. It lists sizes and capacities of most machines available on the U.S. market in the fall of 1981. Also included are average values of machine mass and list price. Such parameters are useful for power requirement calculations and for cost analysis. Costs have been obtained from two sources: NFPEDA (1981) and Michigan dealers through verbal communication. Implement and Tractor (1981) provided an exhaustive listing of specific farm machinery on the U.S. market.

Tractors have not been listed although they are required for harvest. Their main characteristics may be simplified as follows: the average tractor weighs about 100 lb per Hp (60 kg/kW) and costs about $300. per Hp ($400./kW) in the fall of 1981.

One can observe from tables A.1 to A.13 that price is closely correlated to mass. For most machines the initial cost runs at about $5. to $7. per kg ($2. to $3. per lb).

Most costs were based on those from the large, well established companies. There are some substantial price differences for the same size of equipment when it is manufactured by a small or by a large company. The survey does not show these specific differences. It only provides a generic guide for the potential user. Prices will change quickly and even the sizes and the capacities available are likely to change within the next few years.

Table A.1. A generic summary of mowers and mower-conditioners on the U.S. market (1981).

Mower type	Width (m)	Mass (kg)	Cost ($)	Specific examples (1)
Cutterbar	2.1	360.	2000.	JD350, IH1300
	2.7	385.	2200.	JD350, IH1300
	4.3	820.	6000.	ROWSE D7
	5.5	865.	6300.	ROWSE D9
Cutterbar mower-cond.	2.2	1140.	6000.	JD1207, SNH472
	2.8	1360.	7200.	JD1209, SNH472
	3.7	1930.	9700.	SNH495
Cutterbar cond.-wind.	3.6	1860.	10000.	JD1308, SNH114
	4.3	1950.	10800.	JD1308, SNH114
Disk	1.6	350.	2300.	IH3104, SNH442
	2.4	450.	3000.	IH3106, SNH462
Drum	1.7	365.	2400.	DZKM22, KMN165
	2.1	570.	3500.	DZKM25, KMN210
	2.7	1000.	5500.	DZ108, KMN270
	3.3	1100.	6000.	KMN330
Drum mower-cond.	2.7	1300.	7500.	KMN270C
	3.3	1400.	8000.	KMN330C

(1) See table A.14 for names of manufacturers.

Table A.2. A generic summary of tedders on the U.S. market (1981).

Width (m)	Mass (kg)	Cost ($)	Specific examples
2.1	190.	1500.	GRIMM 'B'
2.4	195.	1700.	GRIMM '8'
3.0	200.	1850.	KNGF23N
4.0	260.	2000.	KNGF440
4.8	400.	2400.	GRIMM '16', KNGF452
7.2	550.	3300.	KNGF671

Table A.3. A generic summary of side-delivery rakes.

Width (m)	Mass (kg)	Cost ($)	Specific examples
2.6	350.	2500.	JD660, SNH256
2.9	375.	2700.	JD670, SNH258
5.8	790.	5800.	JD670-671, SNH258-260

Table A.4. A generic summary of conventional small rectangular balers.

Baler size	Pickup width (m)	Maximum continuous throughput (tDM/h)	Mass (kg)	Cost ($)	Specific examples
Small	1.55	6.	1230.	5900.	JD336, SNH310
Medium	1.70	8.	1450.	7900.	JD346, SNH315
Large	1.80	11.	1640.	9900.	SNH320, JD446
Commercial	1.88	14.	2000.	10900.	SNH420

Table A.5. A generic summary of round balers.

Maximum throughput (tDM/h)	Bale size (kg)	Mass of baler (kg)	Cost ($)	Specific examples
7.5	400.	1500.	8000.	JD410, SNH846
12.0	800.	1900.	10500.	JD510, SNH851

Table A.6. A generic summary of large hay stackers.

Maximum throughput (tDM/h)	Bale size (kg)	Mass of baler (kg)	Cost ($)	Specific examples
10.	1350.	2400.	8500.	OW540, HS10
12.	2700.	4000.	12500.	OW560, HS30
14.	4500.	4500.	20000.	OW60A

Table A.7. A generic summary of automatic bale wagons that pick and stack small rectangular bales.

Wagon capacity (t)	Maximum loading rate (tDM/h)	Unloading time (min)	Wagon mass (kg)	Cost ($)	Specific examples
2.	15.	5.	2000.	11000.	SNH1036
3.	15.	5.	2500.	13500.	SNH1037
5.	15.	5.	4200.	20000.	SNH1063

Table A.8. A generic summary of bale ejectors.

Throughput	Mass (kg)	Cost ($)	Specific examples
Same as baler	250.	2000.	SNH70, JD ejector.

Table A.9. Hay wagons.

Capacity (t)	Mass (kg)	Cost ($)	Specific examples
4.	320.	1400.	JD965
6.	400.	1700.	JD1065A
8.	550.	2200.	JD1075

Table A.10. A generic summary of forage harvester cutterheads on the U.S. market (1981).

Typical PTO power required (kW)	Type of hitch	Maximum Continuous throughput (t-DM/h)	Mass (kg)	Cost ($)	Specific examples
30.	Integral	6.	530.	4300.	SNH707
45.	Pull-type	8.	1130.	6000.	SNH718
60.	Pull-type	11.	1460.	8000.	SNH782
75.	Pull-type	14.	1650.	10500.	SNH892
90.	Pull-type	18.	1700.	12000.	GEHL1250

Table A.11. Attachments for cutterheads.

Type of attachment (P): pull-type (I): Integral	Size	Mass (kg)	Cost ($)
Row-crop (I)	1-row	125.	1500.
Row-crop (P)	1-row	230.	1800.
Row-crop (P)	2-row	360.	2800.
Row-crop (P)	3-row	630.	5100.
Windrow pickup (I)	1.4 m	175.	1400.
Windrow pickup (P)	1.7 m	320.	2200.
Windrow pickup (P)	2.2 m	410.	2600.
Direct-cut mower (P)	1.8 m	360.	2800.
Direct-cut mower (P)	2.3 m	550.	3200.

Table A.12. Forage wagons with unloading mechanism.

Capacity (m3)	Capacity (t)	Mass of wagon (kg)	Cost ($)	Specific examples
12.2	5.4	1350.	7500.	KASTEN 21
16.7	7.2	1500.	9000.	JD714A
19.0	9.1	1650.	10000.	JD716A

Table A.13. Forage blowers on the market.

Capacity range (t-WM/h)		PTO power range (kW)	Mass (kg)	Cost ($)	Specific examples
Corn silage	Alfalfa haylage				
70-120	35-60	50-90	500.	2500.	JD6500
80-140	40-70	60-100	600.	2700.	JD66
120-170	60-85	120-170	450.	2500.	JD6000

Table A.14. List of manufacturers quoted for specific examples. Complete addresses are available in Implement and Tractor (1981).

Company code	Name and location of company
DZ	Deutz Corp., Atlanta, GA
GEHL	Gehl Co., West Bend, WI
GRIMM	G.H. Grimm Co., Rutland, VT
HS	Hesston Corp., Hesston, Kan
IH	International Harvester Co., Chicago, IL
JD	Deere & Co., Moline, IL
KASTEN	Kasten Corp., Allenton, WI
KMN	KMN Modern Farm Equip. Inc.
KN	Kuhn S.A., Vernon, NY
OW	Owatonna Mfg. Co., Owatonna, MN
ROWSE	Rowse Hydraulic Rake Co., Burwell, NE
SNH	Sperry New Holland, New Holland, PA

APPENDIX B

A USER'S GUIDE TO FORHRV

APPENDIX B

A USER'S GUIDE TO FORHRV

Program FORHRV estimates forage harvest rates for a given set of machines. It is a static model, whose results are used later in a dynamic simulation of forage harvest on a day-to-day basis. It calculates actual field capacity (ha/h), actual throughput (tDM/h), fuel consumption (L/h), electricity consumption (kW.h/h) and labor requirements (man.h/h) for up to 18 forage harvest operations, at six yield levels.

A matrix called RATES(108,8) is created by the program. The 108 rows allow a maximum of 18 operations at six yield levels. Each column contains the following parameters:

RATES(K,1) is dry matter yield (t/ha);
RATES(K,2) is effective field capacity (ha/h);
RATES(K,3) is effective throughput (tDM/h);
RATES(K,4) is actual tractor load (decimal);
RATES(K,5) is fuel consumption (L/h);
RATES(K,6) is electricity consumption (kW.h/h);

RATES(K,7) is labor requirement (man.h/h);

RATES(K,8) is operating speed (km/h).

The reason for calculating rates at six yield levels is to minimize later calculations. For example, alfalfa yield per cut might be expected to vary from a minimum of 1 tDM/ha to a maximum of 6 tDM/ha. The harvest capacity will also change with yield as three main constraints become alternately limiting: maximum operating speed, maximum machine throughput and maximum continuous tractor load. A 20-year simulation might generate 80 different yields; the harvest capacity and material flow rates need be calculated each time. The RATES matrix provides the data for efficient linear interpolation at various yields. Beyond the minimum and maximum yields, flow rates will be assumed constant except for field capacity which will be calculated from throughput capacity and yield.

The input data are read as follows:

1. General information (1 card).
2. Machinery data file (up to 100 cards, one per machine). A last card with 0000 in the first columns will indicate the end of the machinery file.
3. Operations file (up to 18 operations and 60 cards). The last card must show 0000 in the first four columns.
4. Print-out options (1 card).

General Information

Seven parameters for general use throughout the program are read into the array XINFO(7). They are read under the format 7F10.2. They are:

XINFO(1), the power safety factor;

XINFO(2), the soil traction number CN as defined in ASAE Data 230.3 (ASAE Yearbook, 1981);

XINFO(3), the average soil slope (the tangent);

XINFO(4), the absolute minimum alfalfa yield (t DM/ha);

XINFO(5), the absolute maximum alfalfa yield (t DM/ha);

XINFO(6), the absolute minimum corn silage yield (t DM/ha);

XINFO(7), the absolute maximum corn silage yield (t DM/ha).

The power safety factor is actually the inverse of the allowable continous tractor load. A value of 1.4 will generally be used, based on several observations of measured power requirements and actual tractor size recommendations by PAMI (1979). A firm soil is usually assumed for forage harvesting (CN = 30.). The average soil slope is generally zero. A value greater than zero should however be assigned whenever slopes are important and affect the choice of tractor size. The absolute minimum and maximum yields of alfalfa and corn silage should be based on prior knowledge of extreme values.

Machinery Data File

Each machinery data card contains 14 parameters to be read under the format I4, 3F8.2, 10F5.1. The first parameter is the machine code and is stored in an array MCODE(100). There can be up to 100 data cards, including the last one (0000). The other 13 parameters are stored in matrix XMDATA(100,13). The parameters are the following machinery characteristics:

XMDATA(I,1), mass (kg);

XMDATA(I,2), list price ($);

XMDATA(I,3), actual value ($);

XMDATA(I,4), machine age (h);

XMDATA(I,5), annual use other than for forage harvest (h);

XMDATA(I,6), width (m);

XMDATA(I,7), maximum continuous throughput (tDM/h);

XMDATA(I,8), transport capacity (t WM);

XMDATA(I,9), self-propelled machine dummy variable: 1. for self-propelled machines, 0. for non self-propelled machines;

XMDATA(I,10), engine type dummy variable: 1. for a gasoline engine, 2. for a diesel engine, 3. for an electric motor;

XMDATA(I,11), engine power (kW);

XMDATA(I,12), time to load one bale (h);

XMDATA(I,13), time to unload a bale wagon (h).

Not all data are relevant to all machines. The first five parameters are required for all. When a machine characteristic is irrelevant, zero (0.0) should be inserted on the data card in the appropriate columns. Table B.1 lists all the machines that are considered for forage harvesting and the relevant data that are required as input to characterize each machine. Some characteristics, especially maximum continuous throughput and time to load or unload, are difficult to estimate accurately. Some values are given in Appendix A. Others are found in the example at the end of this appendix.

Two exceptions to the above parameter defenitions occur with machines 0260 and 0270, dump trucks and forage compacting tractors. Ownership is assumed for all machines except for those two cases, for which leasing will be assumed. Input for XMDATA(I,2) should be leasing cost ($/h), excluding labor and fuel costs, instead of the list price.

Table B.1. Machines used for forage harvest.

Code number range	Machine	Relevant characteristics
0010-0019	Tractor	Power
0020-0029	Electric motor	Power
0030-0039	Cutterbar mower	Width, throughput
0040-0049	Cutterbar mower-conditioner	Width, throughput
0050-0059	Drum mower-conditioner	Width, throughput
0060-0069	Other types of mowers	Width, throughput
0070-0079	Side-delivery rake	Width
0080-0089	PTO-driven rake	Width
0090-0099	PTO-driven tedder	Width
0100-0109	Rectangular baler	Throughput
0110-0119	Large round baler	Throughput
0120-0129	Large stack maker	Throughput
0130-0139	Forage harvester cutterhead	Throughput
0140-0149	FH row-crop attachment	
0150-0159	FH windrow pickup	
0160-0169	FH direct-cut mower	
0170-0179	Bale thrower	
0180-0189	Bale wagon (small rectangular bales)	Capacity (tons)
0190-0199	Automatic bale wagon (small rectangular bales)	Capacity, troughput and time to unload
0200-0209	Round bale loader	Time to load, time to unload
0210-0219	Round bale mover	Capacity
0220-0229	Large stack loader-mover	Time to load, time to unload
0230-0239	Small bale elevator	Throughput
0240-0249	Forage blower	Throughput
0250-0259	Forage boxes	Capacity
0260-0269	Dump trucks for forages	Power,capacity
0270-0279	Large tractor for compacting silage in a bunk silo	Power

Table B.2. Operations modelled in FORHRV.

Code number range	Operation name	Number of data cards
0010-0019	Cutterbar mowing	1
0020-0029	Cutterbar mowing-conditioning	1
0030-0039	Drum mowing-conditioning	1
0040-0049	Raking	1
0050-0059	Double-raking	1
0060-0069	Tedding	1
0070-0079	Rectangular baler, with bales dropped on the ground	1
0080-0089	Round baler	1
0090-0099	Large stack maker	1
0100-0109	Forage harvester, with windrow pickup, blowing the forage on the ground	2
0110-0119	Automatic rectangular bale pickup wagon	1
0120-0129	Large stack moving	1
0130-0139	Round bale loading-moving	2
0140-0149	Corn silage chopping, transport and unloading	5
0150-0159	Alfalfa haylage chopping,transport and unloading	5
0160-0169	Alfalfa direct-cut chopping, transport and unloading	5
0170-0179	Rectangular baler, with bales simultaneously ejected or stacked in a trailing wagon, transport and unloading	5
0180-0189	Handpicking rectangular bales dropped on the field, transport and unloading	5

Operation File

Some forage harvest operations are simple, involving only a tractor and an implement, while others are more complex, involving a harvester, transport units and an unloading component. The varying complexity is reflected by varying the number of data cards required for each operation. There are 18 different harvest operations modelled by FORHRV: they are listed in table B.2.

The first nine operations are individual operations, whose working rate depends only on one tractor and one implement (or a multiple of the combination). These operations are fully defined with one data card containing eight data, read under the format 3I4, 5F10.2. The first three data are read into the matrix ICODE(60,3). They are:

ICODE(I,1), the operation code number;

ICODE(I,2), the implement code number from the machinery data file;

ICODE(I,3), the power source code number from the machinery data file.

Implement and power source numbers used here must have been previously defined in the machinery data file, otherwise execution will be stopped and the error will be identified.

The other five parameters are read into matrix XOPER(60,5). They are:

XOPER(I,1), the number of units;

XOPER(I,2), the maximum allowable speed (km/h);

XOPER(I,3), the actual working width (m);

XOPER(I,4), the average bale size (kg WM);

XOPER(I,5), the average hauling distance (km).

The last two data are relevant only for certain operations: when baling or when a transport component is included in the operation. The datum XOPER(I,1) allows the use of multiple, identical machines.

Two operations (0100 and 0130) require two data cards. In the case of a forage harvester blowing material on the ground (operation 0100), only one tractor is required but two distinct implements are required: the cutterbar head and the windrow pickup attachment. The first data card is identical to a single-card operation. The second card contains information about the second implement. For operation 0100, all data on both cards are identical except the following:

ICODE(I,2) is the cutterbar code number;

ICODE(I+1,2) is the windrow pickup code number.

In the case of loading and moving large round bales (operation 0130), the first data card identifies the loading implement while the second card specifies the moving wagon if there is one.

ICODE(I,2) is the bale loader code number;

ICODE(I+1,2) is the bale mover code number.

If no distinct multiple bale mover is used (i.e. round bales are moved one by one from the field to storage with the loader), then ICODE(I+1,2) should read 0000. All other data are identical on both cards.

Five operations (0140 t0 0180) require five data cards. Operation 0180 is a special case and will be dealt with separately. In the case of the other four operations, the first data card describes the harvester: tractor and harvest implement. The second data card specifies any additional attachment to the harvester: a bale thrower, a corn head, a windrow pickup or a direct-cut mower. The third and fourth cards are usually identical and describe the transport system. The fifth data card identifies the unloading system. Table B.3 shows in detail all the data required for each operation.

It should be kept in mind that each operation between 0140 and 0170 includes harvest, transport and unloading. The use of two transport information cards (cards 3 and 4) allows the analysis of a special case: when no distinct transport tractor is available, i.e. the same tractor is used for field harvest and for transport to storage. Such an analysis is done by setting the number of transport units initially at zero on card 3 (TR1 = 0.) and by setting the number on card 4 to one (TR2 = 1.).

The last operation (code 0180) is hand-picking small rectangular hay bales. Five data cards are also used to define this operation. Table B.3 shows the information required. Since this is a transport-unloading operation, little information is needed in the first two cards which relate mostly to harvest. Maintaining the same data structure as in the other five-data-card operations simplified the simulation by allowing the use of the same subroutines, especially for transport and unloading calculations.

Print-out Options

The last data card contains three print-out parameters: IPR1, IPRINT and IPRIN read under the format 3I2. When IPR1 is equal to one (1), values from the RATES matrix are printed out for each operation at six yield levels. When IPRINT is equal to one (1), detailed information is printed out on cycle times for operations that include transport to storage (operations 0110 to 0180). When IPRIN is equal to one, the input data are printed out. Any value other than one will disactivate the

Table B.3. Data required for harvest operations

One-data-card operations (0010 to 0090, 0110, 0120)

1.	Operation code	Implement code	Tractor code	Number of units	Maximum allowable speed (km/h)	Working width (m)	Average bale size (kg WM)	Hauling distance (km)

Two-data-card operations (0100, 0130)

Both data cards are identical in form to the one defined above for one-data-card operations. On the first card, the implement code is for the cutterhead or the round bale loader. On the second card, the implement code is for the windrow-pickup or for the round bale mover. ICODE(I+1,2) is 0000 if there is no distinct bale mover and all bales are moved one by one by the loader from the field to storage.

Five-data-card operation (0180)

1.	Operation code	0	0	0.	0.	0.	Bale size (kg WM)	Hauling distance (km)
2.	"	0	0	0.	0.	Labor in the field per transport unit, excluding the driver		
3.	"	Transport wagon code	Transport tractor code	Number of units	Maximum allowable transport speed (km/h)	Total number of wagons	Total extra labor at unloading site	Minimum interface time at storage, excluding conveying (h)
4.	"	"	"	"	"	"	"	"
5.	"	Unloader code	Power source code	Number of units				

Table B.3. (continued)

Five-data-card operations (0140 to 0170)

1.	Operation code	Cutterhead or baler code	Harvesting tractor code	Number of units	Maximum allowable speed for harvest (km/h)	Working width (m)	Average bale size (kg WM)	Hauling distance (km)
2.	"	Cutterhead attachment or bale thrower code	"	Minimum interface time between the harvester and a transport unit (h)	Is a transport wagon pulled by the harvester? Yes=1. No=0.			
3.	"	Transport wagon code	Transport tractor code	Number of transport units (TR1)	Maximum allowable speed for transport (km/h)	Total number of wagons	Number of extra men unloading	Minimum interface time at storage, excluding conveying (h)
4.	"	"	"	Number of transport units (TR2)	"	"	"	"
5.	"	Unloader code	Power source code	Number of unloading units	Silo height (m)			

print-out options.

An Example

Table B.4 is an example of input data used by program FORHRV. The first page of input data includes general information (first line) and an extensive machinery data file (from the second line to the last line on the page). Sixty-four different machines are specified, between machine 10 (a 20-kW tractor) and machine 270 (a 150-kW tractor for compacting silage). Of course not all machines will be used. The extensive machinery data file is useful because it provides readily a large number of alternatives. Only the machines atually used are cost accounted.

The second page of input data starts with 0000, the separator between the machinery data file and the operations file. Ten operations are identified between operation 40 (raking) and operation 160 (direct-cut alfalfa chopping). Twenty-eight (28) lines are needed to identify the ten operations because some operations require up to five data cards.

The first operation is a raking operation (40) and uses machines 70 (a 2.9 m wide rake) and 10 (a 20-kW tractor). Note that the user must define what machines are matched together.

Operation 170 is a baling-transport-unloading operation. Tractor 13 (60 kW) pulls a conventional baler 103 (14 tons DM/h as maximum throughput) with a bale ejector 181. One transport unit composed of tractor 12 (40 kW) and hay wagon 181 (5.4 ton capacity) travels an average distance of one km from the field to storage. A bale elevator (230) and a 5-kW electric motor are used to unload bales at storage.

As can be seen, each operation can be defined with a fair amount of detail. The present operation file identifies ten operations. Up to 18 operations may be defined in the same file. Not all operations need to be used on a given farm. Only those operations actually done and the machines required are accounted.

The end of the operations file is recognized when 0000 appears in the first four columns. Finally the printout options are read. Here 1-0-1 means that the rates of each operation are printed out, without detail, and the input data are also printed.

Table B.5 shows the calculated work rates for the ten operations defined above. The order in which operations are defined in FORHRV does not matter (the order will matter in the dynamic simulation, in ALHARV). Rates are estimated at six different yields. These rates are conserved in the RATES matrix for subsequent use, by interpolation, in the dynamic simulation.

Program FORHRV is independent of the dynamic simulation and can be used alone. It should actually be used to test various minor or major changes in implement matchings (e.g. tractor size, number of transport units) before going on with the dynamic simulation.

Table B.4. Example of input data for FORHRV.

THE INPUT DATA FILE FOR FORHRV WAS READ AS FOLLOWS

1.40 30.00 0.00 1.00 6.00 7.50 20.00

10	1200.00	8000.00	8000.00	0.0	0.0	0.0	0.0	0.0	1.0	2.0	20.0	0.0	0.0
11	1800.00	12000.00	12000.00	0.0	0.0	0.0	0.0	0.0	1.0	2.0	30.0	0.0	0.0
12	2400.00	16000.00	16000.00	0.0	0.0	0.0	0.0	0.0	1.0	2.0	40.0	0.0	0.0
13	3600.00	24000.00	24000.00	0.0	0.0	0.0	0.0	0.0	1.0	2.0	60.0	0.0	0.0
14	4800.00	32000.00	32000.00	0.0	0.0	0.0	0.0	0.0	1.0	2.0	80.0	0.0	0.0
15	6000.00	40000.00	40000.00	0.0	0.0	0.0	0.0	0.0	1.0	2.0	100.0	0.0	0.0
16	1800.00	12000.00	12000.00	0.0	0.0	0.0	0.0	0.0	1.0	1.0	30.0	0.0	0.0
20	150.00	800.00	800.00	0.0	0.0	0.0	0.0	0.0	1.0	3.0	5.0	0.0	0.0
30	360.00	2000.00	2000.00	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	1140.00	6000.00	6000.00	0.0	0.0	2.2	10.0	0.0	0.0	0.0	0.0	0.0	0.0
41	1360.00	7200.00	7200.00	0.0	0.0	2.7	12.0	0.0	0.0	0.0	0.0	0.0	0.0
42	1930.00	9700.00	9700.00	0.0	0.0	3.7	15.0	0.0	0.0	0.0	0.0	0.0	0.0
43	4500.00	22000.00	22000.00	0.0	0.0	3.7	15.0	0.0	1.0	2.0	56.0	0.0	0.0
50	1400.00	8000.00	8000.00	0.0	0.0	3.3	17.0	0.0	0.0	0.0	0.0	0.0	0.0
70	375.00	2700.00	2700.00	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
71	790.00	5800.00	5800.00	0.0	0.0	5.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	400.00	2400.00	2400.00	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
91	550.00	3300.00	3300.00	0.0	0.0	7.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	1200.00	6000.00	6000.00	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0
101	1450.00	8000.00	8000.00	0.0	0.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0
102	1650.00	10000.00	10000.00	0.0	0.0	0.0	11.0	0.0	0.0	0.0	0.0	0.0	0.0
103	2000.00	11000.00	11000.00	0.0	0.0	0.0	14.0	0.0	0.0	0.0	0.0	0.0	0.0
110	1500.00	8000.00	8000.00	0.0	0.0	0.0	7.5	0.0	0.0	0.0	0.0	0.0	0.0
111	1900.00	11000.00	11000.00	0.0	0.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0
120	2400.00	8500.00	8500.00	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0
121	4000.00	12500.00	12500.00	0.0	0.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0
122	6500.00	20000.00	20000.00	0.0	0.0	0.0	14.0	0.0	0.0	0.0	0.0	0.0	0.0
130	530.00	4300.00	4300.00	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0
131	1130.00	6000.00	6000.00	0.0	0.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0
132	1460.00	8000.00	8000.00	0.0	0.0	0.0	11.0	0.0	0.0	0.0	0.0	0.0	0.0
133	1650.00	10500.00	10500.00	0.0	0.0	0.0	14.0	0.0	0.0	0.0	0.0	0.0	0.0
134	1700.00	12000.00	12000.00	0.0	0.0	0.0	18.0	0.0	0.0	0.0	0.0	0.0	0.0
140	125.00	1500.00	1500.00	0.0	0.0	.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
141	230.00	1800.00	1800.00	0.0	0.0	.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
142	360.00	2800.00	2800.00	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
143	630.00	5100.00	5100.00	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
150	175.00	1400.00	1400.00	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
151	320.00	2200.00	2200.00	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
152	410.00	2600.00	2600.00	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
160	360.00	2800.00	2800.00	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
161	550.00	3200.00	3200.00	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
170	250.00	2000.00	2000.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
180	320.00	1400.00	1400.00	0.0	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	0.0
181	400.00	1700.00	1700.00	0.0	0.0	0.0	0.0	5.4	0.0	0.0	0.0	0.0	0.0
182	550.00	2200.00	2200.00	0.0	0.0	0.0	0.0	7.2	0.0	0.0	0.0	0.0	0.0
190	2000.00	11000.00	11000.00	0.0	0.0	0.0	15.0	2.0	0.0	0.0	0.0	0.0	.1
191	2500.00	13500.00	13500.00	0.0	0.0	0.0	15.0	3.0	0.0	0.0	0.0	0.0	.1
192	4200.00	20000.00	20000.00	0.0	0.0	0.0	15.0	5.0	0.0	0.0	0.0	0.0	.1
200	110.00	1000.00	1000.00	0.0	0.0	0.0	0.0	.8	0.0	0.0	0.0	.1	.1
201	450.00	2800.00	2800.00	0.0	0.0	0.0	0.0	.8	0.0	0.0	0.0	.1	.1
210	400.00	2000.00	2000.00	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0
211	650.00	4000.00	4000.00	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0
220	460.00	3000.00	3000.00	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	.1	.1
221	600.00	4000.00	4000.00	0.0	0.0	0.0	0.0	2.7	0.0	0.0	0.0	.1	.1
222	1000.00	6000.00	6000.00	0.0	0.0	0.0	0.0	4.5	0.0	0.0	0.0	.1	.1
230	600.00	3000.00	3000.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
240	500.00	2500.00	2500.00	0.0	0.0	0.0	40.0	0.0	0.0	0.0	0.0	0.0	0.0
241	600.00	2700.00	2700.00	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0
242	450.00	2500.00	2500.00	0.0	0.0	0.0	55.0	0.0	0.0	0.0	0.0	0.0	0.0
250	1350.00	7500.00	7500.00	0.0	0.0	0.0	0.0	5.4	0.0	0.0	0.0	0.0	0.0
251	1500.00	9000.00	9000.00	0.0	0.0	0.0	0.0	7.2	0.0	0.0	0.0	0.0	0.0
252	1650.00	10000.00	10000.00	0.0	0.0	0.0	0.0	9.1	0.0	0.0	0.0	0.0	0.0
260	6000.00	30.00	0.00	0.0	0.0	0.0	0.0	9.1	1.0	1.0	150.0	0.0	0.0
270	9000.00	30.00	0.00	0.0	0.0	0.0	0.0	0.0	1.0	2.0	150.0	0.0	0.0

Table B.4. Example of input data for FORHRV (continued).

0000							
40	70	10	1.00	8.00	2.70	0.00	0.00
170	103	13	1.00	10.00	2.70	30.00	1.00
170	170	13	.05	1.00	0.00	0.00	0.00
170	181	12	1.00	20.00	3.00	1.00	.05
170	181	12	1.00	20.00	3.00	1.00	.05
170	230	20	1.00	0.00	0.00	0.00	0.00
150	132	14	1.00	10.00	2.70	0.00	1.00
150	151	14	.05	1.00	0.00	0.00	0.00
150	251	12	1.00	20.00	2.00	0.00	.05
150	251	12	1.00	20.00	2.00	0.00	.05
150	241	13	1.00	20.00	0.00	0.00	0.00
22	41	12	1.00	12.00	2.70	0.00	0.00
60	90	10	1.00	8.00	4.00	0.00	0.00
100	132	14	1.00	12.00	2.70	0.00	0.00
130	151	14	1.00	12.00	2.70	0.00	0.00
80	111	14	1.00	10.00	2.70	800.00	0.00
130	201	14	1.00	20.00	2.70	800.00	1.00
130	210	14	1.00	20.00	2.70	800.00	1.00
140	132	14	1.00	10.00	1.50	0.00	.50
140	142	14	.05	1.00	0.00	0.00	0.00
140	251	12	1.00	20.00	2.00	0.00	.05
140	251	12	1.00	20.00	2.00	0.00	.05
140	241	13	1.00	20.00	0.00	0.00	0.00
160	132	14	1.00	10.00	2.20	0.00	1.00
160	161	14	.05	1.00	0.00	0.00	0.00
160	251	12	1.00	20.00	2.00	0.00	.05
160	251	12	1.00	20.00	2.00	0.00	.05
160	241	13	1.00	20.00	0.00	0.00	0.00
0000							
1	0	1					

Table B.5. Example of output from FORHRV.

CALCULATED WORK RATES FOR OPERATION 40 KNOWN AS RAKING

YDM(T/HA)	EFC(HA/H)	ETP(TDM/H)	LOAD(DEC)	FUEL(L/H)	ELEC(KWH/H)	LABOR(MH/H)	SPEED(KM/H)
1.00	1.73	1.73	.29	3.80	0.00	1.00	8.00
2.00	1.73	3.46	.29	3.80	0.00	1.00	8.00
3.00	1.73	5.18	.29	3.80	0.00	1.00	8.00
4.00	1.73	6.91	.29	3.80	0.00	1.00	8.00
5.00	1.73	8.64	.29	3.80	0.00	1.00	8.00
6.00	1.73	10.37	.29	3.80	0.00	1.00	8.00

CALCULATED WORK RATES FOR OPERATION 170 KNOWN AS BALE EJECT TR UL

YDM(T/HA)	EFC(HA/H)	ETP(TDM/H)	LOAD(DEC)	FUEL(L/H)	ELEC(KWH/H)	LABOR(MH/H)	SPEED(KM/H)
1.00	2.11	2.11	.60	17.13	.94	3.00	10.00
2.00	2.06	4.11	.67	18.67	1.84	3.00	10.00
3.00	1.96	5.87	.71	19.86	2.62	3.00	9.73
4.00	1.59	6.36	.71	18.06	2.84	3.00	8.89
5.00	1.27	6.36	.71	15.99	2.84	3.00	8.19
6.00	1.06	6.36	.71	14.61	2.84	3.00	7.59

CALCULATED WORK RATES FOR OPERATION 150 KNOWN AS CHOP (ALF-WP) TR UL

YDM(T/HA)	EFC(HA/H)	ETP(TDM/H)	LOAD(DEC)	FUEL(L/H)	ELEC(KWH/H)	LABOR(MH/H)	SPEED(KM/H)
1.00	2.10	2.10	.66	26.90	0.00	2.00	10.00
2.00	1.83	3.67	.71	30.63	0.00	2.00	8.95
3.00	1.54	4.61	.71	32.00	0.00	2.00	7.61
4.00	1.32	5.30	.71	32.99	0.00	2.00	6.62
5.00	1.16	5.81	.71	33.74	0.00	2.80	5.85
6.00	1.04	6.22	.71	34.32	0.00	2.00	5.25

CALCULATED WORK RATES FOR OPERATION 22 KNOWN AS CUTTERBAR MOW-COND

YDM(T/HA)	EFC(HA/H)	ETP(TDM/H)	LOAD(DEC)	FUEL(L/H)	ELEC(KWH/H)	LABOR(MH/H)	SPEED(KM/H)
1.00	2.59	2.59	.53	10.46	0.00	1.00	12.00
2.00	2.59	5.18	.58	10.96	0.00	1.00	12.00
3.00	2.59	7.78	.62	11.49	0.00	1.00	12.00
4.00	2.40	9.60	.63	11.61	0.00	1.00	11.11
5.00	1.92	9.60	.58	10.99	0.00	1.00	8.89
6.00	1.60	9.60	.55	10.60	0.00	1.00	7.41

Table B.5. Example of output from FORHRV (continued).

CALCULATED WORK RATES FOR OPERATION 60 KNOWN AS TEDDING

YDM(T/HA)	EFC(HA/H)	ETP(TDM/H)	LOAD(DEC)	FUEL(L/H)	ELEC(KWH/H)	LABOR(MH/H)	SPEED(KM/H)
1.00	2.56	2.56	.56	5.38	0.00	1.00	8.00
2.00	2.56	5.12	.56	5.38	0.00	1.00	8.00
3.00	2.56	7.68	.56	5.38	0.00	1.00	8.00
4.00	2.56	10.24	.56	5.38	0.00	1.00	8.00
5.00	2.56	12.80	.56	5.38	0.00	1.00	8.00
6.00	2.56	15.36	.56	5.38	0.00	1.00	8.00

CALCULATED WORK RATES FOR OPERATION 100 KNOWN AS CHOP ON THE GROUND

YDM(T/HA)	EFC(HA/H)	ETP(TDM/H)	LOAD(DEC)	FUEL(L/H)	ELEC(KWH/H)	LABOR(MH/H)	SPEED(KM/H)
1.00	2.59	2.59	.42	18.34	0.00	1.00	12.00
2.00	2.59	5.18	.58	22.07	0.00	1.00	12.00
3.00	2.46	7.37	.71	25.33	0.00	1.00	11.38
4.00	2.01	8.03	.71	25.33	0.00	1.00	9.30
5.00	1.70	8.49	.71	25.33	0.00	1.00	7.86
6.00	1.47	8.80	.71	25.28	0.00	1.00	6.79

CALCULATED WORK RATES FOR OPERATION 80 KNOWN AS ROUND BALING

YDM(T/HA)	EFC(HA/H)	ETP(TDM/H)	LOAD(DEC)	FUEL(L/H)	ELEC(KWH/H)	LABOR(MH/H)	SPEED(KM/H)
1.00	2.03	2.03	.31	14.66	0.00	1.00	10.00
2.00	2.03	4.05	.38	16.37	0.00	1.00	10.00
3.00	2.03	6.08	.45	17.88	0.00	1.00	10.00
4.00	2.03	8.10	.52	19.32	0.00	1.00	10.00
5.00	1.80	9.00	.52	19.42	0.00	1.00	8.89
6.00	1.50	9.00	.49	18.70	0.00	1.00	7.41

Table B.5. Example of output from FORHRV (continued).

CALCULATED WORK RATES FOR OPERATION 130 KNOWN AS ROUND BALE MOVER

YDM(T/HA)	EFC(HA/H)	ETP(TDM/H)	LOAD(DEC)	FUEL(L/H)	ELEC(KWH/H)	LABOR(MH/H)	SPEED(KM/H)
1.00	5.49	5.49	.43	13.64	0.00	1.00	20.00
2.00	2.74	5.49	.43	13.64	0.00	1.00	20.00
3.00	1.83	5.49	.43	13.64	0.00	1.00	20.00
4.00	1.37	5.49	.43	13.64	0.00	1.00	20.00
5.00	1.10	5.49	.43	13.64	0.00	1.00	20.00
6.00	.91	5.49	.43	13.64	0.00	1.00	20.00

CALCULATED WORK RATES FOR OPERATION 140 KNOWN AS CHOP (CS) TR UL

YDM(T/HA)	EFC(HA/H)	ETP(TDM/H)	LOAD(DEC)	FUEL(L/H)	ELEC(KWH/H)	LABOR(MH/H)	SPEED(KM/H)
7.50	.68	5.13	.71	32.56	0.00	2.00	6.47
10.00	.57	5.72	.71	33.40	0.00	2.00	5.50
12.50	.49	6.15	.71	34.00	0.00	2.00	4.78
15.00	.43	6.47	.71	34.45	0.00	2.00	4.23
17.50	.38	6.72	.71	34.80	0.00	2.00	3.79
20.00	.35	6.92	.71	35.08	0.00	2.00	3.43

CALCULATED WORK RATES FOR OPERATION 160 KNOWN AS CHOP (ALF-DC) TR UL

YDM(T/HA)	EFC(HA/H)	ETP(TDM/H)	LOAD(DEC)	FUEL(L/H)	ELEC(KWH/H)	LABOR(MH/H)	SPEED(KM/H)
1.00	1.69	1.69	.66	28.09	0.00	2.00	10.03
2.00	1.46	2.93	.71	32.38	0.00	2.00	8.92
3.00	1.23	3.68	.71	34.19	0.00	2.00	7.61
4.00	1.05	4.22	.71	35.49	0.00	2.00	6.64
5.00	.93	4.63	.71	36.47	0.00	2.00	5.83
6.00	.82	4.95	.71	37.24	0.00	2.00	5.29

APPENDIX C

A USER'S GUIDE TO ALHARV

APPENDIX C

A USER'S GUIDE TO ALHARV

Subroutine ALHARV and all the subroutines called therefrom simulate daily harvest of alfalfa either as direct-silage, field-cured haylage or field-cured hay. A flow chart in chapter 7 describes the algorithm and its location in the overall dynamic simulation. The present appendix explains how to set up the input data and provides an example.

The subroutine that reads the input data for alfalfa harvest is called MGTINF. Up to four alfalfa harvests may be simulated per year. For each harvest, the area in hectares, the sequence of harvest operations and a criterion matrix must be read. Information about silo capacity and cost and about hay barn capacity and cost is also read. Printout options for alfalfa harvest are then read. Finally the dairy cow herd is specified when subroutine COWFD is used to formulate the rations. Table C.1 shows the general structure of the alfalfa harvest management data file.

Table C.1. General structure of alfalfa harvest management input data file.

	Line number	Input data	Format
Harvest 1	1	Area	F10.2
	2	Sequence of harvest operations	9I5
	3	Criterion matrix	9F5.2
	4	" "	9F5.2
	5	" "	9F5.2
	6	" "	9F5.2
Harvest 2	7	Area	F10.2
	8	Sequence of harvest operations	9I5
	9	Criterion matrix	9F5.2
	10	" "	9F5.2
	11	" "	9F5.2
	12	" "	9F5.2
Harvest 3	...		
...			
Harvest n	...		
	6n+1	0.0	F10.2
	6n+2	SILO(1), SILO(2), ALFSIL(1), ALFSIL(2), HAYST(1), HAYST(2), HAYST(3)	7F10.2
	6n+3	IPR2, IPR3, IPR4	3I2
	6n+4	XLCOWS, (HERD(I),I=1,6)	7F10.3
	6n+5	1. if another herd is analyzed 0. if ration analysis is ended	F10.2
	6n+6	XLCOWS, (HERD(I),I=1,6)	7F10.2
	6n+7	1. or 0. as above etc.	F10.2

Basicly the input data can be broken down into three parts: the alfalfa harvest parameters, the storage structures and the dairy herd composition.

Alfalfa harvest parameters

Six input data lines are used to define each harvest. Table C.2 shows all the parameters that define one alfalfa harvest. The first line specifies the area harvested as alfalfa (ha). The second line lists up to nine harvest operations that might be involved in alfalfa harvest. Operations are identified by the same numbers defined previously in the FORHRV program (Appendix B). For example, 00020 would identify a mowing-conditioning operation with specific mower and tractor sizes defined in FORHRV. The nine operations must be identified in the order shown in table C.2. Some operations may be omitted such as extra curing treatment (e.g. tedding), treatment after rain (e.g. tedding or raking) or independent transport of bales (e.g. hauling big bales several days after harvest). When such operations do not exist, 00000 should be inserted for the operation number.

The last four lines for each alfalfa harvest contain decision parameters that affect the scheduling of each operation. These decision parameters are stored in the criterion matrix (CRTR,lines 3 to 6).

Table C.2. Input data for each alfalfa harvest.

	1	2	3	4	5	6	7	8	9
Line 1:	Area (ha)								
Line 2:	Mowing-condition.	Extra curing treatment	Raking	Treatment after rain	First priority harvest	Second priority harvest	Forced hay harvest	Destroy the harvest	Independent transport of bales
Line 3:	Can M be simultan. with H? Yes=1. No=0.	Can XT be simultan. with M? Yes=1. No=0.	Can R be simultan. with H? Yes=1. No=0.	——	Maximum moisture content (dec,db)	Maximum moisture content (dec,db)	Maximum moisture content (dec,db)	——	Are bales stored outside? Yes=1. No=0.
Line 4:	Windrow to swath ratio (WR)	WR	WR	WR	Critical crude protein	Critical days for destruct.	Critical crude protein	Critical days for destruct.	Is T simult. with H? Yes=1. No=0.
Line 5:	Drying factor	Drying factor	——	Drying factor	Is there independ. transport of bales? Yes=1. No=0.	Is there independ. transport of bales? Yes=1. No=0.	Is there independ. transport of bales? Yes=1. No=0.	Is there independ. transport of bales? Yes=1. No=0.	——
Line 6:	Is mowing limited to a half day? Yes=1. No=0.	Maximum nb of days mowing can be ahead of harvest	Mowing crude protein criterion	——	Feeding method	Feeding method	Feeding method	——	——

Some explanation may be useful as to the difference between first and second priority harvests. These two operations are usually the same operation. A plot of alfalfa will be shifted to second priority harvest if the actual crude protein is lower than the "critical crude protein" (line 4, column 5) or if silo 1 is full and silo 2 is not full. In the case of alfalfa silage or haylage, when both silos are full, the alfalfa plots remaining are harvested as dry hay. There are no storage capacity limitations for dry hay except that a marginal yearly storage cost is added if the volume of hay harvested is above the specified barn capacity. The storage policy is further described in chapter 7. It is implied that there can be two silos receiving forages of different quality. A single silo is also allowed. Alfalfa plots may be harvested as soon as their moisture content drops below the "maximum moisture content" specified in the criterion matrix (line 3, column 5, 6 and 7).

Another criterion is used to decide if some plots are irremediably wasted because of overexposure. If a plot is exposed for a period longer than the "critical days for destruction" (line 4, columns 6 and 8), then it is shifted to the harvest operation defined as "destroy the harvest". This operation can be either a baling with transport operation or a chopping operation blowing material on the ground. In either cases, the value of the material is assumed to be zero and the use of machinery for this disposal operation is accounted. Column 6 applies to first and second priority harvests. Column 8 applies to forced hay harvest.

The ninth operation, "independent transport of bales", is required when baling dry hay is independent from transport, i.e. bales are dropped on the ground and left for some time before they are hauled to a storage area. If the bales are always transported the same day they are harvested, the criterion "average number of days left in the field" should be 0. Otherwise a constant additional field loss will be accounted for weathering of bales left outside.

The windrow to swath ratio (line 4) should be defined for mowing and for all curing treatments. Generally it is 0.8 for mowed alfalfa left in a wide windrow and 0.5 or less for raked material.

The drying factors (line 5) refer to coefficients in equation 6.3. The drying factor for the mowing operation is CD in equation 6.3. It is generally 0 for a simple mower and 1 for a mower-conditioner. In the case of extra curing treatments, the drying factor should be equal to b9*XTR in equation 6.3. For example, a value of 0.05 was suggested for maceration. If there is treatment after rain (tedding or raking), the drying factor is equal to RK in equation 6.3. A value of 1 should be used. Chapter 6 describes more fully the alfalfa drying model and the drying parameters.

The maximum number of days mowing can be ahead of harvest (line 6, column 2) can be used to reduce the risk of having too many plots curing at the same time. The minimum default value is two days (four plots). If a very high value were used, mowing would proceed regardless of the delays with harvesting.

The mowing crude protein criterion (line 6, column 3) is the crude protein below which mowing should no longer be postponed. The criterion is used as a mesure of maturity. If the crude protein of the growing alfalfa is higher than the criterion, mowing is postponed for a maximum of ten days on the assumption that the plant is still too immature. The mowing crude protein criterion should be in the range between 0.15 and 0.23 to activate the postponing decision algorithm. If the criterion is outside the range, mowing is not postponed and starts on the first date BGNCUT(NTHCUT).

The feeding method for each harvesting operation is a number between 1 and 7. Table 7.1 lists the seven feeding methods considered. It is the model user's responsibility to make sure the feeding method is compatible with the harvest operation.

Presently the model is able to read information for up to five alfalfa harvests per year. Any number between 1 and 5 is allowed ($1 < n < 5$). A value of 0.0 in line 6n+1, after the last harvest, will indicate the end of alfalfa harvest parameters.

Storage structures

The next line includes seven parameters for the storage of alfalfa:

SILO(1) is the storage capacity of the first silo (t DM);

SILO(2) is the storage capacity of the second silo (t DM);

ALFSIL(1) is the initial cost of silo 1, including the unloading equipment ($);

ALFSIL(2) is the initial cost of silo 2, including the unloading equipment ($);

HAYST(1) is the marginal cost for storing hay once the fixed hay storage capacity is filled ($/t DM/year);

HAYST(2) is the initial cost of a hay barn ($);

HAYST(3) is the fixed hay storage capacity (t DM).

The following line (6n+3) includes three printout parameters. When their value is 1, they activate detailed printouts. Any other value will disactivate the printouts. When IPR2 is 1, a daily printout will show how much area is mowed and harvest each day. A seasonal summary will appear at the end of each harvest. When IPR3 is 1, a yearly detailed output will show the feeding value of all alfalfa plots harvested in a year. When IPR4 is 1, a yearly summary of the use of each machine and the resources required for harvest and feeding is printed out.

Dairy herd composition

The last lines, starting at 6n+4, are required only when subroutine COWFD, written by this author, is used for the ration formulation of the dairy herd. While all the previous lines are read from subroutine MGTINF, the last line is read from COWFD. The seven variables read in are:

XLCOWS, the number of lactating cows (representing the total of fractions HERD(1), HERD(2), HERD(3) and HERD(4));

HERD(1), the fraction of the total herd as high yield lactating cows (35 kg milk/day);

HERD(2), the fraction of the total herd as medium yield lactating cows (30 kg milk/day);

HERD(3), the fraction of the total herd as medium low yield lactating cows (25 kg milk/day);

HERD(4), the fraction of the total herd as low yield lactating cows (20 kg milk/day);

HERD(5), the fraction of the total herd as dry cows;

HERD(6), the fraction of the total herd as heifers.

The sum of HERD(1) to HERD(6) must be equal to 1. Each group of cows is fed farm grown feeds (alfalfa, corn silage, high moisture corn). Additional corn grain or soybean meal may be purchased to satisfy the net energy and the crude protein requirements. Any excess farm grown feeds are sold on the market. Subroutine COWFD is further explained in chapter 8.

The input on the following line is either 0 or 1. A value of 0 means the end of the feed analysis. A value of 1. means another herd with other values for XLCOWS and HERD will be read. The same harvested feed over 26 years will be allocated to this different dairy herd. Again the next line must specify either 0 (end) or 1 (continue with another herd). There must always be an even number of data lines in the dairy herd composition section, and the last card must always read 0.

An example

Table C.3 lists the input data read for the dynamic simulation using the ALHARV set of subroutines for daily harvest simulation and the COWFD subroutine for ration formulation. The second page of table C.3 lists input data read from the alfalfa growth model (Parsch,1982).

Four alfalfa harvests per year are simulated in this example. The four earliest mowing dates are defined as Julian days 135, 180, 225 and 285. No area is grown as corn. On the first page, all four harvests are seen to cover 100 ha. The sequence of operations is the same in all four harvests: operation 22 (mowing-conditioning) is followed by raking (40) and by chopping alfalfa haylage (operation 150). The 26th line indicates that there are two silos with a 375-ton capacity each. There is also a hay barn with a 250-ton DM capacity.

When the first silo is filled, haylage goes into the second silo. When both silos are filled, operation 80 (round baling) takes over the haylage operation. Note that operation 130 (transport of large bales) is also required. If the crop is left field curing more than 14 days, it will be destroyed by operation 100 (chop and blow on the ground).

All the machines used for these operations (22, 40, 150, 80, 100, 130) are those defined in the FORHRV program explained in appendix B.

Table C.4 is a partial output from the dynamic simulation based on input from table C.3. The first page shows the potential yield and quality of alfalfa on the earliest mowing date for each harvest over a 26-year simulation. The second page shows the actual harvested alfalfa available as feed from each harvest. The third page provides information on the starting and ending dates of alfalfa harvest. The fourth page shows how the total alfalfa was distributed in the four storage locations: first silo, second silo, high quality hay and low quality hay. The fifth page shows the feed utilization with 160 low milk producing cows. The sixth page lists costs, milk income and net return. The seventh page is a summary of the resource utilization.

Table C.3. Example of input data for ALHARV.

```
   THE MANAGEMENT INPUTS FOR AREA AND OPERATION SEQUENCE WERE READ AS FOLLOWS
  100.00
  22    0   40    0  150  150   80  100  130
0.00 0.00 1.00 0.00 1.20 1.20  .30 0.00 1.00
 .80 0.00  .50 0.00  .1714.00  .1714.00 0.00
1.00 0.00 0.00 0.00 0.00 0.00 1.00 0.00 0.00
0.00 5.00  .23 0.00 6.00 6.00 3.00 0.00 0.00
  100.00
  22    0   40    0  150  150   80  100  130
0.00 0.00 1.00 0.00 1.20 1.20  .30 0.00 1.00
 .80 0.00  .50 0.00  .1714.00  .1714.00 0.00
1.00 0.00 0.00 0.00 0.00 0.00 1.00 0.00 0.00
0.00 5.00  .23 0.00 6.00 6.00 3.00 0.00 0.00
  100.00
  22    0   40    0  150  150   80  100  130
0.00 0.00 1.00 0.00 1.20 1.20  .30 0.00 1.00
 .80 0.00  .50 0.00  .1714.00  .1714.00 0.00
1.00 0.00 0.00 0.00 0.00 0.00 1.00 0.00 0.00
0.00 5.00  .23 0.00 6.00 6.00 3.00 0.00 0.00
  100.00
  22    0   40    0  150  150   80  100  130
0.00 0.00 1.00 0.00 1.20 1.20  .30 0.00 1.00
 .80 0.00  .50 0.00  .1714.00  .1714.00 0.00
1.00 0.00 0.00 0.00 0.00 0.00 1.00 0.00 0.00
0.00 5.00  .23 0.00 6.00 6.00 3.00 0.00 0.00
     0.00
  375.00     375.00   46250.00  46250.00     10.00   9000.00    250.00
0 0 0
```

The following data were read in COWFD

```
160.      .000      .000      .000      .600      .100      .300
  0
```

Table C.3. Example of input data for **ALHARV** (continued).

```
 INPUT VALUES FOR ALFALFA SIMULATION RUN READ INTO SUBROUTINE ALFIN

-------------------------------.

FIRST AND LAST SIMULATION YEARS=  1953  1978
FIRST AND LAST SIMULATION DAY (JULIAN)=     91    335
IPRT1 (PRINT CONTROL) AND OUTPUT UNITS (0=ENGLISH 1=METRIC)=    999      1
OPTION TO DIRECT-CATALOG AFEED AND TCOST MATRICES=       0       0
SOIL MOISTURE PARAMETERS: AWFC,AWINIT,AWFS=  200.  200. .400
CUTTING DATES (JULIAN) FOR 4 CUTS/YR=  135.  180.  225.  285.


INPUT VALUES FOR CORN SIMULATION:  SUBROUTINES CRNIN AND CORN

SIMULATION LENGTH, YEARS=  26
AREA INTENDED AS CS HMC CG AND TOTAL(HA)=     0.00     0.00     0.00     0.00
STORAGE CAPACITY OF CS AND HMC (DM TONS)=     0.00     0.00
INVESTMENT IN STORAGE STRUCTURES FOR CS AND HMC, $        0.         0.
WORK DAYLENGTH, PLANT PD (HRS/DAY)=   8.00
WORK DAYLENGTH, HARVEST PD (HRS/DAY)=   8.00
CS OPERATION NO. (140-149 W/SAVOIE MODEL ONLY)= 140
CORN MACHINERY INPUT DATA, COLS:  1=WIDTH (M) 2=PPM ($)  3=XMEN (MANHRS/HR)  4=NTRAC (MCODE)  5=NTBLOW (MCODE)  6=NBLOJR (MCODE)
CORN PLANTING:                 1.50         0.  2.0    12
CS HARVEST:                    1.50         0.  3.0    14  13 241
HMC HARVEST:                   1.50         0.  3.0    12  13 241
DISCOUNT RATES CHARGED: SHORT, MEDIUM, LONG-TERM=   .17   .15   .13
LABOR CHARGE($/HR); DIESEL, GAS CHARGE($/L)=  5.00  .309  .317
FERTILIZER/SEED/CHEMICALS ($/HA): SEEDING YEAR ALFALFA,ESTABLISHED ALFALFA, CS, HMC/CG=  301.09  118.58  227.73  207.11
DRYING CHARGE, CG-SOLD ($/PT/BU); CUSTOM HARVEST CHARGE, CG ($/HA)=    .03     59.77
CUSTOM CHARGE FOR PRE-PLANT TILLAGE, CORN; PRE-HARVEST TILLAGE/SEEDING, ALFALFA ($/HA)=  0.00    0.00
STORAGE STRUCTURE LIFE (YRS); SV/INVEST=  30.0 0.00
MACHINERY LIFE (YRS); SV/INVEST=  10.0  .10
```

Table C.4. Example of output from ALHARY.

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	2.75	.23	.70	.21	183.	2.68	.23	.70	.28	430.	2.34	.23	.70	.29	453.	2.83	.18	.65	.30	499.	10.60	.22	.69	.27	1566.
2	2.84	.23	.70	.22	211.	2.49	.23	.70	.28	417.	2.54	.23	.70	.27	398.	2.14	.21	.69	.31	511.	10.02	.23	.70	.27	1537.
3	4.85	.19	.66	.25	332.	3.99	.23	.70	.30	476.	2.70	.23	.70	.35	663.	2.03	.23	.70	.31	529.	13.58	.21	.69	.29	1999.
4	2.32	.23	.70	.20	160.	2.97	.23	.70	.28	433.	2.38	.23	.70	.28	411.	2.70	.17	.64	.26	357.	10.38	.22	.69	.26	1361.
5	2.99	.23	.70	.24	269.	2.77	.23	.70	.27	403.	2.93	.23	.70	.29	440.	2.70	.16	.61	.29	453.	11.39	.21	.68	.27	1563.
6	4.04	.23	.70	.22	221.	3.28	.23	.70	.27	373.	1.89	.23	.70	.28	431.	2.63	.19	.66	.30	475.	11.84	.22	.69	.26	1499.
7	3.81	.23	.70	.23	239.	3.69	.23	.70	.30	477.	2.82	.23	.70	.31	527.	2.80	.17	.64	.31	533.	13.12	.22	.69	.28	1776.
8	3.13	.23	.70	.23	233.	2.76	.23	.70	.25	335.	2.80	.23	.70	.28	429.	2.72	.19	.66	.31	511.	11.40	.22	.69	.27	1508.
9	2.89	.23	.70	.21	192.	2.96	.23	.70	.27	385.	1.07	.23	.70	.29	468.	2.99	.19	.66	.32	573.	9.92	.22	.69	.27	1618.
10	3.51	.23	.70	.24	275.	3.53	.23	.70	.29	464.	1.19	.23	.70	.30	490.	1.61	.23	.70	.31	508.	9.85	.23	.70	.28	1738.
11	4.03	.23	.70	.23	265.	4.22	.21	.69	.30	501.	3.43	.23	.70	.34	619.	1.74	.23	.70	.32	543.	13.42	.23	.70	.29	1928.
12	4.10	.22	.70	.25	331.	4.21	.22	.70	.31	513.	1.69	.23	.70	.33	592.	2.07	.20	.67	.29	453.	12.07	.22	.69	.29	1890.
13	3.91	.23	.70	.24	286.	3.32	.23	.70	.29	468.	.29	.23	.70	.28	428.	2.23	.23	.70	.29	471.	9.75	.23	.70	.27	1653.
14	2.60	.23	.70	.20	140.	2.93	.23	.70	.28	428.	2.29	.23	.70	.28	423.	1.56	.23	.70	.30	474.	9.38	.23	.70	.26	1465.
15	3.32	.23	.70	.21	197.	2.94	.23	.70	.29	468.	2.39	.23	.70	.29	440.	2.33	.20	.68	.28	439.	10.97	.23	.70	.27	1543.
16	4.32	.22	.69	.24	267.	3.53	.23	.70	.29	466.	3.38	.23	.70	.31	531.	3.38	.15	.60	.33	594.	14.61	.21	.68	.29	1859.
17	3.85	.23	.70	.23	264.	3.23	.23	.70	.26	370.	3.04	.23	.70	.30	497.	3.11	.16	.61	.34	616.	13.23	.21	.68	.28	1746.
18	3.85	.23	.70	.24	294.	3.66	.23	.70	.29	466.	3.34	.23	.70	.32	566.	2.98	.17	.64	.34	644.	13.82	.22	.69	.30	1970.
19	3.58	.23	.70	.22	206.	3.53	.23	.70	.31	530.	.96	.23	.70	.27	389.	1.78	.23	.70	.32	573.	9.86	.23	.70	.28	1698.
20	3.12	.23	.70	.22	214.	2.91	.23	.70	.27	390.	1.91	.23	.70	.28	438.	2.38	.21	.68	.30	498.	10.32	.22	.70	.27	1540.
21	3.55	.23	.70	.23	248.	2.29	.23	.70	.27	396.	2.56	.23	.70	.30	502.	2.47	.22	.69	.33	604.	10.88	.23	.70	.28	1750.
22	3.31	.23	.70	.22	221.	2.74	.23	.70	.26	369.	1.13	.23	.70	.28	434.	2.44	.20	.68	.28	433.	9.63	.22	.70	.26	1456.
23	2.88	.23	.70	.22	208.	2.40	.23	.70	.28	408.	1.85	.23	.70	.29	454.	2.55	.21	.69	.27	382.	9.69	.23	.70	.26	1453.
24	3.05	.23	.70	.22	214.	2.75	.23	.70	.28	432.	2.75	.23	.70	.28	410.	2.16	.23	.70	.29	463.	10.71	.23	.70	.27	1520.
25	3.75	.23	.70	.25	307.	3.31	.23	.70	.28	439.	2.12	.23	.70	.29	451.	1.92	.23	.70	.29	457.	11.10	.23	.70	.27	1654.
26	2.65	.23	.70	.20	155.	2.52	.23	.70	.26	360.	1.94	.23	.70	.28	428.	2.22	.23	.70	.30	496.	9.32	.23	.70	.26	1439.

SAMPLE STATISTICS FOR SIMULATION OUTPUT. ROWS: 1=MEAN 2=STANDARD DEVIATION 3=COEF. OF VARIATION

	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	3.42	.23	.70	.23	236.	3.14	.23	.70	.28	431.	2.22	.23	.70	.29	474.	2.40	.20	.67	.30	503.	11.19	.22	.70	.27	1643.
2	.61	.01	.01	.01	51.	.54	.00	.00	.01	50.	.81	.00	.00	.02	71.	.48	.03	.03	.02	69.	1.56	.01	.01	.01	179.
3	.18	.04	.01	.07	.22	.17	.02	.00	.05	.12	.36	.00	.00	.07	.15	.20	.13	.05	.07	.14	.14	.03	.01	.04	.11

Table C.4. Example of output from ALHARV (continued).

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	3.29	.180	.653	3.25	.186	.660	2.26	.175	.651	2.01	.138	.601	10.81	.173	.645
2	3.48	.174	.644	3.16	.189	.664	2.28	.164	.637	1.27	.144	.634	10.19	.173	.647
3	4.08	.151	.613	3.43	.169	.632	1.66	.204	.681	1.05	.161	.654	10.23	.167	.634
4	2.86	.198	.680	3.36	.179	.653	2.43	.151	.619	1.85	.130	.590	10.50	.169	.641
5	3.43	.183	.656	3.51	.171	.633	2.43	.148	.619	.36	.112	.527	9.74	.167	.634
6	3.61	.170	.637	3.31	.185	.661	1.71	.205	.690	1.93	.137	.608	10.55	.174	.648
7	3.74	.167	.631	3.15	.190	.666	2.40	.160	.627	1.84	.121	.586	11.12	.164	.633
8	3.67	.172	.641	3.44	.170	.639	2.54	.149	.614	1.26	.126	.605	10.92	.161	.630
9	3.55	.170	.639	2.51	.216	.693	1.52	.204	.684	1.76	.129	.596	9.34	.180	.652
10	3.57	.175	.646	3.30	.177	.654	.98	.214	.694	.12	.182	.685	7.98	.181	.656
11	3.68	.168	.638	3.36	.175	.645	2.37	.169	.643	1.11	.184	.673	10.52	.172	.645
12	3.68	.165	.634	3.55	.169	.637	1.53	.212	.695	1.49	.154	.640	10.25	.172	.645
13	3.59	.169	.640	2.72	.216	.694	.57	.193	.671	1.57	.165	.654	8.46	.185	.662
14	3.44	.174	.640	3.41	.179	.650	1.99	.195	.677	.95	.198	.689	9.80	.182	.656
15	3.47	.172	.646	3.45	.175	.646	1.70	.203	.677	.49	.141	.614	9.11	.178	.650
16	3.75	.157	.630	3.50	.171	.642	2.57	.159	.631	1.68	.118	.553	11.49	.156	.623
17	3.64	.169	.638	3.44	.166	.624	2.48	.165	.635	1.05	.102	.538	10.62	.160	.623
18	3.71	.169	.638	3.54	.167	.626	2.58	.156	.618	1.96	.112	.566	11.78	.156	.618
19	3.44	.167	.639	3.14	.201	.678	.86	.203	.688	1.34	.173	.674	8.78	.184	.663
20	3.49	.168	.639	2.91	.212	.687	1.69	.201	.688	.46	.149	.642	8.56	.188	.665
21	4.04	.163	.627	2.87	.197	.675	2.26	.171	.647	1.73	.157	.636	10.90	.173	.645
22	3.54	.175	.646	3.17	.188	.665	1.26	.203	.679	1.61	.143	.625	9.58	.178	.653
23	3.69	.167	.632	3.00	.199	.675	1.32	.175	.650	1.75	.147	.624	9.75	.174	.646
24	3.52	.174	.648	3.34	.178	.651	2.38	.166	.641	0.00	0.000	0.000	9.24	.174	.647
25	3.46	.173	.647	3.39	.180	.654	1.70	.200	.674	1.21	.165	.665	9.76	.179	.656
26	3.25	.190	.666	2.98	.200	.677	1.70	.205	.686	.73	.152	.638	8.64	.193	.671

SAMPLE STATISTICS FOR SIMULATION OUTPUT. ROW 1=MEAN, ROW 2=STANDARD DEVIATION, ROW 3=COEF. OF VARIATION

1	3.56	.172	.642	3.24	.185	.657	1.89	.183	.658	1.25	.140	.597	9.95	.174	.646
2	.24	.009	.013	.27	.015	.020	.58	.022	.028	.59	.037	.129	.99	.009	.014
3	.07	.054	.020	.08	.082	.030	.30	.122	.042	.47	.265	.216	.10	.055	.021

Table C.4. Example of output from ALHARV (continued).

STARTING AND ENDING HARVEST DATES OF ALFALFA FOR THE WHOLE SIMULATION

YR	HARVEST 1 STARTING DATE	ENDING DATE	SPAN	HARVEST 2 STARTING DATE	ENDING DATE	SPAN	HARVEST 3 STARTING DATE	ENDING DATE	SPAN	HARVEST 4 STARTING DATE	ENDING DATE	SPAN
1	145.	162.	17.	190.	207.	17.	235.	244.	9.	286.	296.	10.
2	145.	165.	20.	190.	207.	17.	235.	248.	13.	286.	300.	14.
3	136.	155.	19.	181.	200.	19.	235.	248.	13.	294.	313.	19.
4	145.	159.	14.	190.	208.	18.	235.	254.	19.	286.	297.	11.
5	145.	163.	18.	190.	208.	18.	232.	250.	18.	286.	308.	22.
6	136.	156.	20.	190.	208.	18.	235.	246.	11.	286.	303.	17.
7	138.	159.	21.	184.	203.	19.	234.	248.	14.	286.	296.	10.
8	144.	163.	19.	189.	206.	17.	233.	247.	14.	286.	305.	19.
9	143.	163.	20.	190.	207.	17.	235.	252.	17.	286.	308.	22.
10	141.	158.	17.	186.	205.	19.	235.	248.	13.	295.	318.	23.
11	136.	154.	18.	181.	197.	16.	230.	244.	14.	295.	312.	17.
12	136.	152.	16.	181.	204.	23.	235.	247.	12.	286.	300.	14.
13	136.	156.	20.	190.	206.	16.	235.	256.	21.	286.	301.	15.
14	145.	162.	17.	190.	207.	17.	235.	245.	10.	295.	317.	22.
15	142.	161.	19.	189.	208.	19.	235.	249.	14.	286.	310.	24.
16	136.	156.	20.	185.	202.	17.	229.	241.	12.	286.	309.	23.
17	139.	162.	23.	187.	212.	25.	232.	241.	9.	286.	307.	21.
18	138.	158.	20.	184.	206.	22.	229.	240.	11.	286.	300.	14.
19	138.	156.	18.	190.	211.	21.	235.	251.	16.	295.	317.	22.
20	142.	160.	18.	190.	205.	15.	235.	248.	13.	286.	307.	21.
21	142.	169.	27.	190.	205.	15.	235.	245.	10.	286.	297.	11.
22	144.	163.	19.	190.	208.	18.	235.	249.	14.	286.	297.	11.
23	145.	167.	22.	190.	209.	19.	235.	255.	20.	286.	301.	15.
24	145.	162.	17.	190.	209.	19.	233.	245.	12.	287.	310.	23.
25	138.	155.	17.	189.	209.	20.	235.	248.	13.	288.	299.	11.
26	145.	162.	17.	190.	207.	17.	235.	247.	12.	286.	305.	19.

SAMPLE STATISTICS FOR SIMULATION OUTPUT. ROW 1=MEAN, ROW 2=STANDARD DEVIATION, ROW 3=COEF. OF VARIATION

1	140.96	159.92	18.96	187.92	206.31	18.38	233.92	247.54	13.62	287.81	305.12	17.31
2	3.70	4.18	2.54	3.20	3.22	2.35	1.94	4.01	3.20	3.51	6.82	4.80
3	.03	.03	.13	.02	.02	.13	.01	.02	.24	.01	.02	.28

Table C.4. Example of output from ALHARV (continued).

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	330.2	.200	.013	.680	.013	323.3	.167	.009	.635	.014	131.0	.187	.009	.667	.013	296.6	.144	.012	.610	.018
2	318.7	.202	.014	.679	.016	322.7	.164	.010	.631	.020	83.9	.188	.001	.670	.001	293.9	.147	.009	.627	.013
3	317.4	.170	.017	.639	.024	313.1	.153	.010	.618	.016	166.3	.204	.006	.680	.017	226.2	.157	.009	.626	.038
4	321.3	.200	.014	.681	.012	317.0	.179	.012	.653	.018	43.4	.186	.008	.662	.018	368.7	.134	.011	.597	.019
5	314.7	.197	.016	.667	.030	331.9	.164	.006	.630	.015	91.6	.182	.005	.664	.005	235.7	.128	.018	.582	.033
6	317.8	.193	.011	.670	.014	313.1	.165	.009	.630	.020	170.6	.205	.005	.690	.004	254.0	.145	.019	.616	.020
7	311.0	.193	.008	.666	.015	321.6	.163	.011	.630	.017	125.7	.183	.005	.664	.009	353.5	.133	.017	.595	.017
8	333.6	.187	.017	.663	.022	330.2	.160	.005	.625	.009	45.9	.174	.001	.654	.001	381.8	.137	.018	.606	.021
9	314.6	.208	.013	.684	.015	317.3	.178	.029	.648	.035	125.8	.203	.013	.685	.010	176.2	.129	.012	.596	.021
10	318.4	.191	.012	.668	.014	330.1	.167	.008	.636	.014	110.6	.211	.010	.693	.005	38.9	.143	.000	.624	.000
11	327.0	.184	.009	.659	.009	317.0	.162	.008	.631	.010	207.0	.190	.007	.674	.008	200.7	.152	.008	.621	.026
12	317.1	.181	.015	.655	.019	315.7	.159	.007	.625	.009	183.5	.206	.015	.688	.015	209.1	.149	.011	.628	.017
13	316.5	.209	.012	.687	.014	314.8	.174	.028	.645	.032	138.5	.193	.012	.675	.011	75.8	.141	.006	.631	.005
14	322.7	.193	.013	.666	.016	319.9	.164	.006	.627	.025	294.5	.197	.008	.683	.011	42.7	.160	.001	.628	.001
15	330.7	.189	.011	.670	.013	316.5	.162	.006	.628	.013	169.8	.204	.008	.677	.023	94.0	.144	.005	.613	.004
16	314.9	.180	.015	.655	.019	318.7	.152	.014	.625	.011	99.0	.178	.006	.660	.007	416.7	.136	.019	.589	.035
17	318.8	.188	.014	.667	.018	323.8	.159	.007	.617	.023	90.0	.189	.006	.672	.007	329.2	.127	.023	.572	.039
18	321.3	.186	.018	.652	.042	332.3	.160	.006	.626	.009	50.0	.177	.000	.640	.012	474.3	.130	.021	.589	.028
19	310.4	.201	.008	.678	.009	328.5	.168	.019	.640	.021	194.0	.197	.012	.684	.009	45.1	.136	.003	.657	.004
20	322.1	.203	.015	.679	.017	318.0	.175	.029	.646	.033	169.3	.201	.008	.688	.006	46.4	.149	.001	.642	.001
21	328.7	.199	.014	.676	.014	322.0	.158	.006	.619	.012	147.9	.182	.010	.663	.012	291.6	.156	.008	.633	.013
22	321.5	.191	.015	.666	.021	329.4	.174	.011	.647	.015	125.5	.203	.011	.679	.018	181.2	.146	.009	.627	.011
23	326.4	.201	.012	.676	.015	320.4	.163	.015	.628	.020	128.3	.185	.015	.665	.018	199.7	.144	.016	.618	.019
24	316.4	.192	.015	.672	.017	323.1	.165	.005	.633	.008	68.6	.198	.005	.678	.004	215.5	.152	.012	.624	.017
25	317.3	.189	.012	.668	.012	327.0	.168	.009	.638	.010	219.4	.192	.014	.672	.016	112.0	.158	.007	.655	.017
26	319.4	.203	.015	.681	.016	317.3	.192	.017	.666	.021	155.1	.204	.007	.686	.007	72.5	.151	.016	.638	.007

SAMPLE STATISTICS FOR SIMULATION OUTPUT. ROW 1=MEAN, ROW 2=STANDARD DEVIATION, ROW 3=COEF. OF VARIATION

1	320.3	.193	.013	.669	.017	321.7	.166	.011	.634	.017	136.0	.193	.008	.673	.010	216.6	.143	.011	.617	.017
2	6.0	.009	.003	.011	.007	5.9	.009	.007	.012	.008	58.5	.010	.004	.012	.006	126.2	.010	.007	.022	.011
3	.02	.047	.190	.017	.400	.02	.052	.632	.018	.444	.43	.054	.514	.018	.573	.58	.068	.581	.035	.665

Table C.4. Example of output from ALHARV (continued).

SUMMARY OF HOW FEEDS WERE USED EACH YEAR
THE NUMBER OF LACTATING COWS IS 160.
THE DAIRY HERD IS DIVIDED INTO SIX GROUPS IN THE FOLLOWING PROPORTIONS: 0.000 0.000 0.000 .600 .100 .300
UNITS ARE METRIC TONS OF DRY MATTER
RATIONS WERE FORMULATED BY SUBROUTINE COWFD

YR	FEEDS PRODUCED ON THE FARM				FEEDS PURCHASED		FEEDS SOLD				NET FED	MAXIMUM
	ALF	CS	HMC	CG	SBM	CG	ALF	CS	HMC	CG		INTAKE
1	1081.10	0.00	0.00	0.00	0.00	95.32	-63.92	0.00	0.00	0.00	1240.34	1240.34
2	1019.20	0.00	0.00	0.00	0.00	108.98	-112.16	0.00	0.00	0.00	1240.34	1240.34
3	1022.98	0.00	0.00	0.00	0.00	139.29	-78.08	0.00	0.00	0.00	1240.34	1240.34
4	1050.30	0.00	0.00	0.00	0.00	104.35	-85.69	0.00	0.00	0.00	1240.34	1240.34
5	973.88	0.00	0.00	0.00	3.05	156.75	-106.66	0.00	0.00	0.00	1240.34	1240.34
6	1055.47	0.00	0.00	0.00	0.00	103.21	-81.66	0.00	0.00	0.00	1240.34	1240.34
7	1111.70	0.00	0.00	0.00	.53	106.33	-21.79	0.00	0.00	0.00	1240.34	1240.34
8	1091.53	0.00	0.00	0.00	0.00	115.09	-33.72	0.00	0.00	0.00	1240.34	1240.34
9	933.92	0.00	0.00	0.00	2.15	133.15	-171.13	0.00	0.00	0.00	1240.34	1240.34
10	797.95	0.00	0.00	0.00	3.58	179.93	-258.88	0.00	0.00	0.00	1240.34	1240.34
11	1051.75	0.00	0.00	0.00	0.00	105.66	-82.93	0.00	0.00	0.00	1240.34	1240.34
12	1025.39	0.00	0.00	0.00	0.00	123.28	-91.66	0.00	0.00	0.00	1240.34	1240.34
13	845.67	0.00	0.00	0.00	2.85	148.90	-242.92	0.00	0.00	0.00	1240.34	1240.34
14	979.78	0.00	0.00	0.00	0.00	116.43	-144.13	0.00	0.00	0.00	1240.34	1240.34
15	911.02	0.00	0.00	0.00	.03	148.67	-180.62	0.00	0.00	0.00	1240.34	1240.34
16	1149.34	0.00	0.00	0.00	0.00	133.56	42.56	0.00	0.00	0.00	1240.34	1240.34
17	1061.72	0.00	0.00	0.00	3.71	163.48	-11.43	0.00	0.00	0.00	1240.34	1240.34
18	1177.93	0.00	0.00	0.00	1.90	146.12	85.61	0.00	0.00	0.00	1240.34	1240.34
19	878.01	0.00	0.00	0.00	1.72	142.63	-217.98	0.00	0.00	0.00	1240.34	1240.34
20	855.88	0.00	0.00	0.00	2.63	143.92	-237.92	0.00	0.00	0.00	1240.34	1240.34
21	1090.24	0.00	0.00	0.00	0.00	81.68	-68.42	0.00	0.00	0.00	1240.34	1240.34
22	957.66	0.00	0.00	0.00	0.00	107.29	-175.39	0.00	0.00	0.00	1240.34	1240.34
23	974.79	0.00	0.00	0.00	0.00	130.33	-135.22	0.00	0.00	0.00	1240.34	1240.34
24	923.59	0.00	0.00	0.00	0.00	137.33	-179.41	0.00	0.00	0.00	1240.34	1240.34
25	975.73	0.00	0.00	0.00	0.00	111.22	-153.39	0.00	0.00	0.00	1240.34	1240.34
26	864.35	0.00	0.00	0.00	3.24	121.19	-251.55	0.00	0.00	0.00	1240.34	1240.34

SAMPLE STATISTICS FOR SIMULATION OUTPUT. ROW 1=MEAN, ROW 2=STANDARD DEVIATION, ROW 3=COEF. OF VARIATION

1	994.65	0.00	0.00	0.00	.98	127.08	-117.63	0.00	0.00	0.00	1240.34	1240.34
2	98.66	0.00	0.00	0.00	1.39	23.23	89.46	0.00	0.00	0.00	.00	.00
3	.10	0.00	0.00	0.00	1.42	.18	-.76	0.00	0.00	0.00	.00	.00

Table C.4. Example of output from ALHARV (continued).

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 REPRESENT:
1=FCM 2=FCSTG 3=FUEL 4=RMM 5=LABFLD 6=LABFEED 7=FSC 8=CUSTCG 9=DRYCG 10=SUM(1-9) 11=FNET 12=CG 13=SUM(10-12) 14=MILK 15=NRET

1	26545.	16157.	3826.	6506.	4636.	4399.	19385.	0.	0.	81454.	5305.	13250.	100009.	334048.	234039.
2	26545.	15561.	3692.	6363.	4529.	4241.	19385.	0.	0.	80315.	9309.	15148.	104772.	334048.	229276.
3	26545.	15736.	3799.	6508.	4625.	4173.	19385.	0.	0.	80771.	6480.	19361.	106612.	334048.	227436.
4	26545.	15970.	3777.	6481.	4605.	4224.	19385.	0.	0.	80988.	7112.	14504.	102604.	334048.	231444.
5	26545.	14956.	3647.	6211.	4415.	4130.	19385.	0.	0.	79289.	9609.	21789.	110687.	334048.	223361.
6	26545.	16120.	3787.	6477.	4615.	4285.	19385.	0.	0.	81214.	6778.	14346.	102337.	334048.	231711.
7	26545.	16773.	3934.	6605.	4724.	4447.	19385.	0.	0.	82413.	1939.	14779.	99131.	334048.	234917.
8	26545.	16157.	3847.	6498.	4623.	4414.	19385.	0.	0.	81468.	2799.	15997.	100264.	334048.	233784.
9	26545.	14654.	3563.	6337.	4457.	3873.	19385.	0.	0.	78814.	14736.	18507.	112057.	334048.	221991.
10	26545.	13541.	3302.	6062.	4228.	3457.	19385.	0.	0.	76522.	22374.	25010.	123906.	334048.	210142.
11	26545.	15918.	3840.	6600.	4687.	4388.	19385.	0.	0.	81364.	6883.	14686.	102933.	334048.	231115.
12	26545.	15737.	3684.	6412.	4551.	4180.	19385.	0.	0.	80494.	7608.	17137.	105239.	334048.	228809.
13	26545.	13605.	3358.	6177.	4324.	3668.	19385.	0.	0.	77062.	20870.	20697.	118629.	334048.	215419.
14	26545.	15075.	3615.	6343.	4495.	4069.	19385.	0.	0.	79527.	11963.	16184.	107674.	334048.	226374.
15	26545.	14196.	3541.	6229.	4383.	3880.	19385.	0.	0.	78160.	14999.	20665.	113825.	334048.	220223.
16	26545.	17211.	4064.	6706.	4789.	4646.	19385.	0.	0.	83346.	-2937.	18565.	98975.	334048.	235073.
17	26545.	16055.	3845.	6458.	4597.	4343.	19385.	0.	0.	81227.	1868.	22724.	105819.	334048.	228229.
18	26545.	17313.	4024.	6676.	4784.	4709.	19385.	0.	0.	83438.	-5435.	20310.	98313.	334048.	235735.
19	26545.	13901.	3449.	6294.	4410.	3784.	19385.	0.	0.	77768.	18520.	19826.	116113.	334048.	217935.
20	26545.	13622.	3457.	6161.	4326.	3538.	19385.	0.	0.	77034.	20399.	20004.	117437.	334048.	216611.
21	26545.	16298.	3794.	6447.	4609.	4407.	19385.	0.	0.	81485.	5679.	11354.	98518.	334048.	235530.
22	26545.	14711.	3619.	6416.	4521.	4052.	19385.	0.	0.	79249.	14557.	14913.	108719.	334048.	225329.
23	26545.	14964.	3588.	6231.	4428.	4109.	19385.	0.	0.	79251.	11223.	18116.	108591.	334048.	225457.
24	26545.	14439.	3584.	6203.	4379.	3903.	19385.	0.	0.	78438.	14891.	19089.	112419.	334048.	221629.
25	26545.	15005.	3672.	6452.	4563.	4051.	19385.	0.	0.	79674.	12732.	15460.	107865.	334048.	226183.
26	26545.	13764.	3445.	6141.	4328.	3728.	19385.	0.	0.	77337.	21684.	16846.	115866.	334048.	218182.

SAMPLE STATISTICS FOR SIMULATION RUN: ROWS 1=MEAN 2=STANDARD DEVIATION 3=COEF OF VARIATION

1	26545.	15286.	3683.	6334.	4524.	4119.	19385.	0.	0.	79927.	10075.	17664.	107666.	334048.	226382.
2	0.	1114.	194.	172.	149.	321.	0.	0.	0.	1926.	7402.	3230.	7034.	0.	7034.
3	.00	.07	.05	.03	.03	.08	0.00	0.00	0.00	.02	.73	.18	.07	0.00	.03

Table C.4. Example of output from ALHARV (continued).

MATRIX TRESS=TOTAL RESOURCE USE AND INVESTMENT.
EACH ROW EQUALS ONE SIMULATION YEAR.
COLUMNS REPRESENT:
1=M/INVS 2=STG/INVS 3=FUEL(L) 4=M/RMS 5=LABFLD(HRS) 6=LABFEED(HRS) 7=CROPS(HA) 8=CG(HA) 9=CG(DMT)

1	136600.	101500.	12382.	6506.	927.	880.	125.	0.	0.	0.	0.	0.	0.	0.	0.
2	136600.	101500.	11947.	6363.	906.	848.	125.	0.	0.	0.	0.	0.	0.	0.	0.
3	136600.	101500.	12293.	6508.	925.	835.	125.	0.	0.	0.	0.	0.	0.	0.	0.
4	136600.	101500.	12225.	6481.	921.	845.	125.	0.	0.	0.	0.	0.	0.	0.	0.
5	136600.	101500.	11803.	6211.	883.	826.	125.	0.	0.	0.	0.	0.	0.	0.	0.
6	136600.	101500.	12255.	6477.	923.	857.	125.	0.	0.	0.	0.	0.	0.	0.	0.
7	136600.	101500.	12731.	6605.	945.	889.	125.	0.	0.	0.	0.	0.	0.	0.	0.
8	136600.	101500.	12430.	6428.	925.	883.	125.	0.	0.	0.	0.	0.	0.	0.	0.
9	136600.	101500.	11530.	6337.	891.	775.	125.	0.	0.	0.	0.	0.	0.	0.	0.
10	136600.	101500.	10687.	6062.	846.	691.	125.	0.	0.	0.	0.	0.	0.	0.	0.
11	136600.	101500.	12429.	6600.	937.	878.	125.	0.	0.	0.	0.	0.	0.	0.	0.
12	136600.	101500.	11922.	6412.	910.	836.	125.	0.	0.	0.	0.	0.	0.	0.	0.
13	136600.	101500.	10867.	6177.	865.	734.	125.	0.	0.	0.	0.	0.	0.	0.	0.
14	136600.	101500.	11700.	6343.	899.	814.	125.	0.	0.	0.	0.	0.	0.	0.	0.
15	136600.	101500.	11461.	6229.	877.	776.	125.	0.	0.	0.	0.	0.	0.	0.	0.
16	136600.	101500.	13152.	6706.	958.	929.	125.	0.	0.	0.	0.	0.	0.	0.	0.
17	136600.	101500.	12443.	6458.	919.	869.	125.	0.	0.	0.	0.	0.	0.	0.	0.
18	136600.	101500.	13022.	6676.	957.	942.	125.	0.	0.	0.	0.	0.	0.	0.	0.
19	136600.	101500.	11163.	6294.	882.	757.	125.	0.	0.	0.	0.	0.	0.	0.	0.
20	136600.	101500.	11186.	6161.	865.	708.	125.	0.	0.	0.	0.	0.	0.	0.	0.
21	136600.	101500.	12277.	6447.	922.	881.	125.	0.	0.	0.	0.	0.	0.	0.	0.
22	136600.	101500.	11712.	6416.	904.	810.	125.	0.	0.	0.	0.	0.	0.	0.	0.
23	136600.	101500.	11613.	6231.	896.	822.	125.	0.	0.	0.	0.	0.	0.	0.	0.
24	136600.	101500.	11599.	6203.	876.	781.	125.	0.	0.	0.	0.	0.	0.	0.	0.
25	136600.	101500.	11883.	6452.	913.	810.	125.	0.	0.	0.	0.	0.	0.	0.	0.
26	136600.	101500.	11148.	6141.	866.	746.	125.	0.	0.	0.	0.	0.	0.	0.	0.

SAMPLE STATISTICS FOR SIMULATION RUN: ROWS 1=MEAN 2=STANDARD DEVIATION 3=COEF OF VARIATION

1	136600.	101500.	11918.	6384.	905.	824.	125.	0.	0.	0.	0.	0.	0.	0.	0.
2	0.	0.	629.	172.	30.	64.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3	0.00	0.00	.05	.03	.03	.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX D

EXPERIMENTAL DATA OF ALFALFA DRYING

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EXPERIMENTAL DATA OF ALFALFA DRYING

Field experiments were conducted in Chatham, Michigan during the first and second alfalfa cuts in 1980 and during the first cut in 1981. Appendix D lists the original data that were collected during those three experiments. The measurement technique is described in Savoie et al. (1981).

Table D.1 represents drying rate measurements as a function of several machinery and environmental factors. Table D.2 shows how rain was adsorbed by field curing alfalfa. Table D.3 illustrates how dew was adsorbed under a variety of environmental conditions.

Table D.1. Alfalfa drying data collected in Chatham, Michigan in June and July 1980 and in June 1981. Each observation contains fourteen variables. Environmental variables are average values during the drying period. The variables are:

1. DMDT, drying rate (dec. d.b. moisture content per hour);
2. MO, the initial moisture content (dec., d.b. = dry basis);
3. MF, the final moisture content;
4. SR, solar radiation intensity (cal/min/cm2);
5. TDB, dry bulb temperature (C);
6. TWB, wet bulb temperature (C);
7. WV, wind velocity (m/s);
8. YDM, yield of dry matter (kg/ha);
9. AM, alfalfa maturity factor equal to the ratio in equation 6.18;
10. WR, windrow to swath ratio (equation 6.4);
11. RK, raking dummy variable
    RK = 1, on the day of raking
    RK = 0 otherwise
12. CD, conditioning dummy variable
    CD = 0 for cutterbar mowing
    CD = 1 for mower-conditioner
    CD = 2 after a second conditioning treatment;
13. RNDW, rain and dew dummy variable
    RNDW = 0 if no rain or dew has occurred
    RNDW = 1 if all the moisture that evaporated during the trial was from rain or dew.
    RNDW can be a fraction between 0 and 1 if part of the evaporated water was dew or rain and the other part was moisture initially in the plant;
14. DAY, a day factor
    DAY = 0 on the first curing day
    DAY = 1 on all subsequent curing days.

DMDT	MO	MF	SR	TDB	TWB	WV	YDM	AM	WR	RK	CD	RNDW	DAY
.329	3.655	2.617	1.17	19.6	14.0	2.8	4129.	1.0	.782	0.	0.	0.	0.
.101	2.617	2.222	0.43	15.0	11.0	0.8	4129.	1.0	.782	0.	0.	0.	0.
.304	3.720	2.807	0.81	13.0	10.8	4.1	2260.	.90	.782	0.	0.	0.	0.
.279	2.807	2.361	0.86	13.3	10.5	3.4	2260.	.90	.782	0.	0.	0.	0.
.130	2.361	2.112	0.72	13.4	10.7	3.8	2260.	.90	.782	0.	0.	0.	0.
.049	2.112	1.926	0.22	11.0	9.0	2.8	2260.	.90	.782	0.	0.	0.	0.
.472	3.398	2.400	1.02	23.6	18.6	4.5	2579.	0.6	.782	0.	0.	0.	0.
.344	2.400	1.234	0.51	23.3	19.6	3.1	2579.	0.6	.782	0.	0.	0.	0.

DMDT	MO	MF	SR	TDB	TWB	WV	YDM	AM	WR	RK	CD	RNDW	DAY
.454	3.302	1.654	0.73	26.6	22.6	1.1	1515.	.55	.782	0.	0.	0.	0.
.219	1.654	0.357	0.36	25.8	21.7	1.7	1515.	.55	.782	0.	0.	0.	0.
.271	3.607	2.481	0.27	20.8	18.4	3.0	2398.	.50	.782	0.	0.	0.	0.
.617	4.446	3.202	0.99	20.0	15.7	0.9	4181.	.95	.852	0.	0.	0.	0.
.313	3.202	2.409	0.97	21.0	15.5	0.9	4181.	.95	.852	0.	0.	0.	0.
.179	2.409	2.122	0.60	21.4	16.0	1.4	4181.	.95	.852	0.	0.	0.	0.
.082	2.122	1.833	0.20	19.4	15.7	2.5	4181.	.95	.852	0.	0.	0.	0.
.484	4.108	3.688	1.10	14.1	12.0	3.3	4817.	.85	.852	0.	0.	0.	0.
.237	3.688	2.715	1.18	20.8	15.5	1.5	4702.	.80	.852	0.	0.	0.	0.
.123	2.715	2.041	0.42	16.3	12.9	2.5	4817.	.85	.852	0.	0.	0.	0.
.635	3.932	3.212	1.06	17.9	14.3	0.8	4702.	.80	.852	0.	0.	0.	0.
.237	3.212	2.057	1.20	20.8	15.5	1.5	4702.	.80	.852	0.	0.	0.	0.
.113	2.057	1.509	0.40	20.2	14.1	2.1	4702.	.80	.852	0.	0.	0.	0.
.415	3.525	2.502	0.85	20.8	16.2	3.2	4019.	.75	.852	0.	0.	0.	0.
.196	2.502	1.759	1.20	23.9	18.4	3.5	4019.	.75	.852	0.	0.	0.	0.
.097	1.759	1.221	0.51	22.2	16.7	3.1	4019.	.75	.852	0.	0.	0.	0.
.095	2.007	1.881	0.60	21.4	16.0	1.4	4824.	.95	.424	1.	0.	0.	0.
.067	1.881	1.646	0.20	19.4	15.7	2.5	4824.	.95	.424	1.	0.	0.	0.
.087	2.354	1.897	0.42	16.3	12.9	2.5	4868.	.85	.424	1.	0.	0.	0.
.115	1.753	1.224	0.40	20.2	14.1	2.1	3354.	.80	.424	1.	0.	0.	0.
.109	1.968	1.386	0.51	22.2	16.7	3.1	4121.	.75	.424	1.	0.	0.	0.
.601	4.446	4.015	1.11	20.5	16.0	0.9	4005.	.95	.443	0.	1.	0.	0.
.276	4.015	3.256	.93	21.0	15.5	0.9	4005.	.95	.443	0.	1.	0.	0.
.261	3.256	2.879	0.48	21.4	16.0	1.4	4005.	.95	.443	0.	1.	0.	0.
.070	2.879	2.641	0.16	19.4	15.7	2.5	4005.	.95	.443	0.	1.	0.	0.
.237	4.108	3.610	0.73	12.2	10.9	3.3	4464.	.85	.443	0.	1.	0.	0.
.277	3.610	2.549	1.16	17.9	14.1	3.8	4464.	.85	.443	0.	1.	0.	0.
.100	2.549	1.976	0.55	16.3	12.9	2.5	4464.	.85	.443	0.	1.	0.	0.
.298	3.932	3.396	1.00	17.9	14.3	0.8	4162.	.80	.443	0.	1.	0.	0.
.247	3.396	2.229	1.20	20.8	15.2	1.5	4162.	.80	.443	0.	1.	0.	0.
.134	2.229	1.558	0.48	20.2	14.1	2.1	4162.	.80	.443	0.	1.	0.	0.
.435	3.525	2.763	0.98	20.8	16.2	3.2	4426.	.75	.443	0.	1.	0.	0.
.239	2.763	1.767	1.20	23.9	18.4	3.5	4426.	.75	.443	0.	1.	0.	0.
.132	1.767	1.082	0.45	22.2	16.7	3.1	4426.	.75	.443	0.	1.	0.	0.
.286	3.655	2.593	1.17	19.6	14.0	2.8	4685.	1.0	.443	0.	1.	0.	0.
.114	2.593	2.122	0.43	15.0	11.0	0.8	4685.	1.0	.443	0.	1.	0.	0.
.225	3.720	3.316	0.70	13.0	10.6	4.1	6005.	.90	.443	0.	1.	0.	0.
.231	3.316	2.868	0.86	13.3	10.5	3.4	6005.	.90	.443	0.	1.	0.	0.
.153	2.868	2.628	0.72	13.4	10.7	3.8	6005.	.90	.443	0.	1.	0.	0.
.044	2.628	2.455	0.22	11.0	9.0	2.8	6005.	.90	.443	0.	1.	0.	0.
.760	3.398	2.993	0.80	25.0	20.2	4.5	3138.	.60	.443	0.	1.	0.	0.
.202	2.993	2.246	0.51	23.3	19.6	3.1	3138.	.60	.443	0.	1.	0.	0.
.337	3.302	1.863	0.74	25.3	21.8	1.1	2809.	.55	.443	0.	1.	0.	0.

DMDT	MO	MF	SR	TDB	TWB	WV	YDM	AM	WR	RK	CD	RNDW	DAY
.157	1.863	0.919	0.36	25.7	21.7	1.7	2984.	.55	.443	0.	1.	0.	0.
.261	3.607	2.346	0.27	20.4	18.3	3.0	2093.	.50	.443	0.	1.	0.	0.
.281	3.156	2.800	0.60	21.4	16.0	1.4	4406.	.95	.394	1.	1.	0.	0.
.101	2.800	2.459	0.20	19.4	15.7	2.5	4406.	.95	.394	1.	1.	0.	0.
.153	2.536	1.685	0.42	16.3	12.9	2.5	4358.	.85	.394	1.	1.	0.	0.
.128	1.988	1.372	0.40	20.2	14.1	2.1	3499.	.80	.394	1.	1.	0.	0.
.118	1.675	1.087	0.51	22.2	16.7	3.1	4196.	.75	.394	1.	1.	0.	0.
.570	4.446	3.715	1.03	20.3	15.9	0.9	4967.	.95	.705	0.	1.	0.	0.
.306	3.715	2.883	0.97	21.0	15.5	0.9	4967.	.95	.705	0.	1.	0.	0.
.263	2.883	2.498	0.60	21.4	16.0	1.4	4967.	.95	.705	0.	1.	0.	0.
.075	2.498	2.229	0.20	19.4	15.7	2.5	4967.	.95	.705	0.	1.	0.	0.
.377	4.108	3.517	1.10	13.6	11.7	3.3	4160.	.85	.705	0.	1.	0.	0.
.309	3.517	2.271	1.18	17.9	14.1	3.8	4160.	.85	.705	0.	1.	0.	0.
.126	2.271	1.571	0.42	16.3	12.9	2.5	4160.	.85	.705	0.	1.	0.	0.
.440	3.932	3.007	0.90	16.2	13.6	0.8	4150.	0.80	.705	0.	1.	0.	0.
.284	3.007	1.772	1.20	20.8	15.5	1.5	4150.	.80	.705	0.	1.	0.	0.
.122	1.772	1.115	0.40	20.2	14.1	2.1	4150.	.80	.705	0.	1.	0.	0.
.677	3.525	2.701	0.98	21.9	17.1	3.2	4597.	.75	.705	0.	1.	0.	0.
.267	2.701	1.552	1.20	23.9	18.4	3.5	4597.	.75	.705	0.	1.	0.	0.
.097	1.552	1.057	0.51	22.2	16.7	3.1	4597.	.75	.705	0.	1.	0.	0.
.263	2.649	2.293	0.60	21.4	16.0	1.4	4948.	.95	.394	1.	1.	0.	0.
.102	2.293	1.938	0.20	19.4	15.7	2.5	4948.	.95	.394	1.	1.	0.	0.
.119	2.028	1.389	0.42	16.3	12.9	2.5	3906.	.85	.394	1.	1.	0.	0.
.144	1.905	1.173	0.40	20.2	14.1	2.1	3968.	.80	.394	1.	1.	0.	0.
.097	1.337	0.868	0.51	22.2	16.7	3.1	4305.	.75	.394	1.	1.	0.	0.
.079	1.937	1.446	0.88	14.1	12.0	3.3	3910.	.95	.852	0.	0.	0.	1.
.041	1.446	1.207	0.74	17.2	13.5	2.8	3910.	.95	.852	0.	0.	0.	1.
.056	1.537	1.186	0.88	14.1	12.0	3.3	4824.	.95	.424	0.	0.	0.	1.
.043	1.186	0.935	0.74	17.2	13.5	2.8	4824.	.95	.424	0.	0.	0.	1.
.044	1.354	1.099	0.74	17.2	13.5	2.8	4080.	.95	.424	1.	0.	0.	1.
.130	1.912	1.368	1.20	20.9	15.3	1.5	4472.	.85	.852	0.	0.	0.	1.
.061	1.368	1.029	0.40	20.2	14.2	2.0	4472.	.85	.852	0.	0.	0.	1.
.110	1.904	1.442	1.20	20.9	15.3	1.5	4936.	.85	.424	0.	0.	0.	1.
.044	1.442	1.198	0.40	20.2	14.2	2.0	4936.	.85	.424	0.	0.	0.	1.
.099	1.397	0.868	0.40	20.2	14.2	2.0	5437.	.85	.424	1.	0.	0.	1.
.109	1.254	0.582	0.94	19.8	15.7	3.1	5072.	.85	.852	0.	0.	0.	1.
.022	0.641	0.509	0.76	22.2	16.7	3.1	5072.	.85	.852	0.	0.	0.	1.
.067	1.182	0.768	0.94	19.8	15.7	3.1	5162.	.85	.424	0.	0.	0.	1.
.030	0.768	0.594	0.76	22.2	16.7	3.1	5162.	.85	.424	0.	0.	0.	1.
.025	0.508	0.363	0.76	22.2	16.7	3.1	3872.	.85	.424	1.	0.	0.	1.
.050	0.816	0.509	0.80	20.3	14.7	2.0	3294.	.95	.852	0.	0.	0.	1.
.031	0.762	0.573	0.80	20.3	14.7	2.0	4452.	.95	.424	0.	0.	0.	1.
.035	0.811	0.605	0.80	20.3	14.7	2.0	4526.	.95	.424	1.	0.	0.	1.

DMDT	MO	MF	SR	TDB	TWB	WV	YDM	AM	WR	RK	CD	RNDW	DAY
.055	1.635	1.279	0.87	22.4	17.4	3.1	5206.	.80	.852	0.	0.	0.	1.
.082	1.302	0.838	0.57	22.3	16.7	3.1	5206.	.80	.852	0.	0.	0.	1.
.071	1.315	0.859	0.87	22.4	17.4	3.1	3354.	.80	.424	0.	0.	0.	1.
.083	0.859	0.388	0.57	22.3	16.7	3.1	3354.	.80	.424	0.	0.	0.	1.
.079	1.226	0.791	0.57	22.3	16.7	3.1	5042.	.80	.424	1.	0.	0.	1.
.087	1.074	0.722	1.05	20.5	16.5	2.2	5136.	.80	.852	0.	0.	0.	1.
.086	0.948	0.604	1.05	20.5	16.5	2.2	4198.	.80	.424	0.	0.	0.	1.
.070	1.106	0.831	1.05	20.5	16.5	2.2	5276.	.80	.424	1.	0.	0.	1.
.143	1.170	0.596	1.05	20.5	16.5	2.2	3962.	.75	.852	0.	0.	0.	1.
.098	1.485	1.090	1.05	20.5	16.5	2.2	4141.	.75	.424	0.	0.	0.	1.
.125	1.130	0.638	1.05	20.5	16.5	2.2	4013.	.75	.424	1.	0.	0.	1.
.131	2.415	1.595	0.88	14.1	12.0	3.3	4913.	.95	.705	0.	1.	0.	1.
.112	1.900	1.208	0.88	14.1	12.0	3.3	4948.	.95	.394	0.	1.	0.	1.
.074	1.590	1.149	0.74	17.2	13.5	2.8	4913.	.95	.705	0.	1.	0.	1.
.018	1.208	1.102	0.74	17.2	13.5	2.8	4948.	.95	.394	0.	1.	0.	1.
.082	1.588	1.113	0.74	17.2	13.5	2.8	5097.	.95	.394	1.	1.	0.	1.
.064	0.803	0.408	0.80	20.3	14.7	2.0	5295.	.95	.705	0.	1.	0.	1.
.014	0.574	0.487	0.80	20.3	14.7	2.0	5022.	.95	.394	0.	1.	0.	1.
.044	0.784	0.514	0.80	20.3	14.7	2.0	4532.	.95	.391	1.	1.	0.	1.
.111	1.419	0.968	1.20	20.9	15.3	1.5	3646.	.85	.705	0.	1.	0.	1.
.090	1.186	0.822	1.20	20.9	15.3	1.5	3906.	.85	.394	0.	1.	0.	1.
.073	0.952	0.535	0.40	20.2	14.2	2.0	3643.	.85	.705	0.	1.	0.	1.
.051	0.822	0.535	0.40	20.2	14.2	2.0	3906.	.85	.394	0.	1.	0.	1.
.067	0.970	0.603	0.40	20.2	14.2	2.0	5442.	.85	.394	1.	1.	0.	1.
.063	0.708	0.323	0.94	19.8	15.7	3.1	3721.	.85	.705	0.	1.	0.	1.
.036	0.595	0.375	0.94	19.8	15.7	3.1	4674.	.85	.394	0.	1.	0.	1.
.010	0.320	0.261	0.76	22.2	16.7	3.1	3721.	.85	.705	0.	1.	0.	1.
.026	0.375	0.219	0.76	22.2	16.7	3.1	4674.	.85	.394	0.	1.	0.	1.
.008	0.322	0.275	0.76	22.2	16.7	3.1	3572.	.85	.394	1.	1.	0.	1.
.081	1.277	0.768	0.87	22.4	17.4	3.1	4198.	.80	.705	0.	1.	0.	1.
.092	1.322	0.751	0.87	22.4	17.4	3.1	3967.	.80	.394	0.	1.	0.	1.
.063	.782	0.419	0.57	22.3	16.7	3.1	4198.	.80	.705	0.	1.	0.	1.
.035	0.751	0.548	0.57	22.3	16.7	3.1	3698.	.80	.394	0.	1.	0.	1.
.016	0.730	0.636	0.57	22.3	16.7	3.1	4237.	.80	.394	1.	1.	0.	1.
.140	0.871	0.296	1.05	20.5	16.5	2.2	3336.	.80	.705	0.	1.	0.	1.
.087	0.966	0.610	1.05	20.5	16.5	2.2	4102.	.80	.394	0.	1.	0.	1.
.116	0.851	0.391	1.05	20.5	16.5	2.2	5061.	.80	.394	1.	1.	0.	1.
.090	1.020	0.655	1.05	20.5	16.5	2.2	4733.	.75	.705	0.	1.	0.	1.
.098	0.971	0.578	1.05	20.5	16.5	2.2	4305.	.75	.394	0.	1.	0.	1.
.098	1.151	0.768	1.05	20.5	16.5	2.2	4618.	.75	.394	1.	1.	0.	1.
.122	2.678	1.905	0.88	14.1	12.0	3.3	4081.	.95	.479	0.	1.	0.	1.
.099	2.471	1.843	0.88	14.1	12.0	3.3	4406.	.95	.394	0.	1.	0.	1.
.080	1.905	1.438	0.74	17.2	13.5	2.8	4081.	.95	.479	0.	1.	0.	1.

DMDT	MO	MF	SR	TDB	TWB	WV	YDM	AM	WR	RK	CD	RNDW	DAY
.098	1.843	1.367	0.74	17.2	13.5	2.8	4406.	.95	.394	0.	1.	0.	1.
.098	1.718	1.162	0.74	17.2	13.5	2.8	4099.	.95	.394	1.	1.	0.	1.
.029	0.861	0.687	0.80	20.3	14.7	2.0	4064.	.95	.479	0.	1.	0.	1.
.038	0.814	0.587	0.80	20.3	14.7	2.0	4252.	.95	.394	0.	1.	0.	1.
.063	1.014	0.636	0.80	20.3	14.7	2.0	4099.	.95	.394	1.	1.	0.	1.
.127	1.731	1.236	1.20	20.9	15.3	1.5	4741.	.85	.479	0.	1.	0.	1.
.095	1.323	0.954	1.20	20.9	15.3	1.5	4358.	.85	.394	0.	1.	0.	1.
.037	0.954	0.742	0.40	20.2	14.2	2.0	4358.	.85	.394	0.	1.	0.	1.
.070	1.247	0.843	0.40	20.2	14.2	2.0	4741.	.85	.479	0.	1.	0.	1.
.085	1.194	0.716	0.40	20.2	14.2	2.0	4019.	.85	.394	1.	1.	0.	1.
.060	0.925	0.567	0.94	19.8	15.7	3.1	5413.	.85	.479	0.	1.	0.	1.
.072	0.870	0.441	0.94	19.8	15.7	3.1	4188.	.85	.394	0.	1.	0.	1.
.035	0.525	0.313	0.76	22.2	16.7	3.1	5413.	.85	.479	0.	1.	0.	1.
.023	0.441	0.305	0.76	22.2	16.7	3.1	4188.	.85	.394	0.	1.	0.	1.
.045	0.601	0.339	0.76	22.2	16.7	3.1	4069.	.85	.394	1.	1.	0.	1.
.113	1.699	0.982	0.87	22.4	17.4	3.1	4422.	.80	.479	0.	1.	0.	1.
.107	1.525	0.845	0.87	22.4	17.4	3.1	3499.	.80	.394	0.	1.	0.	1.
.061	0.931	0.581	0.57	22.3	16.7	3.1	4422.	.80	.479	0.	1.	0.	1.
.067	0.845	0.463	0.57	22.3	16.7	3.1	3499.	.80	.394	0.	1.	0.	1.
.031	1.061	0.888	0.57	22.3	16.7	3.1	4305.	.80	.394	1.	1.	0.	1.
.114	0.916	0.458	1.05	20.5	16.5	2.2	4331.	.80	.479	0.	1.	0.	1.
.118	1.214	0.734	1.05	20.5	16.5	2.2	3902.	.80	.394	0.	1.	0.	1.
.125	1.221	0.726	1.05	20.5	16.5	2.2	4514.	.80	.394	1.	1.	0.	1.
.152	1.185	0.571	1.05	20.5	16.5	2.2	4919.	.75	.479	0.	1.	0.	1.
.146	1.442	0.852	1.05	20.5	16.5	2.2	4196.	.75	.394	0.	1.	0.	1.
.190	1.157	0.410	1.05	20.5	16.5	2.2	3671.	.75	.394	1.	1.	0.	1.
.225	3.815	2.505	.38	15.9	15.2	3.2	3967.	.95	.852	0.	0.	1.	1.
.113	2.505	1.825	.57	20.6	17.8	2.5	3967.	.95	.852	0.	0.	.74	1.
.094	2.638	2.093	.38	15.9	15.2	3.2	4824.	.95	.424	0.	0.	1.	1.
.091	2.093	1.545	.57	20.6	17.8	2.5	4824.	.95	.424	0.	0.	.82	1.
.179	4.422	3.376	.38	15.9	15.2	3.2	4973.	.95	.705	0.	1.	1.	1.
.161	3.376	2.411	.57	20.6	17.8	2.5	4980.	.95	.705	0.	1.	1.	1.
.192	3.972	2.851	.38	15.9	15.2	3.2	4948.	.95	.394	0.	1.	1.	1.
.147	2.851	1.968	.57	20.6	17.8	2.5	4948.	.95	.394	0.	1.	1.	1.
.179	4.526	3.478	.38	15.9	15.2	3.2	4088.	.95	.479	0.	1.	1.	1.
.154	3.478	2.552	.57	20.6	17.8	2.5	4088.	.95	.479	0.	1.	.89	1.
.092	4.179	3.643	.38	15.9	15.2	3.2	4406.	.95	.394	0.	1.	1.	1.
.153	3.643	2.762	.57	20.6	17.8	2.5	4406.	.95	.394	0.	1.	1.	1.
.554	5.280	2.234	.83	22.3	19.4	3.1	2497.	.50	.852	0.	0.	.90	1.
.134	2.234	1.311	.24	21.8	19.0	2.4	2643.	.50	.852	0.	0.	0.	1.
.133	2.060	1.170	.24	21.8	19.0	2.4	2291.	.50	.424	0.	0.	0.	1.
.637	5.443	1.953	.83	22.3	19.4	3.1	2114.	.50	.852	0.	1.	.88	1.
.138	1.893	0.965	.24	21.8	19.0	2.4	2114.	.50	.424	0.	1.	0.	1.

DMDT	MO	MF	SR	TDB	TWB	WV	YDM	AM	WR	RK	CD	RNDW	DAY
.560	4.991	1.921	.83	22.3	19.4	3.1	2858.	.50	1.000	0.	0.	.78	1.
.131	1.878	1.002	.24	21.8	19.0	2.4	2858.	.50	.424	0.	0.	0.	1.
.607	5.310	2.176	.83	22.3	19.4	3.1	2033.	.50	.479	0.	1.	.92	1.
.141	2.176	1.161	.24	21.8	19.0	2.4	2863.	.50	.479	0.	1.	0.	1.
.146	2.014	1.006	.24	21.8	19.0	2.4	1355.	.50	.394	0.	1.	0.	1.
.601	4.690	1.606	.83	22.3	19.4	3.1	2467.	.50	.479	0.	2.	.80	1.
.137	1.388	0.442	.24	21.8	19.0	2.4	2467.	.50	.394	0.	2.	0.	1.
.548	4.128	1.308	.83	22.3	19.4	3.1	1690.	.50	1.000	0.	1.	.66	1.
.052	1.202	0.843	.24	21.8	19.0	2.4	1690.	.50	.394	0.	1.	0.	1.

Table D.2. Rain adsorbed by mowed alfalfa. Data collected in Chatham, Michigan.

Previous treatments (1)	No of samples	Moisture cont. (d.b.) Before rain	After rain	Change	YDM (kg/ha)	WR	RAIN (mm)	Percent of rain absorbed
CB	6	1.999	3.815	1.816	3967.	.852	5.3	16.5
CB-R	2	1.646	2.638	0.992	4824.	.424	5.3	24.7
MC	6	2.297	4.422	2.125	4973.	.705	5.3	28.3
MC-R	2	1.938	3.972	2.034	4948.	.394	5.3	54.4
MCW	6	2.657	4.526	1.869	3872.	.479	5.3	28.5
MCW-R	2	2.459	4.179	1.720	4406.	.394	5.3	41.0
CB	4	2.548	5.280	2.738	2467.	.782	30.7	2.8
CB-CR	2	2.378	5.443	3.065	2114.	.782	30.7	2.7
CB-TD	2	2.582	4.991	2.409	2858.	1.000	30.7	2.2
MCW	4	2.431	5.310	2.879	2109.	.407	30.7	4.9
MCW-CR	2	2.218	4.690	2.472	2467.	.407	30.7	4.9
MCW-TD	2	2.272	4.128	1.856	1690.	1.000	30.7	1.0
CB	4	0.838	2.048	1.210	5207.	.852	28.2	2.6
CB-R	4	0.589	1.746	1.157	4198.	.424	28.2	4.1
MC	4	0.419	2.373	1.954	4198.	.705	28.2	4.1
MC-R	4	0.592	2.343	1.751	4102.	.394	28.2	6.5
MCW	4	0.581	2.650	2.069	4422.	.479	28.2	6.8
MCW-R	4	0.675	2.645	1.970	3902.	.394	28.2	6.9
CB	6	1.138	2.079	0.941	3978.	.852	28.2	1.6
CB-R	2	1.386	2.371	0.985	4141.	.424	28.2	3.4
MC	6	1.110	2.661	1.551	4695.	.705	28.2	3.7
MC-R	2	0.868	2.428	1.560	4305.	.394	28.2	6.0
MCW	6	1.097	2.365	1.268	4503.	.479	28.9	4.2
MCW-R	2	1.087	2.775	1.688	4196.	.394	28.2	6.4

(1) Previous treatments are: CB, cutterbar mower; MC, mower-conditioner; MCW, mower-conditioner-windrower; R, rake and TD, tedder.

Table D.3. Dew adsorption during the night (between 20:00 in the evening and 8:00 the next morning).

Previous treatments (1)	Moisture contents (d.b.) Previous morning	Previous evening	Morning after	Dew	Temperatures (C) TDB (C)	TWB (C)	Minimum night TDB
CB + rain	3.815	1.825	1.937	.112	19.5	16.0	7.8
CB-R + rain	2.637	1.545	1.537	-.008	19.5	16.0	7.8
CB	1.852	0.999	1.254	.255	18.8	13.2	7.2
CB-R	1.968	1.033	1.283	.150	18.8	13.2	7.2
CB	3.932	1.597	1.635	.038	18.8	13.2	7.2
CB-R	3.932	1.224	1.315	.091	18.8	13.2	7.2
CB	2.048	0.876	1.090	.214	14.2	10.9	7.0
CB-R	1.748	0.827	0.948	.121	14.2	10.9	7.0
CB	2.653	1.366	1.752	.386	20.2	19.6	13.3
CB-R	2.374	1.086	1.270	.184	20.2	19.6	13.3
CB	1.752	0.646	1.264	.618	23.3	21.1	11.1
CB-R	1.270	0.472	0.822	.350	23.3	21.1	11.1
CB + rain	5.047	1.440	1.888	.348	18.2	17.6	13.9
CB-R + rain	5.513	1.170	1.364	.194	18.2	17.6	13.9
CB	1.579	0.322	1.157	.825	18.5	16.3	16.7
CB-R	1.731	0.532	0.856	.324	18.5	16.3	16.7
CB	3.398	1.357	2.477	1.120	20.0	17.0	7.8
CB	3.302	0.322	1.655	1.333	23.3	21.1	11.1

APPENDIX E

LISTING OF THE COMPUTER PROGRAMS

APPENDIX E

LISTING OF THE COMPUTER PROGRAMS

The computer models developed by this author are listed on the following pages. Before they are presented however, the list of control statements and the organizing main program prepared by Parsch (1982) and this author are briefly explained.

Table E.1 shows the commands that were used on the MSU Cyber 750 to link five input data files and five binary coded files to run the complete simulation of forage systems. The input data files were MACHINPUT for the FORHRV program (appendix B), MGTALFINPUT for the ALHARV algorithm (appendix C), ALFCRNINPUT for the alfalfa and corn models (Parsch, 1982), ELANSWTHR5378 for historical weather data and BMATRIXLP for the stochastic corn yield distributions.

The five binary files were FORHRVBIN from program FORHRV listed in table E.3, ALHARVBIN from program ALHARV listed in table E.4, ALFMODBIN from the alfalfa growth model (Parsch, 1982), CRNMODBIN from the corn yield, planting and harvest model (Parsch, 1982) and BIGMODBINPS from the organizing main program listed in table E.2.

The organizing main program (table E.2) sets up reading of the input data and links the binary files together. Subroutine REPORT follows immediately after BIGMOD and generates the end of simulation printout tables.

Table E.3 lists program FORHRV, the static machinery model. It can be run independently as described in appendix B. Table E.4 lists program ALHARV, the dynamic harvest, storage and feeding model for alfalfa. It cannot be run independently: it requires FORHRV and the models developed by Parsch (1982), namely the alfalfa growth model (ALFMOD) and the corn model (CRNMOD). The listing includes a main program, TEST, that was used to run ALHARV for testing purposes only with fixed growth and weather parameters. When using TEST as the main program, only ALHARVBIN and FORHRVBIN are required as binary files along with their corresponding input data files, MACHINPUT and MGTALFINPUT.

Table E.1. Listing of the CYBER commands to operate the forage simulation model on the MSU computer.

```
*JOBCARD*,RG1,JC2000,CM170000,L100.
ATTACH,B,WOLBBINIT.
HAL,CCEXEC,B.
ATT,DATA1,MACHINPUT.
ATT,DATA2,MGTALFINPUT1.
ATT,DATA3,ALFCRNINPUTB4.
EDITOR,E=DATA1.
EDITOR,E=DATA2.
EDITOR,E=DATA3.
ATT,WEATHR,ELANSWTHR5378.
ATT,BMATRX,BMATRIXLP.
RETURN,DATA1,DATA2,DATA3.
ATT,FORHRV,FORHRVBIN.
ATT,ALHARV,ALHARVBIN.
ATT,ALFMOD,ALFMODBIN.
ATT,CRNMOD,CRNMODBIN.
ATT,BIGMOD,BIGMODBINPS.
LOAD,FORHRV.
LOAD,ALHARV.
LOAD,ALFMOD.
LOAD,CRNMOD.
LOAD,BIGMOD.
EXECUTE.
EXIT,C,S.
REWIND,ZZZZZMP,OUTPUT.
*EOS
SAVE,MACH,NS.
*EOS
SAVE,MGTALF,NS.
*EOS
SAVE,ALFCRN,NS.
```

Table E.2. Listing of the main program linking FORHRV, ALHARV, ALFMOD and CRNMOD.

```
C
C ***********************************************************************
      PROGRAM BIGMOD
C ***********************************************************************
C
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)
C
200   FORMAT(F7.0,1X,F4.0,1X,F4.0,1X,F5.0,1X,F4.0,1X)
      END
C  ******************************************************
      SUBROUTINE REPORT(NTHYR,NYRS)
C  ******************************************************
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)
C     COMMON/COWDTA/........
      COMMON/PRICE/PLABOR,PFUELD,PFUELG,RATEIM,PDRYCG,PHRVCG,COEFSV(3),
     +      PFSCA1,PFSCA2,PFSCCS,PFSCHM,ALFYRS,RATEIS,RATEIL,XLIFE(3)
C
```

```
      COMMON /SUMRY2/ TRESP(26,20),TCOSTP(26,20),TCOST(26,20),
     +       STCOST(4,20),TRES(26,20),SRES(4,20)
      DIMENSION HERD(5)
      DATA TRESP,TCOSTP,TCOST,STCOST,TRES,SRES/520*0.,520*0.,520*0.,
     +       80*0.,520*0.,80*0./
C
C     OPEN(7,FILE='FEED')
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     CALL COWMOD(NYRS)
C
C
C  GENERATE THE SUB-RESOURCE AND SUB-COST MATRICES, (TRESP,TCOSTP).
C  COLUMNS REPRESENT: (TRES)
C    1=MACHINE INVESTMENT, $  2=FEED STORAGE INVESTMENT, $
C    3=FUEL USE, LITERS       4=REPAIR, MAINTENANCE, $
C    5=FIELD LABOR, MAN/HRS   6=FEEDING LABOR, MAN/HRS
C    7=AREA IN CROPS, HA      8=AREA HARVESTED AS CG, HA
C    9=CG PRODUCTION, DMT
C
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)+AREA(1)+(AREA(1)/ALFYRS)
      TRESP(N,8)=YCORN(N,8)
      TRESP(N,9)=YCORN(N,19)
C
C  COLUMNS REPRESENT: (TCOST)
C     1=MACHINE FIXED COST, ANNUAL $  2=STORAGE FIXED COST, $/YR
C     3=FUEL COST, $                  4=REPAIR/MAINT, MACHINES, $
C     5=FIELD LABOR, $                6=FEED LABOR, $
C     7=FERT/SEED/CHEMS, $            8=CUSTOM HARVEST (CG), $
C     9=DRYDOWN (CG), $
C
      TCOSTP(N,1)=CCOST(N,13)
      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)+(AREA(1)*(PFSCA2+PFSCA1/ALFYRS))
      TCOSTP(N,8)=CCOST(N,8)
      TCOSTP(N,9)=CCOST(N,9)
C
10    CONTINUE
C
C  ADD THE SUB-RESOURCE AND SUB-COST MATRICES TO GENERATE
C  THE TOTAL RESOURCE USE (TRES) AND TOTAL COST/RETURNS (TCOST)
C  MATRICES.
C
      DO 20 N=1,NYRS
      DO 24 I=1,20
      TRES(N,I)=TRESP(N,I)+TRESS(N,I)
      TCOST(N,I)=TCOSTP(N,I)+TCOSTS(N,I)
24    CONTINUE
C
      DO 22 JCOL=21,23
      AFEED(N,JCOL)=YCORN(N,JCOL-4)
   22 CONTINUE
C     WRITE(7,300) (AFEED(N,JCOL),JCOL=1,23)
C
20    CONTINUE
C
C   DAIRY HERD INFORMATION IS READ IN.
C   THE HARVESTED FEED IS ALLOCATED TO COWS AND SUPPLEMENTS ARE
C   PURCHASED TO BALANCE THE RATION IN COWFD.
C
      CALL COWFD(NYRS,XLCOWS,HERD)
C
C  WRITE OUT THE COST/PROFIT AND RESOURCE MATRICES.
C
      WRITE(6,100)NYRS
      DO 30 N=1,NYRS
30    WRITE(6,110)N,(TCOST(N,I),I=1,15)
C
      CALL SSTAT(15,TCOST,NYRS,STCOST)
      WRITE(6,118)
      WRITE(6,120)
      DO 35 I=1,2
35    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(6,200)
      DO 40 N=1,NYRS
40    WRITE(6,210)N,(TRES(N,I),I=1,15)
C
      CALL SSTAT(15,TRES,NYRS,SRES)
      WRITE(6,118)
```

```
      WRITE(6,120)
      DO 45 I=1,2
45    WRITE(6,210) I,(SRES(I,J),J=1,15)
      WRITE(6,225) I,((SRES(I,J),J=1,15),I=3,3)
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 REPRESENT:',/,
     +       ' 1=FCM 2=FCSTG 3=FUEL 4=RMM 5=LABFLD',
     +       ' 6=LABFEED 7=FSC 8=CUSTCG 9=DRYCG',
     +   ' 10=SUM(1-9) 11=FNET 12=CG 13=SUM(10-12) 14=MILK ',
     +   '15=NRET',///)
C
110   FORMAT(I3,2(1X,F7.0),1X,F6.0,13(1X,F7.0))
125   FORMAT(I3,2(1X,F7.2),1X,F6.2,13(1X,F7.2))
C
118   FORMAT(//)
120   FORMAT(' SAMPLE STATISTICS FOR SIMULATION RUN:',
     +   ' ROWS 1=MEAN  2=STANDARD DEVIATION  3=COEF OF VARIATION',/)
C
200   FORMAT('1','MATRIX TRESS=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),11(1X,F6.0))
225   FORMAT(I3,2(1X,F8.2),2(1X,F7.2),11(1X,F6.2))
C
      RETURN
      END
```

Table E.3. Listing of program FORHRV.

```
C ********************************************************************
      PROGRAM DUMMY
C ********************************************************************
      OPEN (5,FILE='MACH')
      OPEN (6,FILE='OUTPUT')
      CALL FORHRV
      STOP
      END
C ********************************************************************
      SUBROUTINE FORHRV
C ********************************************************************
C
C   PROGRAM FORHRV ESTIMATES FORAGE HARVEST RATES FOR A GIVEN SET OF
C   MACHINES.
C   IT WAS WRITTEN BY PHILIPPE SAVOIE, AGRICULTURAL ENGINEERING DEPT.,
C   MICHIGAN STATE UNIVERSITY, EAST LANSING, MICHIGAN, USA  48824
C   A USER"S GUIDE IS AVAILABLE IN APPENDIX B OF THE AUTHOR"S DOCTORAL
C   DISSERTATION (1982).
C   IT CAN BE RUN INDEPENDENTLY WITH THE USE OF PROGRAM DUMMY.
C   SUBROUTINE FORHRV AND ITS APPENDED SUBROUTINES WERE HOWEVER WRITTEN
C   TO BE USED WITH THE DYNAMIC HARVEST MODEL ALHARV.
C
      COMMON /Y1/ XINFO(7),MCODE(100),XMDATA(100,13)
      COMMON /Y2/ ICODE(60,3),XOPER(60,5)
      COMMON /Y3/ NMDATA,NOPER,IN,IO
      COMMON /Y4/ XOPMD(60,26)
      COMMON /Y5/ A(15),OPNAME(5,60),XTTP,JOP
      COMMON /Y6/ RATES(108,8),YAR(6)
      COMMON /Y7/ NBOP(18),NBMACH(18,7),XNBM(18,7)
      COMMON /Y9/ IPRINT,IPR1
      DIMENSION IEXTRA(18)
      DATA IEXTRA /0,0,0,0,0,0,0,0,0,1,0,0,1,4,4,4,4,4/
      DATA IN/5/,IO/6/
      CALL READ
      IOP=1
C   NBMACH INCLUDES THE MACHINERY NUMBERS OF ALL MACHINES USED IN OPERAT
C   NBO(IOP). THERE MAY BE UP TO 7 DIFFERENT MACHINES IN AN OPERATION.
C   XNBM IS THE NUMBER OF UNITS OF EACH MACHINE USED IN AN OPERATION.
      DO 29 I=1,18
      DO 29 J=1,7
      XNBM(I,J)=0.
   29 NBMACH(I,J)=0
      I=1
C   THERE ARE NOPER OPERATION CARDS
   10 CALL DCODEI (I)
```

```
      CALL DCODET (I)
      JOP=ICODE(I,1)
      DO 50 J=1,18
      JLOW=J*10-1
      JHIGH=JLOW+10
      IF (JOP.LE.JLOW.OR.JOP.GT.JHIGH) GO TO 50
      JEXTRA=IEXTRA(J)
   50 CONTINUE
      IF (JEXTRA.EQ.0) GO TO 30
      IX1=I+1
      IX2=I+JEXTRA
      DO 40 IJ=IX1,IX2
      CALL DCODEI (IJ)
   40 CALL DCODET (IJ)
   30 CALL BUILDA (I)
      CALL RATE (I,IOP)
      NBOP(IOP)=JOP
      NBMACH(IOP,1)=ICODE(I,2)
      NBMACH(IOP,2)=ICODE(I,3)
      XNBM(IOP,1)=XOPER(I,1)
      XNBM(IOP,2)=XOPER(I,1)
      IF(JEXTRA.EQ.0) GO TO 35
      NBMACH(IOP,3)=ICODE(I+1,2)
      XNBM(IOP,3)=XOPER(I,1)
      IF (JEXTRA.LE.1) GO TO 35
      NBMACH(IOP,4)=ICODE(I+2,2)
      NBMACH(IOP,5)=ICODE(I+2,3)
      NBMACH(IOP,6)=ICODE(I+4,2)
      NBMACH(IOP,7)=ICODE(I+4,3)
      XNBM(IOP,4)=XOPER(I+2,3)
      XNBM(IOP,5)=XOPER(I+2,1)
      XNBM(IOP,6)=XOPER(I+4,1)
      XNBM(IOP,7)=XOPER(I+4,1)
   35 IF (IPR1.NE.1) GO TO 21
      WRITE (10,200) JOP,(OPNAME(J,I),J=1,5)
  200 FORMAT (    ///,5X,'CALCULATED WORK RATES FOR OPERATION',I6,'  KNO
     +WN AS  ',5A4,///,11X,'YDM(T/HA)    EFC(HA/H)    ETP(TDM/H)   LOAD(DEC
     +)    FUEL(L/H)    ELEC(KWH/H)   LABOR(MH/H)   SPEED(KM/H)',///)
      DO 20 K=1,6
      IR=(IOP-1)*6+K
      WRITE (10,210) (RATES(IR,J),J=1,8)
  210 FORMAT (10X,8F12.2)
   20 CONTINUE
   21 IOP=IOP+1
      I=I+JEXTRA+1
      IF (I.LE.NOPER) GO TO 10
      RETURN
      END
C ********************************************************************
      SUBROUTINE READ
```

```
C ********************************************************************
      COMMON /Y1/ XINFO(7),MCODE(100),XMDATA(100,13)
      COMMON /Y2/ ICODE(60,3),XOPER(60,5)
      COMMON /Y3/ NMDATA,NOPER,IN,IO
      COMMON /Y9/ IPRINT,IPR1
C
C   THIS SUBROUTINE READS THE MACHINERY DATA FILE AND THE OPERATION FILE
C   IT INITIALLY READS A GENERAL INFORMATION ARRAY
C   XINFO(1) IS THE POWER SAFETY FACTOR (USUALLY 1.4)
C   XINFO(2) IS THE SOIL CONDITION PARAMETER ,ASAE CN NUMBER -- 30 FOR F
C   XINFO(3) IS THE AVERAGE SOIL SLOPE (ITS TANGENT)  THE SOIL SLOPE IS
C      CONVERTED INTO AN ANGLE(RADIANS) IN THE PRESENT SUBROUTINE
C   XINFO(4) IS THE ABSOLUTE MINIMUM ALFALFA YIELD (TDM/HA)
C   XINFO(5) IS THE ABSOLUTE MAXIMUM ALFALFA YIELD (TDM/HA)
C   XINFO(6) IS THE ABSOLUTE MINIMUM CORN SILAGE YIELD (TDM/HA)
C   XINFO(7) IS THE ABSOLUTE MAXIMUM YIELD OF CORN SILAGE (TDM/HA)
C
      READ (IN,110) (XINFO(I),I=1,7)
      XINFO(3)=ATAN(XINFO(3))
C
C   READ THE MACHINERY DATA FILE
C
      I=0
    1 I=I+1
      READ (IN,120) MCODE(I),(XMDATA(I,J),J=1,13)
      IF (MCODE(I).GT.0) GO TO 1
C
C   THE LAST CARD AT THE END OF THE MACHINERY DATA FILE MUST HAVE 0000
C   IN THE LAST FOUR COLUMNS.
C   THE NUMBER OF MACHINES IN THE FILE IS NMDATA.
C
      NMDATA=I-1
C
C   READ THE OPERATION FILE
C
      I=0
    2 I=I+1
      READ (IN,130) (ICODE(I,J),J=1,3),(XOPER(I,J),J=1,5)
      IF (ICODE(I,1).GT.0) GO TO 2
C
C   THE LAST CARD AT THE END OF THE OPERATION FILE MUST BE ZERO
C   NOPER IS THE NUMBER OF OPERATION CARDS
C
      NOPER=I-1
C   WHEN IPRINT IS 1 (ONE), A DETAILED PRINTOUT OF CYCLE TIMESOF HARVEST
C   TRANSPORT MACHINES WILL APPEAR
      READ (IN,140)IPR1,IPRINT,IPRINP
      IF (IPRINP.EQ.0) RETURN
      WRITE (IO,105)
      WRITE (IO,110) (XINFO(I),I=1,7)
```

```
      DO 10 I=1,NMDATA
10    WRITE (IO,120) MCODE(I),(XMDATA(I,J),J=1,13)
      WRITE (IO,125)
      DO 20 I=1,NOPER
20    WRITE (IO,130) (ICODE(I,J),J=1,3),(XOPER(I,J),J=1,5)
      WRITE (IO,125)
      WRITE (IO,140) IPR1,IPRINT,IPRINP
  105 FORMAT (/,5X,'THE INPUT DATA FILE FOR FORHRV WAS READ AS FOLLOWS')
  110 FORMAT (7F10.2)
  120 FORMAT (I4,3F8.2,10F5.1)
125   FORMAT ('0000')
  130 FORMAT (3I4,5F10.2)
  140 FORMAT (3I2)
      RETURN
      END
C ********************************************************************
      SUBROUTINE DCODEI (I)
C ********************************************************************
      COMMON /Y1/ XINFO(7),MCODE(100),XMDATA(100,13)
      COMMON /Y2/ ICODE(60,3),XOPER(60,5)
      COMMON /Y3/ NMDATA,NOPER,IN,IO
      COMMON /Y4/ XOPMD(60,26)
C
C      THIS SUBROUTINE DECODES THE IMPLEMENT NUMBER FOR A GIVEN OPERATIO
C   AND INSERTS THE MACHINERY DATA IN A WORKING MATRIX XOPMD(I,J),J=1,13
C
      K=0
C   WHEN THE IMPLEMENT NUMBER IS ZERO, THE WORKING MATRIX IS INITIALIZED
C   AS ZERO.
C   THIS CAN HAPPEN IN AT LEAST TWO CASES
C   1. WHEN ROUND BALES ARE HAULED ONE BY ONE FROM THE FIELD TO STORAGE,
C   THERE IS ONLY A LOADER AND NO MULTIPLE BALE WAGON (MOVER).
C   ZEROES APPEAR ON THE SECOND DATA CARD.
C   2. WHEN NO EJECTOR IS USED IN THE BALER-WAGON SYSTEM, BUT INSTEAD
C   ONE MAN STACKS THE BALES IN THE WAGON BEHIND THE BALER.
      IF (ICODE(I,2).NE.0) GO TO 4
      DO 1 J= 1,13
    1 XOPMD(I,J)=0
      GO TO 7
    4 K=K+1
      IF (ICODE(I,2).NE.MCODE(K).AND.K.LT.NMDATA) GO TO 4
      IF (ICODE(I,2).EQ.MCODE(K)) GO TO 5
C
C   AT THIS POINT THE DATA FILE DOES NOT CONTAIN THE SPECIFIC MACHINE
C   GIVEN IN THE OPERATION DATA CARD
C
      WRITE (IO,140) ICODE(I,1)
  140 FORMAT (///,'THE IMPLEMENT NUMBER FOR OPERATION',I10,'  DOES NOT E
     +XIST IN THE DATA FILE',/,'MAKE THE CORRECTION')
      STOP
```

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C *

C *






C
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C
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C











C

C
```

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    5 DO 6 J=1,13
      XOPMD(I,J)=XMDATA(K,J)
    6 CONTINUE
    7 RETURN
      END
C *********************************************************************
      SUBROUTINE DCODET (I)
C *********************************************************************
      COMMON /Y1/ XINFO(7),MCODE(100),XMDATA(100,13)
      COMMON /Y2/ ICODE(60,3),XOPER(60,5)
      COMMON /Y3/ NMDATA,NOPER,IN,IO
      COMMON /Y4/ XOPMD(60,26)
C
C   THIS SUBROUTINE DECODES THE TRACTOR (OR POWER SOURCE) NUMBER FOR
C   A GIVEN
C   OPERATION AND INSERTS THE TRACTOR MACHINERY DATA IN A WORKING MATRIX
C   XOPMD(I,J),J=14,26
      K=0
C   IN THE CASE OF A SELF-PROPELLED MACHINE, TRACTOR CODE IS 0000.
C   IN SUCH A CASE, ALL THE POWER AND ENGINE SPECIFICATIONS ARE GIVEN
C   WITH THE IMPLEMENT
      IF (ICODE(I,3).NE.0) GO TO 7
      DO 9 J=14,26
      XOPMD(I,J)=0.
    9 CONTINUE
      GO TO 10
    7 K=K+1
      IF (ICODE(I,3).NE.MCODE(K).AND.K.LT.NMDATA) GO TO 7
      IF (ICODE(I,3).EQ.MCODE(K)) GO TO 8
C
C   AT THIS POINT THE DATA FILE DOES NOT CONTAIN THE SPECIFIC MACHINE
C
      WRITE (IO,150) ICODE(I,1)
  150 FORMAT(///,'THE TRACTOR NUMBER FOR OPERATION',I10,'  DOES NOT EXIS
     +T IN THE DATA FILE',/,'MAKE THE CORRECTION')
      STOP
    8 DO 11 J=14,26
      JJ=J-13
      XOPMD(I,J)=XMDATA(K,JJ)
   11 CONTINUE
   10 RETURN
      END
C *********************************************************************
      SUBROUTINE BUILDA (I)
C *********************************************************************
      COMMON /Y1/ XINFO(7),MCODE(100),XMDATA(100,13)
      COMMON /Y2/ ICODE(60,3),XOPER(60,5)
      COMMON /Y3/ NMDATA,NOPER,IN,IO
      COMMON /Y4/ XOPMD(60,26)
      COMMON /Y5/ A(15),OPNAME(5,60),XTTP,JOP
```

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C
C   THIS SUBROUTINE CREATES THE A ARRAY WHICH INCLUDES PARAMETERS FOR
C   ESTIMATING SPEED, LOAD, FIELD CAPACITY, THROUGHPUT RATE
C
C   A(1)  IS TRACTOR POWER (KW)
C   A(2)  IS TRACTOR MASS  (KG)
C   A(3)  IS IMPLEMENT MASS, INCLUDING WAGON IF PULLED (KG)
C   A(4)  IS PTO POWER (CONSTANT,INDEPENDENT OF THROUGHPUT, KW)
C   A(5)  IS PTOC (COEFFICIENT, DEPENDENT OF THROUGHPUT, KW/KGDM/S)
C   A(6)  IS THE POWER SAFETY FACTOR
C   A(7)  IS THE SOIL CONDITION CN
C   A(8)  IS THE SOIL SLOPE ANGLE (RADIANS)
C   A(9)  IS THE MAXIMUM ALLOWABLE SPEED   (KM/H)
C   A(10)  IS THE WORKING WIDTH (M)
C   A(11)  IS THE DRY MATTER YIELD (T/HA)
C   A(12)  IS THE ACTUAL OPERATING SPEED (KM/H)
C   A(13)  IS THE TRACTOR LOAD (DEC)
C   A(14)  IS THE FIELD EFFICIENCY (DECIMAL)
C   A(15)  IS THE ENGINE TYPE  1. GAS  2. DIESEL  3. ELECTRIC
C   XTTP IS THE MAXIMUM MACHINE THROUGHPUT (TDM/H)
C   JOP IS THE OPERATION CODE (SAME AS ICODE(I,1))
C   DNAME(I,J) CONTAINS THE NAMES OF EACH OPERATION
C   THE OPNAME MATRIX CONTAINS THE NAME OF EACH OPERATION
C
      DIMENSION EFF(18),PTOW(18),PTOC(18),DNAME(5,18)
      DATA EFF/.8,.8,.8,.8,.8,.8,.8,.75,.70,.8,.8,.8,.8,.8,.8,.8,.8,.8/
      DATA PTOW/1.2,3.0,6.00,1.,1.,2.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,
     +0.,0./
      DATA PTOC/0.,2.,4.,0.,0.,0.,5.,7.5,7.5,15.,6.,0.,0.,15.,15.,18.,
     +5.,0./
      DATA DNAME /4HCUTT,4HERBA,4HR MO,4HWING,4H    ,4HCUTT,4HERBA,4HR M
     +O,4HW-CO,4HND  ,4HDRUM,4H MOW,4H CON,4HD   ,4H    ,4HRAKI,4HNG  ,
     +4H    ,4H    ,4H    ,4HDOUB,4HLE R,4HAKIN,4HG   ,4H    ,4HTEDD,4HI
     +NG ,4H    ,4H    ,4H    ,4HRECT,4H BAL,4HING ,4H(DRO,4HP)  ,4HROUN
     +,4HD BA,4HLING,4H    ,4H    ,4HLARG,4HE ST,4HACK ,4H BAL,4HING ,
     +4HCHOP,4H ON ,
     +            4HTHE ,4HGROU,4HND  ,4HAUTO,4H BAL,4HE WA,4HGON ,4H    ,
     +4HLARG,4HE ST,4HACK ,4HMOVE,4HR   ,4HROUN,4HD BA,4HLE M,4HOVER,4H
     +    ,4HCHOP,4H (CS,4H) TR,4H UL ,4H    ,4HCHOP,4H (AL,4HF-WP,4H) TR
     +,4H UL ,4HCHOP,4H (AL,4HF-DC,4H) TR,4H UL ,4HBALE,4H EJE,4HCT T,4H
     +R UL ,4H    ,4HHAND,4HPICK,4H BAL,4HES T,4HR UL/
      JOP=ICODE(I,1)
      A(1)=XOPMD(I,24)
      A(2)=XOPMD(I,14)
      A(3)=XOPMD(I,1)+XOPER(I,4)
      A(15)=XOPMD(I,23)
C
C   CHECK IF THE IMPLEMENT IS A SELF-PROPELLED MACHINE
C
      IF (XOPMD(I,9).NE.1.) GO TO 1
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      A(1)=XOPMD(I,11)
      A(2)=A(3)
      A(3)=0.
      A(15)=XOPMD(I,10)
    1 A(6)=XINFO(1)
      A(7)=XINFO(2)
      A(8)=XINFO(3)
      A(9)=XOPER(I,2)
      A(10)=XOPER(I,3)
      IF (JOP.GE.100.AND.JOP.LT.110) A(3)=A(3)+XOPMD(I+1,1)
      IF(JOP.GE.110.AND.JOP.LT.120) A(3)=A(3)+XOPMD(I,8)*1000.
      IF (JOP.LT.140.OR.JOP.GE.180) GO TO 6
      A(3)=A(3)+XOPMD(I+1,1)+XOPMD(I+2,1)+XOPMD(I+2,8)*1000.
      IF (XOPER(I+1,2).EQ.0.) A(3)=A(3)-XOPMD(I+2,8)*1000.
    6 DO 22 J=1,18
      JLOW=10*J-1
      JHIGH=JLOW+10
      IF (JOP.LE.JLOW.OR.JOP.GT.JHIGH) GO TO 22
      A(4)=PTOW(J)*A(10)
      A(5)=PTOC(J)
      A(14)=EFF(J)
      XTTP=XOPMD(I,7)
      IF (XTTP.LE.0.) XTTP=1000.
C   THIS MEANS THAT MAXIMUM THROUGHPUT WILL NOT BE A CONSTRAINT
      DO 21 K=1,5
   21 OPNAME(K,I)=DNAME(K,J)
   22 CONTINUE
C   NEXT CONSIDER THE CASE OF A BALE THROWER.  THE PTO REQUIREMENT IS
C   INCREASED BY 0.5 KW/KG/S IF A BALE THROWER IS PRESENT.
      IF (JOP.LT.170. OR.JOP.GE.180) GO TO 5
      IF (ICODE(I+1,2).NE.0) A(5)=A(5)+0.5
    5 RETURN
      END
C ********************************************************************
      SUBROUTINE RATE (I,IOP)
C ********************************************************************
      COMMON /Y1/ XINFO(7),MCODE(100),XMDATA(100,13)
      COMMON /Y2/ ICODE(60,3),XOPER(60,5)
      COMMON /Y5/ A(15),OPNAME(5,60),XTTP,JOP
      COMMON /Y6/ RATES(108,8),YAR(6)
      COMMON /Y10/ XLD,XLABOR
C
C   THIS SUBROUTINE CALCULATES RATES OF HARVEST FOR ALL OPERATIONS AND
C   INSERTS THE VALUES IN A WORKING MATRIX RATES(108,8) FOR LATER USE
C   THE RATES(108,8) MATRIX WILL CONTAIN INFORMATION ABOUT HARVEST RATES
C   AT 6 DIFFERENT YIELD VALUES FOR EACH OPERATION
C   HARVEST RATES ARE ESTIMATED FOR A MAXIMUM OF 18 OPERATIONS AT
C   SIX YIELDS.  THERE ARE THUS 108 ROWS.
C   THE SIX YIELD LEVELS ARE EQUALLY SPACED BETWEEN
C   MINIMUM AND MAXIMUM YIELDS SPECIFIED IN THE GENERAL INFORMATION
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C   ARRAY.
C   THE EIGHT PARAMETERS IN EACH ROW ARE
C   RATES(I,1) IS THE DRY MATTER YIELD (T/HA)
C   RATES(I,2) IS EFFECTIVE FIELD CAPACITY (HA/H)
C   RATES(I,3) IS THE EFFECTIVE THROUGHPUT (TDM/H)
C   RATES(I,4) IS THE TRACTOR LOAD (DECIMAL)
C   RATES(I,5) IS THE FUEL CONSUMPTION (L/H)
C   RATES(I,6) IS THE ELECTRICITY CONSUMPTION (KW-H/H)
C   RATES(I,7) IS THE LABOR REQUIREMENT PER UNIT OPERATION TIME (MAN-H/H
C   RATES(I,8) IS THE OPERATING SPEED (KM/H)
C
      YMAX=XINFO(5)
      YMIN=XINFO(4)
      IF (JOP.LT.140.OR.JOP.GT.149) GO TO 2
      YMAX=XINFO(7)
      YMIN=XINFO(6)
    2 DIFF=(YMAX-YMIN)/5.
      YAR(1)=YMIN
      DO 1 J=2,6
    1 YAR(J)=YAR(J-1)+DIFF
      IF (JOP.GE.120.AND.JOP.LT.140) GO TO 40
      K=(IOP-1)*6
      XLABOR=XOPER(I,1)
      IF (JOP.LT.140) GO TO 7
      IF (JOP.LT.180) GO TO 8
C   HAND PICKING BALES IN THE FIELD
      XLABOR=(1.+XOPER(I+1,3))*XOPER(I+3,1)+XOPER(I+2,4)
      GO TO 45
    8 IF (JOP.LT.170) GO TO 9
C   THE BALER WITH A WAGON PULLED BEHIND
      IF (ICODE(I+1,2).EQ.0) XLABOR=2.*XLABOR
C   INCLUDING LABOR AT UNLOADING SITE (STORAGE) AND TRANSPORT OPERATORS
    9 XLABOR=XLABOR+XOPER(I+2,4)+XOPER(I+2,1)
    7 DO 30 J=1,6
      A(11)=YAR(J)
      CALL SPEED
      K=K+1
      RATES(K,1)=A(11)
C   XOPER(I,2) IS THE NUMBER OF UNITS DOING THE SAME OPERATION
C   SIMULTANEOUSLY.  TOTAL HARVEST RATES ARE
C   THE SINGLE UNIT HARVEST RATES TIMES XOPER(I,1).
      RATES(K,2)=A(12)*A(10)*A(14)/10.
      RATES(K,3)=RATES(K,2)*A(11)
      RATES(K,4)=A(13)
      RATES(K,7)=XLABOR
      RATES(K,8)=A(12)
      XLD=A(13)
      PWR=A(1)
      ENG=A(15)
      EFF=A(14)
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      FUI=1.10
      FUEL=0.
      ELECT=0.
      CALL ENERGY (XLD,PWR,ENG,EFF,FUI,FUEL,ELECT)
      RATES(K,5)=FUEL
      RATES(K,6)=ELECT
   30 CONTINUE
   40 IF (JOP.GE.110.AND.JOP.LT.140) CALL TRCYCI (I,IOP)
      IF (JOP.GE.140.AND.JOP.LT.180) CALL HRTR (I,IOP)
   45 IF (JOP.GE.180) CALL HAYPCK (I,IOP)
      IF (JOP.GE.140.OR.XOPER(I,1).EQ.1.) GO TO 50
      DO 25 J=1,6
      K=(IOP-1)*6+J
      RATES(K,2)=RATES(K,2)*XOPER(I,1)
      RATES(K,3)=RATES(K,3)*XOPER(I,1)
      RATES(K,5)=RATES(K,5)*XOPER(I,1)
      RATES(K,6)=RATES(K,6)*XOPER(I,1)
   25 CONTINUE
   50 RETURN
      END
C **********************************************************************
      SUBROUTINE SPEED
C **********************************************************************
      COMMON /Y3/ NMDATA,NOPER,IN,IO
      COMMON /Y5/ A(15),OPNAME(5,60),XTTP,JOP
C
C   THIS SUBROUTINE CALCULATES OPERATING SPEED AND TRACTOR LOAD
C   THREE CONSTRAINTS MUST BE RESPECTED:  MAXIMUM ALLOWABLE THROUGHPUT,
C   MAXIMUM ALLOWABLE SPEED AND MAXIMUM ALLOWABLE TRACTOR LOAD
C
      DATA CF1/1.10/,CF2/1.20/
      TTP=A(9)*A(10)*A(11)/10.
      IF (TTP.LE.XTTP) GO TO 1
C   REDUCE MAXIMUM ALLOWABLE SPEED SO THROUGHPUT WILL NOT EXCEED MAXIMUM
      A(9)=XTTP*10./(A(10)*A(11))
    1 V=A(9)
      TETA=A(8)
      RRC=0.04+1.2/A(7)
      DBP=A(3)*9.8*(RRC*COS(TETA)+SIN(TETA))
      FR=(DBP+A(2)*9.8*SIN(TETA))/(0.75*A(2)*9.8*COS(TETA))
      CH1=0.75-(FR+RRC)
      IF (CH1.GT.0.) GO TO 5
      WRITE (IO,10) JOP
   10 FORMAT (///,'SLIP IS EXCESSIVE AND CANNOT BE CALCULATED FOR OPERAT
     +ION',I10,/,'REDUCE SLOPE, OR INCREASE TRACTOR MASS OR REDUCE TRAIL
     +ING IMPLEMENT MASS ')
      STOP
    5 SL=(1./(0.3*A(7)))*ALOG(0.75/CH1)
      SLF=1./(1.-SL)
      TRPWR=A(2)*9.8*(RRC*COS(TETA)+SIN(TETA))*V*CF1*SLF/3600.
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      DBPWR=DBP*V*CF2*SLF/3600.
      PTO=A(4)
      PTOV=A(5)*A(10)*A(11)*V/36.
      PWR=TRPWR+DBPWR+PTO+PTOV
      ALOAD=PWR/A(1)
      XLOAD=1./A(6)
      IF (ALOAD.LE.XLOAD) GO TO 15
C   AT THIS POINT, MAXIMUM SPEED ASSUMED RESULTS IN EXCESSIVE LOAD.
C   REDUCE LOAD TO XLOAD AND RECALCULATE SPEED
      V=(A(1)*XLOAD-PTO)*V/(TRPWR+DBPWR+PTOV)
      ALOAD=XLOAD
   15 A(12)=V
      A(13)=ALOAD
      RETURN
      END
C *******************************************************************
      SUBROUTINE ENERGY (XLD,PWR,ENG,EFF,FUI,FUEL,ELECT)
C *******************************************************************
C
C   THIS SUBROUTINE CALCULATES ENERGY FOR FARM OPERATIONS, EITHER LIQUID
C   FUEL FOR TRACTORS (GASOLINE OR DIESEL ENGINES) OR ELECTRICAL ENERGY
C   FOR ELECTRIC MOTORS.
C
C   XLD IS THE POWER SOURCE LOAD (DECIMAL)
C   PWR IS THE MAXIMUM POWER (KW)
C   ENG IS THE ENGINE TYPE 1. FOR GAS  2. FOR DIESEL AND 3. FOR ELECTRIC
C   EFF IS THE MACHINE FIELD EFFICIENCY
C   FUI IS THE FUEL USE FACTOR TO ACCOUNT FOR IDLING OR TURNING (USUALLY
C   EQUAL TO 1.10).
C
      IF (ENG.LE.2.) GO TO 1
C   WE HAVE AN ELECTRIC POWER SOURCE
      FC=0.
      ELECT=XLD*PWR*EFF*FUI
      GO TO 3
    1 IF (ENG.LT.2.) GO TO 2
C   WE HAVE A DIESEL POWER SOURCE
      ELECT=0.
      FC=2.64*XLD+3.91-0.2*(738.*XLD+173.)**0.5
      GO TO 3
    2 ELECT=0.
C   WE HAVE A GASOLINE ENGINE
      FC=2.74*XLD+3.15-0.2*(697.*XLD)**0.5
    3 FUEL=FC*PWR*EFF*XLD*FUI
      RETURN
      END
C *******************************************************************
      SUBROUTINE TRCYCI (I,IOP)
C *******************************************************************
      COMMON /Y1/ XINFO(7),MCODE(100),XMDATA(100,13)
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      COMMON /Y2/ ICODE(60,3),XOPER(60,5)
      COMMON /Y3/ NMDATA,NOPER,IN,IO
      COMMON /Y4/ XOPMD(60,26)
      COMMON /Y5/ A(15),OPNAME(5,60),XTTP,JOP
      COMMON /Y6/ RATES(108,8),YAR(6)
      COMMON /Y9/ IPRINT,IPR1
C
C   THIS SUBROUTINE CALCULATES TRANSPORT CYCLE TIMES FOR INDIVIDUAL
C   TRANSPORT OPERATIONS (110,120,130) WHICH ARE NOT AFFECTED BY
C   EXTERNAL HARVEST OR
C   UNLOADING OPERATIONS
C   OPERATION CODE BETWEEN 110 AND 119 IS FOR AUTOMATIC BALE WAGON
C   OPERATION CODE BETWEEN 120 AND 129 IS FOR A LARGE STACK LOADER-MOVER
C   OPERATION CODE BETWEEN 130 AND 139 IS FOR A ROUND BALE LOADER-MOVER
C   T1 IS THE LOADING TIME IN THE FIELD (H)
C   T4 IS THE UNLOADING TIME AT STORAGE (H)
C   T2 IS THE TIME TO TRAVEL FROM FIELD TO STORAGE WITH A FULL LOAD (H)
C   T3 IS THE TIME TO TRAVEL FROM STORAGE TO FIELD WITH AN EMPTY WAGON (
C   XMC IS THE MOISTURE CONTENT ON A DRY BASIS
C   DMCAP IS THE DRY MATTER CAPACITY OF A TRANSPORT WAGON (T)
      XMC=0.25
      DMCAP=XOPMD(I,8)/(1.+XMC)
      IF (DMCAP.GT.0.) GO TO 6
      WRITE (IO,101) JOP,I
  101 FORMAT (///,1X,'THE DRY MATTER CAPACITY OF THE TRANSPORT UNIT IN O
     +PERATION',I6,'IS CALCULATED TO BE LESS OR EQUAL TO 0',/,1X,'CHECK
     +OPERATION DATA CARD NUMBER,',I6,'  AND DATA FILE FOR ERROR')
      STOP
    6 T4=XOPMD(I,13)
      IF (JOP.GE.120.AND.JOP.LT.130) T1=XOPMD(I,12)
      IF (JOP.LT.130) GO TO 1
C   HERE WE CALCULATE THE NUMBER OF ROUND BALES THAT WILL BE MOVED AT
C   EACH TRIP FROM
C   THE FIELD (XNBL) AND THE LOADING AND UNLOADING TIMES
      IF (ICODE(I+1,2).EQ.0) XNBL=1.
      IF (ICODE(I+1,2).NE.0)  XNBL=XOPMD(I+1,8)*1000./XOPER(I,4)
      T1=XOPMD(I,12)*XNBL
      IF (XNBL.GT.1.) T4=T4+T1/3.
      IF (XNBL.GT.1.)  DMCAP=XOPMD(I+1,8)/(1.+XMC)
C   TRAVELLING WITH A FULL LOAD
    1 A(3)=XOPMD(I,1)+DMCAP*(1.+XMC)*1000.
      IF (JOP.GE.130) A(3)=A(3)+XOPMD(I+1,1)
      A(4)=0.
      A(5)=0.
      A(9)=XOPER(I,2)
      XTTP=1000.
      CALL SPEED
      VFULL=A(12)
      T2=XOPER(I,5)/A(12)
      XLD2=A(13)
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C   TRAVELLING WITH AN EMPTY WAGON
      A(3)=A(3)-DMCAP*(1.+XMC)*1000.
      CALL SPEED
      T3=XOPER(I,5)/A(12)
      VEMPT=A(12)
      XLD3=A(13)
      PWR=A(1)
      ENG=A(15)
      FUEL=0.
      ELECT=0.
      FUI=1.
      K=(IOP-1)*6
      IF (JOP.GT.119) GO TO 2
C   HERE WE CONSIDER THE AUTOMATIC BALE WAGON AT 6 DIFFERENT YIELDS
      DO 3 J=1,6
      K=K+1
      T1=DMCAP/RATES(K,3)
      XLD1=RATES(K,4)
      AVLD=(XLD1*T1+XLD2*T2+XLD3*T3)/(T1+T2+T3)
      RATES(K,3)=DMCAP/(T1+T2+T3+T4)
      RATES(K,2)=RATES(K,3)/RATES(K,1)
      RATES(K,4)=AVLD
      EFF=(A(14)*T1*1.1+T2+T3)/(T1+T2+T3)
      CALL ENERGY (AVLD,PWR,ENG,EFF,FUI,FUEL,ELECT)
      RATES(K,5)=FUEL
      RATES(K,6)=ELECT
      IF (IPRINT.NE.1) GO TO 3
      WRITE (6,100) JOP,T1,T2,T3,T4,VFULL,VEMPT
    3 CONTINUE
      GO TO 4
C   HERE WE CONSIDER THE LARGE STACK MOVER AND THE ROUND BALE MOVER
    2 ETP=DMCAP/(T1+T2+T3+T4)
      AVLD=(XLD2*T2+XLD3*T3)/(T2+T3)
      EFF=(T2+T3+(T1+T4)/2.)/(T1+T2+T3+T4)
      CALL ENERGY (AVLD,PWR,ENG,EFF,FUI,FUEL,ELECT)
      DO 5 J=1,6
      K=K+1
      RATES(K,1)=YAR(J)
      RATES(K,2)=ETP/YAR(J)
      RATES(K,3)=ETP
      RATES(K,4)=AVLD
      RATES(K,5)=FUEL
      RATES(K,6)=ELECT
      RATES(K,7)=XOPER(I,1)
      RATES(K,8)=VFULL
    5 CONTINUE
      IF (IPRINT.NE.1) GO TO 4
      WRITE (6,100) JOP,T1,T2,T3,T4,VFULL,VEMPT
  100 FORMAT (///,5X,'FOR OPERATION',I6,'  PARTIAL CYCLE TIMES ARE',
     +4F10.3,//,5X,'SPEEDS FULL AND EMPTY ARE (KM/H)',2F10.3)
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    4 RETURN
      END
C **********************************************************************
      SUBROUTINE TRANSP (I,IOP)
C **********************************************************************
      COMMON /Y1/ XINFO(7),MCODE(100),XMDATA(100,13)
      COMMON /Y2/ ICODE(60,3),XOPER(60,5)
      COMMON /Y3/ NMDATA,NOPER,IN,IO
      COMMON /Y4/ XOPMD(60,26)
      COMMON /Y5/ A(15),OPNAME(5,60),XTTP,JOP
      COMMON /Y6/ RATES(108,8),YAR(6)
      COMMON /Y8/ TTR(6),THR(3),XMC,FUELTR,FUELUL,ELECTT,ELECTU,DMCAP,UT
      COMMON /Y10/ XLD,XLABOR
C  THIS SUBROUTINE CALCULATES THE MINIMUM CYCLE TIME OF ONE TRANSPORT
C   UNIT.  THE TRANSPORT CYCLE TIME INCLUDES
C   TTR(1), MINIMUM INTERFACE TIME IN THE FIELD WITH THE HARVESTER
C   TTR(2), TIME TO TRAVEL FROM THE FIELD TO STORAGE WITH A FULL WAGON
C   TTR(3), TIME TO TRAVEL FROM STORAGE TO THE FIELD WITH AN EMPTY WAGON
C   TTR(4), MINIMUM INTERFACE TIME AT STORAGE
C   TTR(5), EXTRA TIME AT STORAGE TO HELP UNLOAD
C   TTR(6), IDLE TIME WAITING FOR THE HARVESTER
C   THE HARVEST CYCLE TIME INCLUDES
C   THR(1), MINIMUM INTERFACE TIME IN THE FIELD WITH THE TRANSPORT UNIT
C   THR(2), TIME TO FILL A WAGON
C   THR(3), IDLE TIME WAITING FOR A TRANSPORT UNIT
      TTR(1)=XOPER(I+1,1)
C   WHEN THE WAGON IS PULLED BY A VEHICLE OTHER THAN THE HARVESTER, INTE
C   TIME IN THE FIELD ALSO INCLUDES TIMEFOR THE HARVESTER TO FILL A WAGO
      IF (XOPER(I+1,2).EQ.0.) TTR(1)=TTR(1)+THR(2)
C   CREATE VECTOR A TO CALCULATE TRAVEL SPEED TO AND FROM STORAGE
      A(1)=XOPMD(I+2,24)
      A(2)=XOPMD(I+2,14)
      A(3)=XOPMD(I+2,1)+XOPMD(I+2,8)*1000.
      A(15)=XOPMD(I+2,23)
C   IF THE HARVESTER MUST ALSO TRANSPORT, THEN ADD THE MASS OF BOTH
C   THE HARVESTER AND THE ATTACHMENT.
      IF (XOPER(I+2,1).EQ.0.) A(3)=A(3)+XOPMD(I,1)+XOPMD(I+1,1)
C  CHECK IF A DUMP TRUCK IS BEING USED FOR TRANSPORT
      IF (ICODE(I+2,2).LT.260) GO TO 5
      A(1)=XOPMD(I+2,11)
      A(2)=A(3)
      A(3)=0.
      A(15)=XOPMD(I+2,10)
    5 A(4)=0.
      A(5)=0.
      A(6)=XINFO(1)
      A(7)=XINFO(2)
      A(8)=XINFO(3)
      A(9)=XOPER(I+2,2)
      A(10)=0.
```

```
      A(11)=0.
      A(14)=1.
      XTTP=1000.
      CALL SPEED
      TTR(2)=XOPER(I,5)/A(12)
      VFULL=A(12)
      XLD2=A(13)
C    FROM STORAGE TO THE FIELD, THE WAGON IS EMPTY
      A(3)=A(3)-XOPMD(I+2,8)*1000.
      CALL SPEED
      TTR(3)=XOPER(I,5)/A(12)
      VEMPT=A(12)
      XLD3=A(13)
      TTR(4)=XOPER(I+2,5)
C    CALCULATE UNLOADING  RATES IN THE ABSENCE (ULA) AND IN THE PRESENCE
C    OF THE TRANSPORT UNIT (ULTR)
      TTR(5)=0.
      QULA=0.
      ULTR=0.
      FUELUL=0.
      ELECTU=0.
C    IF ICODE(I+4,2) IS NOT ZERO, THERE IS AN UNLOADING DEVICE AND ENERGY
C    REQUIRED FOR UNLOADING WILL BE CALCULATED
      IF (ICODE(I+4,2).NE.0) GO TO 21
C    IN THE CASE OF HAND UNLOADING RECTANGULAR BALES, NO MECHANICAL
C    ENERGY ISREQUIRED, BUT THE IMPACT ON UNLOADING TIME MUST BE
C.   CALCULATED
C    CALL NUMBER 22.
      IF (JOP.GE.170) GO TO 22
      GO TO 20
C    POWER AND ENERGY REQUIREMENTS ARE CALCULATED HER FOR THE BLOWER, THE
C    ELEVATOR AND THE COMPACTING TRACTOR (BUNK SILOS).  THE ENERGY FOR SE
C    UNLOADING WAGONS IS INCLUDED IN TRANSPORT
   21 PWR=XOPMD(I+4,24)
      ENG=XOPMD(I+4,23)
C   IN THE CASE OF A COMPACTING TRACTOR, POWER AND ENGINE INFORMATION IS
C    GIVEN WITH THE IMPLEMENT.
      IF (ICODE(I+4,2).LT.270) GO TO 25
      PWR=XOPMD(I+4,11)
      ENG=XOPMD(I+4,10)
   25 EFF=1.
      FUI=1.
      XLD=1./XINFO(1)
C    AVERAGE LOAD OF A COMPACTING TRACTOR IS ASSUMED AS 0.5
C    AVERAGE POWER REQUIRED TO OPERATE A BALE ELEVATOR IS ASSUMED TO BE
C    4 KW.
      IF (ICODE(I+4,2).GE.270) XLD=0.5
      IF (ICODE(I+4,2).LT.240.AND.PWR.GT.5.) XLD=4./PWR
      CALL ENERGY (XLD,PWR,ENG,EFF,FUI,FUEL,ELECT)
      FUELUL=FUEL
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      ELECTU=ELECT
      IF (JOP.LT.170) GO TO 10
C   CONSIDER THE CASE OF UNLOADING RECTANGULAR BALES.  UNLOADING RATES
C   ARE ASSUMED TO BE 5 TONNES (METRIC) OF WET MATTER PER MAN-HOUR WITH
C   AN ELEVATOR AND 3.5 TWM/MAN.HOUR FOR HAND STACKING.
   22 RUL=5.0
      IF (ICODE(I+4,2).EQ.0) RUL=3.5
      ULA=RUL*XOPER(I+2,4)/(1.+XMC)
C   QULA IS THE QUANTITY UNLOADED BETWEEN EACH WAGON"S ARRIVAL
      QULA=ULA*(TTR(1)+TTR(2)+TTR(3))/XOPER(I+3,1)
      IF (JOP.GE.180) GO TO 23
      TLABOR=XOPER(I+2,4)+1.
      IF (ICODE(I+1,2).EQ.0.AND.XOPER(I+2,1).EQ.0.) TLABOR=TLABOR+1.
      GO TO 24
   23 TLABOR=XOPER(I+2,4)+XOPER(I+1,3)+1.
   24 ULTR=RUL*TLABOR/(1.+XMC)
      GO TO 15
   10 IF (ICODE(I+4,2).LT.240.OR.ICODE(I+4,2).GE.250) GO TO 20
C   CONSIDER HERE THE CASE OF A BLOWER.  UNLOADING RATE DOES NOT TAKE
C   INTO ACCOUNT TIME FOR SETTING UP THE WAGON AT STORAGE TTR(4)
      HEIGHT=XOPER(I+4,2)
C   MECHANICAL EFFICIENCY FOR BLOWING IS ASSUMED AS .08 FOR CORN SILAGE
C   0.06 FOR ALFALFA HAYLAGE
      EMECH=0.06
      IF (JOP.GE.140.AND.JOP.LT.150) EMECH=0.08
      FWM=PWR*XLD*EMECH*3600./(HEIGHT*9.8)
      ULTR=FWM/(1.+XMC)
   15 TTR(5)=(DMCAP-QULA)/ULTR
      IF (TTR(5).LT.0.) TTR(5)=0.
C   CALCULATE AVERAGE FUEL CONSUMPTION (L/H) FOR TRANSPORT, CONSIDERING
C   IDLE TIME AS ZERO (IDLE TIME WILL BE IDENTIFIED IN SUBROUTINE HRTR)
   20 PWR=XOPMD(I+2,24)
      ENG=XOPMD(I+2,23)
      FUI=1.
      XLD=(XLD2*TTR(2)+XLD3*TTR(3))/(TTR(2)+TTR(3))
      TTC=TTR(1)+TTR(2)+TTR(3)+TTR(4)+TTR(5)
      EFF=(TTR(2)+TTR(3)+0.5*TTR(5))/TTC
      IF (JOP.GE.170) EFF=(TTR(2)+TTR(3))/TTC
      IF (XOPER(I+1,2).EQ.0) EFF=EFF+TTR(1)/TTC
      CALL ENERGY (XLD,PWR,ENG,EFF,FUI,FUEL,ELECT)
      FUELTR=FUEL
      ELECTT=ELECT
C   UT IS THE UNLOADING TIME TO TRANSPORT TIME RATIO.  SINCE ENERGY
C   REQUIREMENTS FOR UNLOADING ARE CALCULATED FOR CONTINUOUS UNLOADING,
C   UT WILL BE USED
C   TO ESTIMATE ACTUAL ENERGY USED FOR UNLOADING
C   ATR AND AUR ARE ACTUAL TRANSPORT AND UNLOADING RATES
      ATR=DMCAP*XOPER(I+3,1)/TTC
      AUR=ULTR*XOPER(I+4,1)
      IF (AUR.NE.0) UT=ATR/AUR
```

```
C    IF THE UNLOADING RATE IS 0. WE MIGHT HAVE EITHER A COMPACTING
C    TRACTOR, IN
C    WHICH CASE UT=0.5 OR WE MAY HAVE NO UNLOADING DEVICE AT ALL (UT=0.)
      IF (AUR.EQ.0.) UT=0.5
      IF (ICODE(I+4,2).EQ.0) UT=0.
      RETURN
      END
C ***********************************************************************
      SUBROUTINE HRTR (I,IOP)
C ***********************************************************************
      COMMON /Y1/ XINFO(7),MCODE(100),XMDATA(100,13)
      COMMON /Y2/ ICODE(60,3),XOPER(60,5)
      COMMON /Y3/ NMDATA,NOPER,IN,IO
      COMMON /Y4/ XOPMD(60,26)
      COMMON /Y5/ A(15),OPNAME(5,60),XTTP,JOP
      COMMON /Y6/ RATES(108,8),YAR(6)
      COMMON /Y8/ TTR(6),THR(3),XMC,FUELTR,FUELUL,ELECTT,ELECTU,DMCAP,UT
      COMMON /Y9/ IPRINT,IPR1
C    THIS SUBROUTINE LINKS THE HARVEST SYSTEM TO THE TRANSPORT SYSTEM
C    IT CALCULATES MINIMUM HARVEST AND TRANSPORT RATES AND ALLOCATES IDLE
C    TIME TO WHICHEVER SYSTEM IS FASTER  SO BOTH RATES BECOME EQUAL.
C    IT ALSO CALCULATES ENERGY REQUIREMENTS FOR THE ENTIRE OPERATION
C    (HARVEST, TRANSPORT AND UNLOADING).
      XMC=2.33
      IF (JOP.GE.170) XMC=0.25
      IF (JOP.GE.150.AND.JOP.LT.160) XMC=1.0
      DMCAP=XOPMD(I+2,8)/(1.+XMC)
      THR(1)=XOPER(I+1,1)
C    THE FOLLOWING FIVE VARIABLES ARE INITIALIZED WITH DUMMY VALUES.  THE
C    ACTUAL VALUE IS CALCULATED SUBSEQUENTLY IN EITHER HRTR OR TRANSPORT
C    SUBROUTINE.
      THR(2)=0.5
      THR(3)=0.
      TTR(6)=0.
C    HTOT AND TTOT ARE RATIOS OF HARVEST TIME AND TRANSPORT TIME
C    TOTAL OPERATION TIME.  IN THE CASE OF A HARVESTER ALSO TRANSPORTING
C    MATERIAL TO STORAGE, TIME MUST BE ALLOCATED IN PART TO HARVEST AND
C    IN PART TO TRANSPORT.
C    IN THIS CASE HTOT AND TTOT WILL BOTH BE LESS THAN 1 A
C    THEIR SUM WILL BE EQUAL TO 1.
      HTOT=1.
      TTOT=1.
      CALL TRANSP(I,IOP)
      K=(IOP-1)*6
      DO 10 J=1,6
      K=K+1
      THR(2)=DMCAP/RATES(K,3)
C    TRANSPORT RATES WILL BE INDEPENDENT OF YIELD EXCEPT WHEN THE WAGON
C    IS PULLED BY THE HARVESTER.
      IF (XOPER(I+1,2).EQ.0.) CALL TRANSP (I,IOP)
```

```
      THC=THR(1)+THR(2)
      HR=DMCAP*XOPER(I,1)/THC
      TTC=TTR(1)+TTR(2)+TTR(3)+TTR(4)+TTR(5)
      TR=DMCAP*XOPER(I+3,1)/TTC
      IF (XOPER(I+2,1).NE.0.) GO TO 15
      HTOT=TR/(TR+HR)
      TTOT=HR/(TR+HR)
      AHR=HR*HTOT
      GO TO 30
   15 IF (HR.GT.TR) GO TO 20
C   HERE TRANSPORT UNIT WILL IDLE TTR(6) HOUR PER UNIT HARVESTER
      TTR(6)=(XOPER(I+3,1)*THC-XOPER(I,1)*TTC)/XOPER(I,1)
      AHR=HR
      THR(3)=0.
      GO TO 30
C   HERE HARVEST RATE IS GREATER THAN TRANSPORT RATE,
C   HARVESTER WILL IDLE THR(3) HOUR PER TRANSPORT UNIT
   20 THR(3)=(XOPER(I,1)*TTC-XOPER(I+3,1)*THC)/XOPER(I+3,1)
      AHR=TR
      TTR(6)=0.
C   NOW LET US MAKE CHANGES TO HARVEST RATES AND ENERGY CONSUMPTION SO
C   THEY MAY INCLUDE IDLE TIME.
   30 RATES(K,3)=AHR
      RATES(K,2)=AHR/YAR(J)
      THC=THC+THR(3)
      FUELHR=RATES(K,5)*THR(2)/THC
      ELECTH=RATES(K,6)*THR(2)/THC
C   ACTUAL ENERGY CONSUMPTION RATES ARE CALCULATED ON A TOTAL OPERATION
C   BASIS.
      FH=FUELHR*HTOT*XOPER(I,1)
      FT=FUELTR*TTOT*XOPER(I+3,1)*TTC/(TTC+TTR(6))
      FU=FUELUL*TTOT*UT*XOPER(I+4,1)*TTC/(TTC+TTR(6))
      EH=ELECTH*HTOT*XOPER(I,1)
      ET=ELECTT*TTOT*XOPER(I+3,1)*TTC/(TTC+TTR(6))
      EU=ELECTU*TTOT*UT*XOPER(I+4,1)*TTC/(TTC+TTR(6))
      RATES(K,5)=FH+FT+FU
      RATES(K,6)=EH+ET+EU
      IF(IPRINT.NE.1) GO TO 10
      WRITE (10,100) JOP,YAR(J),(THR(KK),KK=1,3),(TTR(KK),KK=1,6)
  100 FORMAT (//,5X,'OPERATION  ',I8,/5X,'YIELD ',F10.2,'  TDM/HA',/,5X,
     +'HARVEST CYCLE TIMES (HOURS) ',/,10X,'T1, INTERFACE TIME WITH TRAN
     +SPORT  ',F10.4,/,10X,'T2, TIME TO FILL A WAGON IN THE FIELD  ',F10
     +.4,/10X,'T3, HARVESTER IDLE TIME  ',F10.4,/,5X,'TRANSPORT CYCLE TI
     +MES (HOURS) ',/   ,10X,'T1, INTERFACE TIME WITH  HARVESTER  ',F10.
     +4,/,10X,'T2, TIME TO TRAVEL WITH A FULL LOAD  ',F10.4,/,10X,'T3, T
     +IME TO TRAVEL WITH AN EMPTY WAGON  ',F10.4,/10X,'T4, MINIMUM INTER
     +FACE TIME AT STORAGE  ',F10.4,/,10X,'T5, TIME HELPING WITH UNLOADI
     +NG  ', F10.4,/10X,'T6, TRANSPORT UNIT IDLE TIME  ',F10.4,/)
      WRITE (10,110) FUELHR,FH,FUELTR,FT,FUELUL,FU,ELECTH,EH,ELECTT,ET,
     +ELECTU,EU,HTOT,TTOT,UT
```

```
  110 FORMAT (//,60X,'PER S1NGLE UNIT',10X,'FOR ALL UNITS',/60X,'ON A CO
     +NTINUOUS',10X,'WITH RESPECT TO',/60X,'BASIS',20X,'TOTAL OPERATION
     +TIME',/,5X,'FUEL CONSUMPTION RATES (L/H)   HARVEST',19X,F10.2,15X,
     +F10.2,/,36X,'TRANSPORT',17X,F10.2,15X,F10.2,/,36X,'UNLOADING',17X,
     +F10.2,15X,F10.2,//,5X,'ELECTRICITY CONSUMPTION RATES (KW-H/H)   HA
     +RVEST',9X,F10.2,15X,F10.2,/46X,'TRANSPORT',7X,F10.2,15X,F10.2,/,
     +46X,'UNLOADING',7X,F10.2,15X,F10.2,///,5X,'THE HARVEST TIME TO TOT
     +AL OPERATION TIME RATIO IS  ',F10.4,/,5X,'THE TRANSPORT TIME TO TO
     +TAL OPERATION TIME RATIO IS  ', F10.4,/,5X,'THE UNLOADING TIME TO
     +TRANSPORT TIME RATIO  IS  ',F10.4)
   10 CONTINUE
      RETURN
      END
C ***********************************************************************
      SUBROUTINE HAYPCK (I,IOP)
C ***********************************************************************
      COMMON /Y1/ XINFO(7),MCODE(100),XMDATA(100,13)
      COMMON /Y2/ ICODE(60,3),XOPER(60,5)
      COMMON /Y3/ NMDATA,NOPER,IN,IO
      COMMON /Y4/ XOPMD(60,26)
      COMMON /Y5/ A(15),OPNAME(5,60),XTTP,JOP
      COMMON /Y6/ RATES(108,8),YAR(6)
      COMMON /Y8/ TTR(6),THR(3),XMC,FUELTR,FUELUL,ELECTT,ELECTU,DMCAP,UT
      COMMON /Y9/ IPRINT,IPR1
      COMMON /Y10/ XLD,XLABOR
C   THIS SUBROUTINE LINKS FIELD HAND-PICKING OF RECTANGULAR HAY BALES
C   AND UNLOADING AT A STORAGE SITE.
C   THIS OPERATION IS CONSIDERED INDEPENDENT OF AND SUBSEQUENT TO HAY
C   BALING.
      XMC=0.25
      DMCAP=XOPMD(I+2,8)/(1.+XMC)
      THR(1)=XOPER(I+1,1)
      THR(3)=0.
      TTR(6)=0.
      K=(IOP-1)*6
      DO 10 J=1,6
      K=K+1
C   PICKING RATE OF BALES IS A FUNCTION OF YIELD AND LABOR AVAILABLE IN
C   THE FIELD.
C   VARIABLES BALES AND RMASS ARE BALES PICKED PER HOUR AND TONNES OF
C   DRY MATTER PICKED PER HOUR.
      FLABOR=XOPER(I+1,3)+1.
      BALES=(48.+4.*YAR(J))*FLABOR
      RMASS=BALES*XOPER(I,4)/(1000.*(1.+XMC))
      THR(2)=DMCAP/RMASS
      CALL TRANSP (I,IOP)
      TTC=TTR(1)+TTR(2)+TTR(3)+TTR(4)+TTR(5)
      AHR=DMCAP*XOPER(I+3,1)/TTC
      RATES(K,1)=YAR(J)
      RATES(K,2)=AHR/YAR(J)
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```
      RATES(K,3)=AHR
      RATES(K,4)=XLD
      FT=FUELTR*XOPER(I+3,1)
      FU=FUELUL*UT*XOPER(I+4,1)
      ET=ELECTT*XOPER(I+3,1)
      EU=ELECTU*UT*XOPER(I+4,1)
      RATES(K,5)=FT+FU
      RATES(K,6)=ET+EU
      RATES(K,7)=XLABOR
      RATES(K,8)=8.
      IF (IPRINT.NE.1) GO TO 10
      WRITE (10,100) JOP,YAR(J),(THR(KK),KK=1,3),(TTR(KK),KK=1,6)
  100 FORMAT (//,5X,'OPERATION  ',I8,/,5X,'YIELD ',F10.2,'  KG/HA',/,5X,
     +'HARVEST CYCLE TIMES (HOURS) ',/,10X,'T1, INTERFACE TIME WITH TRAN
     +SPORT  ',F10.4,/,10X,'T2, TIME TO FILL A WAGON IN THE FIELD  ',F10
     +.4,/10X,'T3, HARVESTER IDLE TIME  ',F10.4,/,5X,'TRANSPORT CYCLE TI
     +MES (HOURS) ',/   ,10X,'T1, INTERFACE TIME WITH  HARVESTER  ',F10.
     +4,/,10X,'T2, TIME TO TRAVEL WITH A FULL LOAD  ',F10.4,/,10X,'T3, T
     +IME TO TRAVEL WITH AN EMPTY WAGON  ',F10.4,/10X,'T4, MINIMUM INTER
     +FACE TIME AT STORAGE  ',F10.4,/,10X,'T5, TIME HELPING WITH UNLOADI
     +NG  ', F10.4,/10X,'T6, TRANSPORT UNIT IDLE TIME  ',F10.4,/)
      WRITE (10,110) FUELTR,FT,FUELUL,FU,ELECTT,ET,ELECTU,EU,UT
  110 FORMAT (//,60X,'PER SINGLE UNIT',10X,'FOR ALL UNITS',/60X,'ON A CO
     +NTINUOUS',10X,'WITH RESPECT TO',/60X,'BASIS',20X,'TOTAL OPERATION
     +TIME',/,5X,'FUEL CONSUMPTION RATES (L/H)',
     +            'TRANSPORT',17X,F10.2,15X,F10.2,/,36X,'UNLOADING',17X,
     +F10.2,15X,F10.2,//,5X,'ELECTRICITY CONSUMPTION RATES (KW-H/H)',
     +                             'TRANSPORT',7X,F10.2,15X,F10.2,/,
     +46X,'UNLOADING',7X,F10.2,15X,F10.2,///,5X, 'THE UNLOADING TIME TO
     +TRANSPORT TIME RATIO  IS  ',F10.4)
   10 CONTINUE
      RETURN
      END
```

Table E.4. Listing of program ALHARV.

```
C
C ***********************************************************************
      SUBROUTINE ALHARV(REMCUT,REMHRV,ICUTON,JDAY)
C ***********************************************************************
      COMMON /W1/ NPLOTS,NMOW,NHRV,NSTO,AREAPL,HARMAT(40,29),ZRT(9,5)
      COMMON /W2/ TPL(9),RAIN,JJDAY,NDAYHR
      COMMON /W4/ NPDCA,NDCTD,IDAH
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
      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
C   THIS SUBROUTINE IS CALLED FROM THE ALFALFA GROWTH SIMULATOR
C   WRITTEN BY LUKE PARSCH, AGICULTURAL ECONOMICS DEPARTMENT, MSU
C   THE PRESENT SUBROUTINE ALHARV AND ALL THE ATTACHED SUBROUTINES
C   CALLED HEREFROM WERE WRITTEN BY PHILIPPE SAVOIE, AGRICULTURAL
C   ENGINEERING DEPARTMENT, MICHIGAN STATE UNIVERSITY.
C   ALHARV IS CALLED ONCE EACH ALFALFA HARVEST DAY.
C   HARVEST WILL NOT BEGIN IF CORN PLANTING (CPLANT) IS NOT FINISHED.
C   IF THE MOWING CRUDE PROTEIN IS SPECIFIED IN THE REASONABLE RANGE,
C   MOWING CAN BE POSTPONED UP TO 10 DAYS BEYOND BGNCUT(NTHCUT)
C   IF ALFALFA IS CONSIDERED IMMATURE.
C   ON THE FIRST DAY OF MOWING, AN INITIALIZATION SUBROUTINE IS CALLED.
C   THE WHOLE AREA TO BE HARVESTED IS DIVIDED INTO NPLOTS, THE
C   NUMBER OF PLOTS.
C   FOR DIRECT-CUT ALFALFA, IDENTIFIED BY IDAH=1 IN THE INITIALIZATION
C   SUBROUTINE, SUBROUTINE DCALF IS CALLED.
C   FOR FIELD CURED ALFALFA, EITHER FOR HAY OR HAYLAGE, SUBROUTINES
C   HRVQ, MOWQ, HRVQ AND UPDATE ARE CALLED IN THAT ORDER.
C   FIRST PRIORITY IS GIVEN TO HARVEST (REMOVING ALFALFA FROM THE
C   FIELD).  SECOND PRIORITY IS GIVEN TO MOWING.
C   HRVQ IS CALLED A SECOND TIME IN CASE SOME PLOTS MOWED IN THE
C   MORNING COULD BE READY FOR HARVEST LATER IN THE AFTERNOON.
C   ALL PLOTS MOWED AND NOT YET HARVESTED (STILL CURING IN THE FIELD)
C   ARE THEN UPDATED FOR WEATHERING LOSSES AND FOR DRYING.
C   FINALLY WHEN ALL PLOTS ARE HARVESTED THEY ARE AGGREGAGATED INTO THE
C   HFEED MATRIX BY CALLING ENDHRV.
C
C   NHTDAY IS THE NUMBER OF PLOTS HARVESTED TODAY
C   NMTDAY IS THE NUMBER OF PLOTS MOWED TODAY
C
      ICUTON=0
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      IF (NDAYHR.GT.0) GO TO 5
      IF (CPLANT.GE.FLOAT(JDAY)) RETURN
      KFIRST=MAX1(CPLANT+1.,BGNCUT(NTHCUT))
C   IF THE CP CRITERION IS UNREASONABLE, BYPASS IT AND HARVEST.
      IF (CRTR(NTHCUT,4,3).LT.0.15.OR.CRTR(NTHCUT,4,3).GT.0.23) GO TO 5
C   ON THE FIRST CHECKING DAY, SET THE PREVIOUS DAY'S CP AND RETURN.
      IF (JDAY.EQ.KFIRST) THEN
      PDCP1=CRTR(NTHCUT,4,3)+0.0001
      PDCP2=QUAL(3,2)+0.0001
      PDCP=AMAX1(PDCP1,PDCP2)
      RETURN
      ENDIF
C   ON SUBSEQUENT DAYS, THE NUMBER OF DAYS MOWING HAS BEEN POSTPONED
C   IS CALCULATED.  IF IT IS GREATER OR EQUAL TO 10, POSTPONEMENT
C   IS STOPPED AND MOWING MUST START.
      CHDAYS=FLOAT(JDAY)-BGNCUT(NTHCUT)
      CHMAX=10.
      IF (CHDAYS.GE.CHMAX) THEN
C
      KFIRST=JDAY
C
      GO TO 5
      ENDIF
      IF (QUAL(3,2).GT.PDCP) GO TO 3
      IF (QUAL(3,2).GT.CRTR(NTHCUT,4,3)) RETURN
C   HERE THE QUALITY IS LOW ENOUGH TO HARVEST.
C   CHECK IF TODAY IS THE FIRST DAY OF HARVEST.
      IF (PDCP.GT.CRTR(NTHCUT,4,3)) THEN
      KFIRST=JDAY
      ENDIF
      PDCP=QUAL(3,2)
      GO TO 4
3     IF (NHRV.EQ.NPLOTS) RETURN
4     CONTINUE
5     I=NTHCUT
      JJDAY=JDAY
      RAIN=PPT
      NHTDAY=0
      NMTDAY=0
      IF(JDAY.EQ.KFIRST) NDAYHR=1
      IF (NDAYHR.EQ.1) CALL INHRV
      IF (NDAYHR.GE.39) CALL ENDHRV
      IF (NDAYHR.GE.39) GO TO 30
      IF (IDAH.EQ.1) GO TO 10
      IF (NHRV.LT.NMOW) CALL HRVQ (NHTDAY)
      IF (NMOW.LT.NPLOTS) CALL MOWQ (NHTDAY,NMTDAY)
      NMOW=NMOW+NMTDAY
      IF (NHRV.LT.NMOW) CALL HRVQ (NHTDAY)
      NHRV=NHRV+NHTDAY
      CALL UPDATE
```

```
      GO TO 20
   10 CALL DCALF
   20 CONTINUE
      IF (NHRV.EQ.NPLOTS) CALL ENDHRV
      NDAYHR=NDAYHR+1
   30 CONTINUE
      REMCUT=1.-FLOAT(NMOW)/FLOAT(NPLOTS)
      REMHRV=1.-FLOAT(NHRV)/FLOAT(NPLOTS)
      IF (NMOW.GT.0) ICUTON=1
      IF (NMOW.GE.NPLOTS) ICUTON=0
      IF (NMTDAY.GE.NPLOTS) ICUTON=1
      CALL WRITAL(1)
      RETURN
      END
C *********************************************************************
      SUBROUTINE MGTINF
C *********************************************************************
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
      COMMON /Z5/ IPR2,IPR3,IPR4
      COMMON /Z8/ ALFSIL(2),HAYST(3)
      COMMON /Y3/ NMDATA,NOPER,IN,IO
C   THIS SUBROUTINE READS MANAGEMENT INFORMATION RELATED TO ALFALFA
C   HARVEST.  THIS INCLUDES THE AREA, THE SEQUENCE OF OPERATIONS, THE
C   CRITERION MATRIX FOR EACH ALFALFA HARVEST AND ALFALFA STORAGE
C   CAPACITIES AND INITIAL COSTS.  THERE CAN BE UP TO 4 DISTINCT
C   ALFALFA HARVESTS IN A GIVEN YEAR.  THE NUMBER MAY VARY.  WHEN AREA
C   READ IN IS ZERO, NO MORE HARVESTS ARE CONSIDERED.
C
      WRITE (IO,95)
   95 FORMAT (/,5X,'THE MANAGEMENT INPUTS FOR AREA AND OPERATION SEQUENC
     +E WERE READ AS FOLLOWS')
      I=0
   15 I=I+1
      READ (IN,100) AREA(I),NBO(I)
      WRITE (IO,100) AREA(I),NBO(I)
  100 FORMAT (F10.2,I2)
      IF (AREA(I).EQ.0.) GO TO 10
      READ (IN,110)  (NOPSQ(I,K),K=1,9)
      WRITE (IO,110)  (NOPSQ(I,K),K=1,9)
  110 FORMAT (9I5)
      READ (IN,120)  ((CRTR(I,J,K),K=1,9),J=1,4)
      WRITE (IO,120)  ((CRTR(I,J,K),K=1,9),J=1,4)
  120 FORMAT (3(9F5.2,/),9F5.2)
      GO TO 15
10    READ (IN,130)  (SILO(I),I=1,2),(ALFSIL(I),I=1,2),(HAYST(I),I=1,3)
      WRITE (IO,130)  (SILO(I),I=1,2),(ALFSIL(I),I=1,2),(HAYST(I),I=1,3)
130   FORMAT (7F10.2)
      READ (IN,140) IPR2,IPR3,IPR4
      WRITE (IO,140) IPR2,IPR3,IPR4
  140 FORMAT (3I2)
```

```
      RETURN
      END
C
C *********************************************************************
      SUBROUTINE YRINIT
C *********************************************************************
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
      COMMON /Z3/ HARDEX,TMSTO(4),NPST(5,5),NCUM(5),OPUSE(5,9)
      COMMON /Z4/FDLABR,FDENER,HRLABR,HRFUEL,HRELEC
      COMMON /Z6/ CSLABR,CSFUEL,CSELEC,CSFDLB,CSFDEN,DMCS
      COMMON /Z7/ ALHRFD(26,15),AFEED(26,23)
      COMMON /YY1/ USEMCH(100),UNITS(100)
C   THIS SUBROUTINE PROVIDES AN INITIALIZATION OF PARAMETERS THAT MUST
C   BE SET TO 0 AT THE BEGINNING OF EACH YEAR.
      DATA ALHRFD,AFEED /390*0.0,598*0.0/
      HARDEX=1.
      IF (SILO(1).EQ.0.) HARDEX=2.
      IF (SILO(1).EQ.0.0.AND.SILO(2).EQ.0.) HARDEX=3.
      FDLABR=0.
      FDENER=0.
      HRLABR=0.
      HRFUEL=0.
      HRELEC=0.
      CSLABR=0.
      CSFUEL=0.
      CSELEC=0.
      CSFDLB=0.
      CSFDEN=0.
      DMCS=0.
      DO 3 I=1,4
    3 TMSTO(I)=0.
      DO 5 I=1,5
      NCUM(I)=0
      DO 4 J=1,9
    4 OPUSE(I,J)=0.
      DO 5 J=1,5
    5 NPST(I,J)=0
      DO 6 I=1,100
      USEMCH(I)=0.
    6 UNITS(I)=0.
      RETURN
      END
C
C *********************************************************************
      SUBROUTINE INHRV
C *********************************************************************
      COMMON /W1/ NPLOTS,NMOW,NHRV,NSTO,AREAPL,HARMAT(40,29),ZRT(9,5)
      COMMON /W2/ TPL(9),RAIN,JJDAY,NDAYHR
      COMMON /W4/ NPDCA,NDCTD,IDAH
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
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      COMMON /Z3/ HARDEX,TMSTO(4),NPST(5,5),NCUM(5),OPUSE(5,9)
      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 /Y3/ NMDATA,NOPER,IN,IO
      COMMON /Y6/ RATES(108,8),YAR(6)
      COMMON /Y7/ NBOP(18),NBMACH(18,7),XNBM(18,7)
      COMMON /Z21/ ADATES(26,12),SDATES(4,12)
      DATA ADATES /312*0./
C
C   THIS IS AN INITIALIZATION SUBROUTINE.  IT IS CALLED ON THE FIRST
C   HARVEST DAY.
C   IT IS CALLED ONLY ONCE FOR EACH HARVEST (OR CUT).
C   UP TO NINE  OPERATIONS MAY BE INCLUDED IN A HARVEST SEQUENCE.
C   THE NUMBER OF OPERATIONS IN A SEQUENCE IS EITHER 1 FOR DIRECT CUT
C   ALFALFA OR CORN SILAGE HARVEST (IDENTIFIED BY IDAH=1) OR UP TO
C   9 SEQUENTIAL OPERATIONS (IDAH=9) FOR FIELD-CURED ALFALFA.
C   WHEN ALFALFA IS FIELD CURED, THERE MAY BE UP TO 6
C   SEQUENTIAL OPERATIONS AND 3 OPTIONAL HARVEST OPERATIONS
C   FOR EACH CUT I IN ANY YEAR, THE POSSIBLE OPERATIONS ARE
C     NOPSQ(I,1), MOWING FOR FIELD CURING
C     NOPSQ(I,2), ADDITIONAL CURING TREATMENT OR 0000
C     NOPSQ(I,3), RAKING JUST BEFORE HARVESTING OR 0000
C     NOPSQ(I,4), ADDITIONAL TREATMENT AFTER RAINFALL OR 0000
C     NOPSQ(I,5), FIRST PRIORITY HARVEST OF FIELD CURED FORAGES
C          OR DIRECT-CUT ALFALFA HARVEST.
C     NOPSQ(I,6), SECOND PRIORITY HARVEST
C     NOPSQ(I,7), FORCED HAY HARVEST WHEN SILOS ARE FULL
C     NOPSQ(I,8), LAST RESORT HARVEST OPERATION TO DESTROY FORAGES AFTER
C          EXCESSIVE EXPOSURE
C     NOPSQ(I,9), TRANSPORT OF BALED HAY DROPPED IN THE FIELD DURING
C          HARVEST.
C   FOR EACH OPERATION (J) DURING HARVEST (I), FIVE PARAMETERS ARE
C   ESTIMATED.  THEY ARE
C     ZRT(J,1), THE HARVEST RATE AT A SPECIFIC YIELD (HA/H)
C     ZRT(J,2), THE FUEL CONSUMPTION RATE (L/H)
C     ZRT(J,3), THE ELECTRICITY CONSUMPTION RATE (KW.H/H)
C     ZRT(J,4), THE LABOR REQUIREMENT (MAN.H/H)
C     ZRT(J,5), THE AVERAGE SPEED OF THE HARVESTING IMPLEMENT (KM/H)
C
C   THE HARMAT MATRIX CONTAINS ALL THE USEFUL CHARACTERISTICS OF ALFALFA
C   BETWEEN MOWING AND STORAGE TIME.  IT KEEPS TRACK OF DRYING, DRY
C   MATTER AND QUALITY CHANGES OF BOTH STEMS AND LEAVES.
C   FOR EACH PLOT (I), THE CHARACTERISTICS ARE
C     HARMAT(I,1), A MOWING DUMMY VARIABLE (1. WHEN MOWED, 0. OTHERWISE)
C     HARMAT(I,2), LEAF YIELD AT TIME OF MOWING (KG-DM/HA)
C     HARMAT(I,3), STEM YIELD AT TIME OF MOWING (KG-DM/HA)
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C     HARMAT(I,4), CRUDE PROTEIN IN THE LEAVES AT MOWING (DEC.)
C     HARMAT(I,5), CRUDE PROTEIN IN THE STEMS AT MOWING (DEC.)
C     HARMAT (I,6), DIGESTIBILITY OF LEAVES AT MOWING (DEC)
C     HARMAT(I,7), DIGESTIBILITY OF STEMS AT MOWING (DEC)
C     HARMAT(I,8), CRUDE FIBER OF LEAVES AT MOWING (DEC)
C     HARMAT(I,9), CRUDE FIBER OF STEMS (DEC)
C     HARMAT(I,10), INITIAL MOISTURE CONTENT EACH DAY AT 8AM (DEC, DB)
C     HARMAT (I,11), FINAL MOISTURE CONTENT AT TIME OF HARVEST (DEC, DB)
C     HARMAT(I,12), HARVEST DUMMY VARIABLE (1. WHEN HARVESTED, 0. OTHERW
C     HARMAT(I,13), STORAGE DUMMY VARIABLE (1. WHEN STORED, 0. OTHERWISE
C     HARMAT(I,14), NUMBER OF EXPOSURE DAYS SINCE MOWING
C     HARMAT(I,15), NUMBER OF EXPOSURE DAYS SINCE HARVESTING (IN THE
C          CASE OF BALES LEFT OUTSIDE FOR STORAGE)
C     HARMAT(I,16), CUMULATIVE RAINFALL ON BALED HAY LEFT IN THE FIELD
C            (MM)
C     HARMAT(I,17), WINDROW TO SWATH WIDTH RATIO
C     HARMAT(I,18), RAKING FACTOR FOR DRYING (1. ON THE DAY MATERIAL IS
C          RAKED, 0. OTHERWISE)
C     HARMAT(I,19), MOWING-CONDITIONING FACTOR FOR DRYING
C     HARMAT(I,20), EXTRA TREATMENT FACTOR FOR DRYING
C     HARMAT(I,21), HARVEST INDEX (1. WHEN FIRST PRIORITY, 2. WHEN SECON
C          PRIORITY, 3. WHEN FORCED BALED HAY AFTER FILLING SILOS, 4. WH
C          DESTROYING EXCESSIVELY EXPOSED FORAGES)
C     HARMAT(I,22), STORAGE TYPE INDEX (1. FOR DRY HAY, 2. FOR WET STORA
C     HARMAT(I,23), THIS PARAMETER HAS NO USE AT PRESENT
C     HARMAT(I,24), REMAINING LEAF FRACTION (DEC)
C      HARMAT(I,25), REMAINING STEM FRACTION(DEC)
C     HARMAT(I,26), REMAINING DRY MATTER FRACTION AFTER RESPIRATION LOSS
C     HARMAT(I,27), CUMULATIVE RAINFALL DURING FIELD CURING (MM)
C     HARMAT(I,28), AVERAGE TIME AFTER 8AM AT WHICH PLOT(I) IS MOWED
C     HARMAT(I,29), MOISTURE CONTENT RIGHT AFTER RAIN OR AT 8AM IN THE
C          CASE OF A NON-RAINY DAY (DEC, DB)
C
C   CONVERT YIELD INTO TDM/HA AND INCREASE BY 10 PERCENT TO ESTIMATE
C   AVERAGE HARVEST RATE THROUGHOUT THE HARVEST SEASON
      K=(NTHCUT-1)*3+1
      ADATES(NTHYR,K)=FLOAT(JJDAY)
      YDM=TOPS*0.01*1.1
      DO 10 J=1,9
      DO 10 K=1,5
   10 ZRT(J,K)=0.
      I=NTHCUT
      NBOX=9
      IF (NOPSQ(I,1).GE.140.AND.NOPSQ(I,1).LT.150) NBOX=1
C   THE FOLLOWING DO LOOP IDENTIFIES EACH OPERATION AND USES INFORMATION
C   IN THE RATES MATRIX TO INTERPOLATE ACTUAL PARAMETERS IN THE ZRT MATR
      DO 20 J=1,NBOX
      II=0
    1 II=II+1
      IF (NOPSQ(I,J).EQ.0) GO TO 20
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      IF (NOPSQ(I,J).NE.NBOP(II).AND.II.LT.18) GO TO 1
      IF (NOPSQ(I,J).EQ.NBOP(II)) GO TO 2
      WRITE (10,100) NOPSQ(I,J)
  100 FORMAT (/,5X,'OPERATION NUMBER ',I6,' HAS NOT BEEN DEFINED INITIAL
     +LY IN SUBROUTINE FORHRV',/,5X,'MAKE THE CORRECTION')
      STOP
    2 K=(II-1)*6
      YDMLOW=RATES(K+1,1)
      YDMHGH=RATES(K+6,1)
      XINCR=(YDMHGH-YDMLOW)/5.
      IF (YDM.LE.YDMLOW) GO TO 3
      IF (YDM.GE.YDMHGH) GO TO 4
      DIFF=(YDM-YDMLOW)/XINCR
      IDIFF=IFIX(DIFF)
      KI=1+IDIFF
      FH=DIFF-FLOAT(IDIFF)
      FL=1.-FH
      GO TO 5
    3 FL=1.
      FH=0.
      KI=1
      GO TO 5
    4 FL=0.
      FH=1.
      KI=5
    5 KL=K+KI
      ZRT(J,1)=RATES(KL,2)*FL+RATES(KL+1,2)*FH
      ZRT(J,2)=RATES(KL,5)*FL+RATES(KL+1,5)*FH
      ZRT(J,3)=RATES(KL,6)*FL+RATES(KL+1,6)*FH
      ZRT(J,4)=RATES(KL,7)
      ZRT(J,5)=RATES(KL,8)*FL+RATES(KL+1,8)*FH
C     IN THE CASE OF A YIELD ABOVE THE MAXIMUM USED IN FORHRV, WE SHOULD
C     ASSUME A CONSTANT THROUGHPUT INSTEAD OF A CONSTANT FIELD CAPACITY
C     ALSO REDUCE FIELD OPERATING SPEED PROPORTIONATELY
      IF (YDM.GE.YDMHGH) ZRT(J,1)=RATES(KL+1,3)/YDM
      IF(YDM.GE.YDMHGH) ZRT(J,5)=ZRT(J,5)*YDMHGH/YDM
   20 CONTINUE
C     NMO,NHRV AND NSTO ARE THE TOTAL NUMBER OF PLOTS MOWED, HARVESTED AND
C     STORED DURING THE CURRENT HARVEST SEASON
C     NPDCA IS THE NUMBER OF PLOTS THAT WILL BE HARVESTED AS DIRECT CUT
C     ALFALFA DURING THE PRESENT HARVEST
      NMOW=0
      NHRV=0
      NSTO=0
      NPDCA=0
C     NDCTD IS THE NUMBER OF PLOTS THAT ARE HARVESTED AS DIRECT CUT
C     ALFALFA TODAY.
      NDCTD=0
C     IDAH IS THE IDENTIFICATION NUMBER FOR ALFALFA HARVEST. ITS VALUE IS
C     1 FOR DIRECT CUT ALFALFA. ANY OTHER VALUE MEANS THE ALFALFA WILL BE
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C   FIELD CURING.  IN THIS CASE, IDAH IS USUALLY 9.
      IDAH=9
      IF  (NOPSQ(I,5).GE.160.AND.NOPSQ(I,5).LE.169)  IDAH=1
      IF  (HARDEX.EQ.3.0.AND.NOPSQ(I,1).NE.0)  IDAH=9
C   WE MUST CALCULATE HOW MANY PLOTS WILL BE HARVESTED
C   THE BASIC ASSUMPTION FOR ALFALFA HARVEST IS THAT ONE PLOT IS
C   EQUIVALENT TO 5 HOURS OF FIRST PRIORITY HARVEST TIME.
C   AS CAN BE SEEN LATER IN SUBROUTINES HRVQ (FOR FIELD CURED ALFALFA)
C   AND DCALF (FOR DIRECT CUT ALFALFA), A MAXIMUM OF 2 PLOTS MAY BE
C   HARVESTED THE SAME DAY.  FOR CORN SILAGE HARVEST, THESE CALCULATIONS
C   ARE NOT NECESSARY.
      IF  (NOPSQ(NTHCUT,1).GE.140.AND.NOPSQ(NTHCUT,1).LE.149)  RETURN
      HRR=ZRT(5,1)
      IF  (HARDEX.EQ.3.0.AND.NOPSQ(NTHCUT,1).NE.0)  HRR=ZRT(7,1)
      XAREA=HRR*5.
      NPLOTS=IFIX(AREA(I)/XAREA)+1
      AREAPL=AREA(I)/FLOAT(NPLOTS)
      IF  (NPLOTS.LE.40)  GO TO 8
      WRITE  (10,110)  NPLOTS,AREA(I),HRR,YDM
  110 FORMAT  (/,5X,'THE NUMBER OF PLOTS TO BE HARVESTED IS GREATER THAN
     +40, THE MAXIMUM ALLOWED',/,5X,'IT IS ACTUALLY ',I6,/,5X,'EITHER TH
     +E AREA TO BE HARVESTED IS EXCESSIVE OR THE HARVEST RATE IS UNREALI
     +STICALLY LOW',/,5X,'AREA IS ',F12.2,' HA AND HARVEST RATE IS ',F12
     +.2,' HA/H FOR A DRY MATTER YIELD OF ',F12.2,' KG/HA',/,5X,'A CHANG
     +E MUST BE MADE')
      STOP
    8 DO 30 I=1,NPLOTS
      DO 30 J=1,29
   30 HARMAT(I,J)=0.
C   CALCULATE THE TIME TO DO EACH OPERATION OVER ONE PLOT
      DO 40 J=1,9
      TPL(J)=AREAPL/ZRT(J,1)
      IF  (ZRT(J,1).LE.0.)  TPL(J)=0.
   40 CONTINUE
      RETURN
      END
C
C *********************************************************************
      SUBROUTINE HRVQ(NHTDAY)
C *********************************************************************
      COMMON /W1/ NPLOTS,NMOW,NHRV,NSTO,AREAPL,HARMAT(40,29),ZRT(9,5)
      COMMON /W2/ TPL(9),RAIN,JJDAY,NDAYHR
      COMMON /W3/ HFEED(4,160,5)
      COMMON /W4/ NPDCA,NDCTD,IDAH
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
      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,
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     +XMATS,TNCS,TMAXC,TMINC
      COMMON /Z3/ HARDEX,TMSTO(4),NPST(5,5),NCUM(5),OPUSE(5,9)
      COMMON /Y3/ NMDATA,NOPER,IN,IO
C   SUBROUTINE HRVQ DETERMINES IF ANY FIELD-CURING (ALREADY MOWED) PLOT
C   MAY BE
C   HARVESTED TODAY.  PLOTS ARE CONSIDERED IN REVERSE CHRONOLOGICAL ORDE
C   STARTING WITH THE LAST MOWED PLOT.  A MAXIMUM OF TWO PLOTS MAY BE
C   HARVESTED THE SAME DAY.
C   (EACH REQUIRES 5 HOURS OF EFFECTIVE FIELD TIME)
C   FOR ONE PLOT TO BE HARVESTED, THE FOLLOWING CRITERIA MUST BE SATISFI
C     1.  THE PLOT MUST NOT HAVE BEEN HARVESTED ALREADY
C     2.  LESS THAN TWO PLOTS MUST HAVE BEEN ALREADY HARVESTED ON THAT
C         DAY.
C     3. THE MOISTURE CONTENT OF ALFALFA IN THE PLOT MUST BE BELOW THE
C          CRITICAL MOISTURE CONTENT FOR HARVEST BY 4PM.
C     4.  IN THE CASE OF A HARVEST INDEX OF 4. , THE PLOT IS HARVESTED
C        TODAY  WITHOUT REGARDS TO MOISTURE CONTENT
C   FOR A SECOND PLOT TO BE HARVESTED ON THE SAME DAY, WE NEED
C     5.  ONE OF THE PLOTS READY FOR HARVEST BY 10AM
C   GENERALLY 2 PLOTS MAY BE HARVESTED ON THE SAME DAY IF THE FIVE
C   CONDITIONS
C   ABOVE ARE SATISFIED.  HOWEVER THERE ARE AT FOUR SPECIAL CASES WHERE
C   ONLY ONE PLOT MAY BE HARVESTED IN A GIVEN DAY
C     1.  WHEN RAKING IS REQUIRED AND CANNOT BE SIMULTANEOUS WITH
C         HARVEST
C     2.  WHEN INDEPENDENT TRANSPORT OF BALES IS REQUIRED, IS NOT
C         SIMULTANEOUS AND MUST BE DONE THE SAME DAY AS HARVEST
C     3.  WHEN WE ARE DESTROYING PLOTS (HARVEST INDEX 4).  HIGHER
C         PRIORITY IS THUS GIVEN TO MOWING.
C     4.  WHEN WE HAVE A HARVEST INDEX OF 2. OR 3. AND THE RATES OF
C         HARVEST FOR THESE TYPES ARE SLOWER THAN FOR HARVEST INDEX 1
C
      I=NTHCUT
C   TIMEFP IS A DUMMY VARIABLE WHOSE VALUE BECOMES 1. IF A PLOT IS
C   FOR HARVEST BY 10AM.
      TIMEFP=0.
C   NFIRST IS THE NUMBER OF THE FIRST ALFALFA PLOT  IN A HARVEST SEASON
C   THAT IS LEFT CURING IN THE FIELD (EITHER FOR HAY OR HAYLAGE).
C   USUALLY NFIRST WILL BE 1 EXCEPT IN THE CASE OF A SWITCH FROM DIRECT
C   CUT ALFALFA HARVEST TO DRY HAY HARVEST ON ACCOUNT OF FILLED SILOS.
C   NPDCA IS THE NUMBER OF PLOTS THAT WERE PREVIOUSLY HARVESTED AS
C   DIRECT CUT ALFALFA DURING THE PRESENT HARVEST.
      NFIRST=NPDCA+1
      J=NMOW+1
      DO 10 II=NFIRST,NMOW
      J=J-1
C     WRITE(IO,184) JJDAY,J,NHTDAY,HARMAT(J,12)
C 184   FORMAT(5X,'JJDAY,J,NHTDAY,HARMAT(J,12) = ',3I8,F8.1)
      IF (NHTDAY.GE.2) RETURN
      IF  (HARMAT(J,12).EQ.1.) GO TO 10
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      NBHR=IFIX(HARMAT(J,21))+4
      IF (NHTDAY.EQ.0) GO TO 2
C   HERE CONSIDER THE SPECIAL CASES WHEN NHTDAY=1
      IF (NOPSQ(I,3).NE.O.AND.CRTR(I,1,3).NE.1.) RETURN
      IF (NOPSQ(I,9).EQ.0.OR.CRTR(I,3,NBHR).EQ.0.) GO TO 1
C   HERE WE CONSIDER INDEPENDENT TRANSPORT OF BALES
      IF (CRTR(I,1,9).EQ.0.0.AND.CRTR(I,2,9).EQ.0.) RETURN
    1 IF (HARMAT(J,21).EQ.4.) RETURN
      IF (HARMAT(J,21).EQ.1.) GO TO 2
      R1=TPL(NBHR)/TPL(5)
      IF (R1.GT.1.) RETURN
C   HERE WE ARE ALLOWED TO CONSIDER HARVESTING A PLOT
    2 IF (HARMAT(J,21).EQ.4.) GO TO 20
      CRMC=CRTR(I,1,NBHR)
      CALL DRY (J,TIME,FMCAM,CRMC)
C       WRITE(10,101)JJDAY,J,TIME,CRMC
C   101   FORMAT(5X,'WITHIN HRVQ, JJDAY=   J=     TIME=   CRMC=',/,
C      + 15X,2I6,2F8.2)
      IF (TIME.GT.8.) GO TO 10
      IF (NHTDAY.LT.1) GO TO 3
      IF (TIME.GT.2.0.AND.TIMEFP.EQ.0.) GO TO 10
    3 IF (TIME.LE.2.0) TIMEFP=1.
      IF (NOPSQ(I,3).NE.0) CALL QUANTC(J,3)
      CALL QUANTC (J,NBHR)
      CALL PLOTCD (J,NS,NBHR)
      HARMAT(J,12)=1.
C   THE FOLLOWING IS TO CHECK WHETHER SILOS ARE FULL OR NOT.  WHEN THE
C   FIRST SILO IS FULL, ALL PLOTS WITH AN INDEX OF 1. MUST BE CHANGED
C   TO AN INDEX OF 2. (SECOND SILO).  WHEN BOTH SILOS
C   ARE FULL, HARVEST INDEX IS SHIFTED TO 3. (FORCED HAY HARVEST)
      IF (NS.GT.2) GO TO 15
      IF (HARDEX.EQ.3.) GO TO 15
      IF (NS.EQ.2) GO TO 35
      IF (TMSTO(1).LT.SILO(1)) GO TO 15
      IF (SILO(2).EQ.0.) GO TO 35
      DO 30 JJ=NFIRST,NMOW
      IF (HARMAT(JJ,12).EQ.1.) GO TO 30
      IF (HARMAT(JJ,22).EQ.1.) GO TO 30
      IF (HARMAT(JJ,21).NE.1.) GO TO 30
      HARMAT(JJ,21)=2.
      IF (NOPSQ(I,6).LT.150.OR.NOPSQ(I,6).GT.159) HARMAT(JJ,22)=1.
C       WRITE(10,132) J
C 132   FORMAT (5X,'SILO 1 IS FILLED.  REASSIGNED PLOT J=',I4)
   30 CONTINUE
      HARDEX=2.
   35 IF (TMSTO(2).LT.SILO(2)) GO TO 15
      DO 40 JJ=NFIRST,NMOW
      IF (HARMAT(JJ,12).EQ.1.) GO TO 40
      IF (HARMAT(JJ,22).EQ.1.) GO TO 40
      IF (TMSTO(1).LT.SILO(1)) THEN
```

```
      HARMAT(JJ,21)=1.
      ELSE
      HARMAT(JJ,21)=3.
      HARMAT(JJ,22)=1.
      ENDIF
C       WRITE (10,133) J
C 133   FORMAT (5X,'SILO 2 IS FILLED.  REASSIGNED PLOT J=',I4)
   40 CONTINUE
      IF (TMSTO(1).GE.SILO(1)) HARDEX=3.
      GO TO 15
   20 NPST(I,5)=NPST(I,5)+1
      NCUM(5)=NCUM(5)+1
   15 OPUSE(I,3)=OPUSE(I,3)+TPL(3)
      OPUSE(I,NBHR)=OPUSE(I,NBHR)+TPL(NBHR)
      IF (CRTR(I,3,NBHR).EQ.1.) OPUSE(I,9)=OPUSE(I,9)+TPL(9)
      NHTDAY=NHTDAY+1
      HARMAT(J,12)=1.
C       WRITE (10,131) J,HARDEX,TMSTO(1),TMSTO(2)
C 131   FORMAT(5X,'HARVESTED PLOT J=',I4,'  HARDEX=',F4.0,'  TMSTO(1)=',
C      +F8.1,'  TMSTO(2)=',F8.1)
   10 CONTINUE
      RETURN
      END
C ******************************************************************
      SUBROUTINE PLOTCD (J,NS,NBHR)
C ******************************************************************
      COMMON /W1/ NPLOTS,NMOW,NHRV,NSTO,AREAPL,HARMAT(40,29),ZRT(9,5)
      COMMON /W2/ TPL(9),RAIN,JJDAY,NDAYHR
      COMMON /W3/ HFEED(4,160,5)
      COMMON /W4/ NPDCA,NDCTD,IDAH
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
      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 /Z3/ HARDEX,TMSTO(4),NPST(5,5),NCUM(5),OPUSE(5,9)
      COMMON /Z4/FDLABR,FDENER,HRLABR,HRFUEL,HRELEC
      COMMON /Z7/ ALHRFD(26,15),AFEED(26,23)
C   SUBROUTINE PLOTCD CONDENSES THE INFORMATION CONCERNING ONE PLOT AT
C   THE TIME OF HARVEST.  IT SPECIFIES IN WHICH OF 4 STORAGE STRUCTURES
C   THE PLOT GOES.  THE STORAGE STRUCTURES ARE
C     1. WET STORAGE, HIGH QUALITY
C     2. WET STORAGE, LOW QUALITY
C     3. DRY STORAGE, HIGH QUALITY
C     4. DRY STORAGE, LOW QUALITY
C   MATRIX HFEED(NS,NBPL,NCHAR) CONTAINS ALL THE FEED INFORMATION FOR
C   EACH PLOT.
C   NS IS THE STORAGE STRUCTURE NUMBER (1 TO 4)
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C   NBPL IS THE PLOT NUMBER DURING A GIVEN YEAR THAT GOES INTO NS.  A
C   A MAXIMUM OF 160 PLOTS IS ALLOWED PER STORAGE STRUCTURE.
C   IN THE CASE OF SILOS (WET ALFALFA), A CHECK
C   EXISTS IN SUBROUTINE HRVQ TO PREVENT THE SILO FROM OVERFLOWING.
C   HAY STORAGE VOLUME OR CAPACITY IS ASSUMED UNCONSTRAINED
C   NCHAR REPRESENTS ONE OF 5 CHARACTERISTICS OF FORAGES STORED
C      1.  TOTAL DRY MATTER (METRIC TONS)
C      2.  CRUDE PROTEIN (DECIMAL)
C      3.  DIGESTIBILITY (DECIMAL)
C      4.  MOISTURE CONTENT (DECIMAL, DRY BASIS)
C      5.  NUMBER OF DAYS OF EXPOSURE WHILE CURING.
C
      DIMENSION XLBR(7),XENE(7)
      DATA XLBR /1.,0.25,0.5,0.20,0.40,0.5,0.15/
      DATA XENE /0.,0.5,1.5,0.5,1.5,0.15,0.1/
      I=NTHCUT
      RFRESP=HARMAT(J,26)
      RFRESP=AMAX1(0.85,RFRESP)
      IF (IDAH.NE.1) RFRESP=AMIN1(0.97,RFRESP)
      TRL=1.-RFRESP
      DML=HARMAT(J,2)*HARMAT(J,24)*RFRESP
      DMS=HARMAT(J,3)*HARMAT(J,25)*RFRESP
      DM=DML+DMS
      PCL=DML/DM
      IF (PCL.LT.0.290) PCL=0.290
      IF (PCL.GT.0.500) PCL=0.500
      PCS=1.-PCL
C   LOSS OF CRUDE PROTEIN DUE TO EXPOSURE TIME
      ET=HARMAT(J,14)*24.+8.
      PLE=ET*0.001
      CPL=HARMAT(J,4)*(1.-PLE)
      CPS=HARMAT(J,5)*(1.-PLE)
      CP=CPL*PCL+CPS*PCS
      IF (CP.LT.0.10) CP=0.10
C   LOSS OF DIGESTIBILITY DUE TO RESPIRATION AND RAINFALL
      TDNBL=HARMAT(J,6)*PCL+HARMAT(J,7)*PCS
      DLR=HARMAT(J,27)*0.002
      TDN=((TDNBL-TRL)/(1.-TRL))*(1.-DLR)
      IF (TDN.LT.0.40) TDN=0.40
C   DECIDE IN WHICH STORAGE LOCATION THE PLOT WILL GO
      IF (HARMAT(J,22).EQ.1.) GO TO 10
      NS=1
      IF (HARMAT(J,21).EQ.2.) NS=2
      GO TO 20
   10 NS=3
      IF (HARMAT(J,21).GT.1.) GO TO 12
      IF (CP.LT.CRTR(NTHCUT,2,5)) NS=4
      GO TO 20
   12 IF (HARMAT(J,21).GT.2.) GO TO 14
      NS=4
```

```
14
20

C  CL
C  FD
C  FI
C  OI

C
C **

C **

C
C
C
C
C
C
C
C
C
```

```
      GO TO 20
   14 IF  (CP.LT.CRTR(NTHCUT,2,7))  NS=4
   20 NPST(I,NS)=NPST(I,NS)+1
      NCUM(NS)=NCUM(NS)+1
      NBPL=NCUM(NS)
      CALL STORE (J,NBHR,DMCH,CPCH,TDNCH,NFEED)
      HFEED(NS,NBPL,1)=DM*AREAPL*0.001*(1.-DMCH)
      HFEED(NS,NBPL,2)=CP*(1.-CPCH)
      HFEED(NS,NBPL,3)=TDN*(1.-TDNCH)
      IF (HARMAT(J,11).EQ.0.)  HARMAT(J,11)=HARMAT(J,10)
      HFEED(NS,NBPL,4)=HARMAT(J,11)
      HFEED(NS,NBPL,5)=HARMAT(J,14)
      TMSTO(NS)=TMSTO(NS)+DM*AREAPL*0.001
C   CUMULATIVE LABOR AND ENERGY REQUIRED FOR FEEDING
C   FDLABR, CUMULATIVE LABOR REQUIRED FOR FEEDING THE FORAGES (MAN.H)
C   FDENER, CUMULATIVE ENERGY REQUIRED FOR FEEDING THE FORAGES (LITERS
C   OF DIESEL FUEL).
      WM=HFEED(NS,NBPL,1)*(1.+HFEED(NS,NBPL,4))
      FDLABR=FDLABR+XLBR(NFEED)*WM
      FDENER=FDENER+XENE(NFEED)*WM
      KK=(NTHCUT-1)*3+1
      ALHRFD(NTHYR,KK)=ALHRFD(NTHYR,KK)+HFEED(NS,NBPL,1)
      ALHRFD(NTHYR,KK+1)=ALHRFD(NTHYR,KK+1)
     + +HFEED(NS,NBPL,1)*HFEED(NS,NBPL,2)
      ALHRFD(NTHYR,KK+2)=ALHRFD(NTHYR,KK+2)
     + +HFEED(NS,NBPL,1)*HFEED(NS,NBPL,3)
      RETURN
      END
C
C ***********************************************************************
      SUBROUTINE STORE (J,NBHR,DMCH,CPCH,TDNCH,NFEED)
C ***********************************************************************
      COMMON /W1/ NPLOTS,NMOW,NHRV,NSTO,AREAPL,HARMAT(40,29),ZRT(9,5)
      COMMON /W2/ TPL(9),RAIN,JJDAY,NDAYHR
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
      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   THIS SUBROUTINE ESTIMATES QUALITY AND QUANTITY LOSSES IN STORAGE AND
C   FEEDING.  THERE ARE 5 STORAGE METHODS
C       1.  ANY DRY HAY STORED INSIDE (0.04 DM LOSS)
C       2.  ROUND BALES STORED OUTSIDE (0.12 DM LOSS)
C       3.  HAY STACKS STORED OUTSIDE (0.16 DM LOSS)
C       4.  ALFALFA IN A VERTICAL SILO (0.07 DM LOSS)
C       5.  ALFALFA IN A BUNK SILO (0.13 DM LOSS)
C   THERE ARE 7 FEEDING METHODS
C       1.  RECTANGULAR BALES, HAND FED (0.05 DM LOSS)
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C      2.  ROUND BALES, SELF FED (0.14 DM LOSS)
C      3.  ROUND BALES, GROUND (0.05 DM LOSS)
C      4.  HAY STACKS, SELF FED (0.16 DM LOSS)
C      5.  HAY STACKS, SHREDDED (0.05 DM LOSS)
C      6.  VERTICAL SILO AND UNLOADER (0.11 DM LOSS, 0.10 DIGESTIBILITY
C      7.  BUNK SILO AND SCOOP (0.11 DM LOSS, 0.15 DIGESTIBILITY LOSS)
C   AT PRESENT, NO CHANGES IN CP OR TDN IS ASSUMED FOR ALL METHODS
C
      DIMENSION STOLS(5),FEEDLS(7)
      DIMENSION CPCHST(7),TDNCHS(7)
      DATA STOLS /0.04,0.12,0.16,0.07,0.13/
      DATA FEEDLS /0.05,0.14,0.05,0.16,0.05,0.11,0.11/
      DATA CPCHST /0.,0.,0.,0.,0.,0.,0./
      DATA TDNCHS /0.,0.,0.,0.,0.,0.,0./
      I=NTHCUT
      NFEED=IFIX(CRTR(I,4,NBHR))
      IF (NFEED.LT.1.OR.NFEED.GT.7) NFEED=1
C   FIND NST, THE STORAGE METHOD, FROM PREVIOUS INFORMATION
      IF (HARMAT(J,22).EQ.2.) GO TO 10
C   CONSIDER DRY HAY
      NST=1
      IF (CRTR(I,1,9).EQ.0.) GO TO 20
      NST=2
      IF (NOPSQ(I,NBHR).GE.0090.AND.NOPSQ(I,NBHR).LE.0099) NST=3
      GO TO 20
   10 NST=4
      IF (CRTR(I,4,NBHR).EQ.7.) NST=5
   20 RFDM=1.*(1.-STOLS(NST))*(1.-FEEDLS(NFEED))
      DMCH=1.-RFDM
      CPCH=0.
      TDNCH=0.
      CPCH=CPCHST(NFEED)
      TDNCH=TDNCHS(NFEED)
      RETURN
      END
C
C **********************************************************************
      SUBROUTINE UPDATE
C **********************************************************************
      COMMON /W1/ NPLOTS,NMOW,NHRV,NSTO,AREAPL,HARMAT(40,29),ZRT(9,5)
      COMMON /W2/ TPL(9),RAIN,JJDAY,NDAYHR
      COMMON /W4/ NPDCA,NDCTD,IDAH
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
      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 /Z3/ HARDEX,TMSTO(4),NPST(5,5),NCUM(5),OPUSE(5,9)
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      COMMON /Y3/ NMDATA,NOPER,IN,IO
C   THIS SUBROUTINE PROVIDES A DAILY UPDATE OF ALL INFORMATION IN HARMAT
C   FOR EXPOSURE LOSSES AND FOR CHANGES IN THE MOISTURE CONTENT.
C   UPDATES ARE MADE ONCE PER DAY, ONLY FOR PLOTS THAT
C   ARE CURING IN THE FIELD AND ARE NOT YET HARVESTED AND STORED
      IF (NMOW.LT.1) RETURN
      IF (NHRV.EQ.NMOW) RETURN
      NFIRST=NPDCA+1
      DO 20 J=NFIRST,NMOW
      IF (HARMAT(J,12).EQ.1.) GO TO 20
      CRMC=1.
      IF (RAIN.LT.2.) GO TO 5
C   HERE WE CHECK IF THERE IS TEDDING OR RAKING AFTER RAIN
      IF (NOPSQ(NTHCUT,4).EQ.0) GO TO 5
      HARMAT(J,17)=CRTR(NTHCUT,2,4)
      HARMAT(J,18)=1.
      HARMAT(J,20)=CRTR(NTHCUT,3,4)
      OPUSE(NTHCUT,4)=OPUSE(NTHCUT,4)+TPL(4)
    5 CALL DRY (J,TIME,FMCAM,CRMC)
C        WRITE(IO,102)J,FMCAM
C 102    FORMAT (5X,'WITHIN UPDATE, J= ',I4,'  FMCAM= ',F10.4)
      IF (NOPSQ(NTHCUT,4).NE.0.AND.RAIN.GE.2.) CALL QUANTC(J,4)
      HARMAT(J,18)=0.
      HARMAT(J,28)=0.
      HARMAT(J,27)=HARMAT(J,27)+RAIN
C   AMC IS THE AVERAGE MOISTURE CONTENT TO ESTIMATE RESPIRATION LOSSES
      AMC=HARMAT(J,10)
      CALL RESP (AMC,RF)
      HARMAT(J,26)=HARMAT(J,26)*RF
      HARMAT(J,10)=FMCAM
      HARMAT(J,14)=HARMAT(J,14)+1.
      IF (HARMAT(J,21).GT.1.) GO TO 14
C   MAKE A PROJECTION OF CRUDE PROTEIN CONCENTRATION OF EACH FIELD CURIN
C   CURING ALFALFA PLOT.
C   IF CRUDE PROTEIN GOES BELOW A CRITICAL LEVEL, SHIFT
C   THE PLOT TO LOWER PRIORITY HARVEST.
      XL=HARMAT(J,2)*HARMAT(J,24)*HARMAT(J,26)
      XS=HARMAT(J,3)*HARMAT(J,25)*HARMAT(J,26)
C   ACCOUNT FOR FUTURE RAKING AND HARVESTING LOSSES
      XL=XL*0.95
      IF (NOPSQ(NTHCUT,3).NE.0) XL=XL*0.95
      XCP=(XL*HARMAT(J,4)+XS*HARMAT(J,5))/(XS+XL)
      XCP=XCP*(1.-0.001*(8.+HARMAT(J,14)*24.))
      IF (XCP.GT.CRTR(NTHCUT,2,5)) GO TO 20
      IF (NOPSQ(NTHCUT,6).EQ.0) GO TO 12
      IF (NOPSQ(NTHCUT,6).LT.150.OR.NOPSQ(NTHCUT,6).GT.159) GO TO 10
      IF (SILO(2).EQ.0.0.OR.TMSTO(2).GE.SILO(2)) GO TO 12
      HARMAT(J,21)=2.
      HARMAT(J,22)=2.
      GO TO 14
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   10 HARMAT(J,21)=2.
      HARMAT(J,22)=1.
      GO TO 14
12    IF (TMSTO(1).LT.SILO(1)) GO TO 14
      HARMAT(J,21)=3.
      HARMAT(J,22)=1.
      GO TO 16
   14 IF (HARMAT(J,21).GT.2.) GO TO 16
      IF (CRTR(NTHCUT,2,6).LE.O.) GO TO 20
      IF (HARMAT(J,14).GT.CRTR(NTHCUT,2,6)) HARMAT(J,21)=4.
      GO TO 20
   16 IF (HARMAT(J,21).GT.3.) GO TO 20
      IF (CRTR(NTHCUT,2,8).LE.O.) GO TO 20
      IF (HARMAT(J,14).GT.CRTR(NTHCUT,2,8)) HARMAT(J,21)=4.
   20 CONTINUE
      RETURN
      END
C
C *********************************************************************
      SUBROUTINE DRY (J,TIME,FMCAM,CRMC)
C *********************************************************************
      COMMON /W1/ NPLOTS,NMOW,NHRV,NSTO,AREAPL,HARMAT(40,29),ZRT(9,5)
      COMMON /W2/ TPL(9),RAIN,JJDAY,NDAYHR
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
      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 /Y3/ NMDATA,NOPER,IN,IO
C    THE SUBROUTINE DRY HAS TWO MAIN PURPOSES
C      1.  IT ESTIMATES THE TIME AT WHICH A PLOT WILL REACH CRITICAL
C          MOISTURE CONTENT (CRMC) FOR HARVEST UNDER TODAY"S DRYING
C          CONDITIONS.  TIME IS ESTIMATED IN HOURS AFTER 8AM.
C      2.  IT ALSO ESTIMATES MOISTURE CONTENT OF THE PLOT ON THE NEXT DAY
C          THIS ESTIMATE INCLUDES DESORPTION FROM 8AM TO 8PM ON A NORMAL
C          DAY AND ADSORPTION THROUGH THE NIGHT FROM DEW.  REWETTING IS A
C          ALSO CONSIDERED ON A RAINY DAY (ON SUCH A DAY, DRYING TIME IS
C          REDUCED FROM 12 TO 6 HOURS).
C    SOLAR RADIATION IS CONVERTED FROM A DAILY ACCUMULATION TO  A
C    RADIATION INTENSITY AVERAGED OVER 12 HOURS (CAL/MIN.CM2)
      SR=SRADF/720.
      TDB=(TMINC+2.*TMAXC)/3.
      IF (HARMAT(J,17).LE.O.) HARMAT(J,17)=0.75
      DENS=(HARMAT(J,2)+HARMAT(J,3))/HARMAT(J,17)
      RK=HARMAT(J,18)
      CD=HARMAT(J,19)
      XTR=HARMAT(J,20)
      RAIN=PPT
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      XKK=(-0.016409)+(.073064*SR)+0.0055486*TDB+(-0.00000734*DENS)
     + +0.019722*RK+0.029649*CD+XTR
      IF (XKK.LT.0.01) XKK=0.01
      XMO=HARMAT(J,10)
      TDRY=12.
      DTRAIN=0.
      IF (RAIN.LE.0.) GO TO 10
C   IF THERE IS RAIN, THE MOISTURE CONTENT IS INCREASED
C   RAIN IS ASSUMED TO OCCUR IN THE MORNING.  DRYING RESUMES IN THE
C   AFTERNOON.  THE DAILY DRYING PERIOD IS REDUCED BY 6 HOURS.
      DTRAIN=6.
      FCR=1.
      IF (HARMAT(J,19).NE.0.) FCR=1.4
      IF (RAIN.LE.5.) DMR=0.25*RAIN*FCR
      IF (RAIN.GT.5.) DMR=(1.25+0.03*(RAIN-5.))*FCR
      IF (DMR.GT.3.) DMR=3.
      IF (HARMAT(J,14).GT.0.) DMR=DMR*(2./3.)
      XMO=XMO+DMR
      IF (XMO.GT.5.5) XMO=5.5
C   CALCULATE TIME AT WHICH CRMC WILL BE REACHED
   10 EMC=0.15
      IF (NTHCUT.EQ.2.OR.NTHCUT.EQ.3) EMC=0.10
      XMR=(CRMC-EMC)/(XMO-EMC)
      IF (XMR.LT.0.01) XMR=0.01
      TIME=(-ALOG(XMR))/XKK
      TIME=TIME+HARMAT(J,28)+DTRAIN
C   CALCULATE FINAL MOISTURE AT THE END OF THE DAY
      ADT=TDRY-(DTRAIN+HARMAT(J,28))
      IF(ADT.LT.0.)ADT=0.
      XMR=EXP(-XKK*ADT)
      XMC=XMR*(XMO-EMC)+EMC
C   CALCULATE DEW PICKUP THROUGH THE NIGHT
      DMPV=HARMAT(J,10)-XMC
      IF (DMPV.LT.0.) DMPV=0.
      FCD=1.
      IF (HARMAT(J,19).NE.0.) FCD=1.2
      RH=RANDRH(JJDAY)
      RH=0.5
      DMDEW=DMPV*HARMAT(J,17)*(RH-0.5)*FCD
      IF (RH.LT.0.5) DMDEW=0.
      FMCAM=XMC+DMDEW
C   MOISTURE CONTENT AFTER RAINFALL IS NEXT RECORDED
      HARMAT(J,29)=XMO
C   WE NEED MOISTURE CONTENT DURING HARVEST IN CASE THE PLOT IS
C   HARVESTED TODAY.
      TIMEHR=TIME+2.
      XMR=EXP(-XKK*TIMEHR)
      HARMAT(J,11)=XMR*(XMO-EMC)+EMC
C     WRITE(10,102)J,XKK,XMO,XMC,FMCAM
C 102   FORMAT(5X,'WITHIN DRY, J= ',I4,'  XKK, XMO, XMC, FMCAM = ',4F10.
```

```
C     +3)
      RETURN
      END
C
C ********************************************************************
      FUNCTION RANDRH (JDAY)
C ********************************************************************
C   THIS FUNCTION GENERATES PSEUDO RANDOM VALUES OF RELATIVE HUMIDITY
C   FOR ESTIMATING DEW ADSORPTION.  A TRIANGULAR DISTRIBUTION IS ASSUMED
C   FOR RELATIVE HUMIDITY, WITH RH=0.5 THE MOST LIKELY OCCURRENCE
C   THIS FUNCTION IS CALLED FROM SUBROUTINE DRY (ABOUT LINE 68)
C   BUT IS NOT PRESENTLY USED.
C   IT SHOULD BE DISCARDED IT HISTORICAL WEATHER DATA INCLUDE
C   RELATIVE HUMIDITY OR WET BULB TEMPERATUR OR DEW POINT.
      X1=FLOAT(JDAY)/1.387
      I1=IFIX(X1)
      X2=(1.+X1-FLOAT(I1))**2.42
      I2=IFIX(X2)
      RN=X2-FLOAT(I2)
      RANDRH=SQRT(RN/2.)
      IF (RN.GT.0.5) RANDRH=1.-SQRT((1.-RN)/2.)
      RETURN
      END
C
C ********************************************************************
      SUBROUTINE RESP (AMC,RF)
C ********************************************************************
      COMMON /W1/ NPLOTS,NMOW,NHRV,NSTO,AREAPL,HARMAT(40,29),ZRT(9,5)
      COMMON /W2/ TPL(9),RAIN,JJDAY,NDAYHR
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
      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   SUBROUTINE RESP CALCULATES THE REMAINING FRACTION (RF) OF DRY MATTER
C   LEFT AFTER 24 HOURS OF RESPIRATION
      K1=0.15
      K2=0.0291
      TIME=24.
      ATC=(TMINC+TMAXC)/2.
      TF=(ATC/30.)*(ATC/30.)
      IF (TF.GT.1) TF=1.
      TRL=TF*(AMC/4.)*K1*(1.-EXP(-K2*TIME))
      IF (TRL.LT.0.) TRL=0.
      RF=1.-TRL
      RETURN
      END
C ********************************************************************
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      SUBROUTINE MOWQ (NHTDAY,NMTDAY)
C *********************************************************************
      COMMON /W1/ NPLOTS,NMOW,NHRV,NSTO,AREAPL,HARMAT(40,29),ZRT(9,5)
      COMMON /W2/ TPL(9),RAIN,JJDAY,NDAYHR
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
      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 /Z3/ HARDEX,TMSTO(4),NPST(5,5),NCUM(5),OPUSE(5,9)
      COMMON /Y3/ NMDATA,NOPER,IN,IO
C    PLOTS ARE MOWED IN A GROUP SUCH THAT MOWING MAY BE CONTIMUOUS FOR 5
C    OR 10 HOURS, A HALF DAY OR A FULL DAY.
C    THE NUMBER OF PLOTS MOWED IN A FULL DAY
C    IS MAXMOW(2) AND IN HALF A DAY IS MAXMOW(1).  THE NUMBER OF PLOTS IS
C    AN INTEGER IN BOTH CASES AND IS AT LEAST EQUAL TO ONE.
      DIMENSION MAXMOW(2)
      NM10=IFIX(10./TPL(1))
      NM5=IFIX(5./TPL(1))
      MAXMOW(2)=MAX0(1,NM10)
      MAXMOW(1)=MAX0(1,NM5)
C
C    THE MAMIMUM NUMBER OF PLOTS THAT MAY BE MOWED IN A DAY IS
C    REDUCED IF MAXMOW VALUES PRESENTLY ESTIMATED PRODUCE TOO MANY
C    CURING PLOTS.  CRTR(NTHCUT,4,2) IS USED TO SPECIFY THE
C    MAXIMUM NUMBER OF DAYS MOWING CAN PROCEED AHEAD OF HARVESTING.
C    A MINIMUM OF 2 DAYS OR 4 PLOTS AHEAD IS ALWAYS ALLOWED.
C
      CURING=FLOAT(NMOW-(NHRV+NHTDAY))
      ALLWD=2.*CRTR(NTHCUT,4,2)
      ALLWD=AMAX1(ALLWD,4.)
      DO 5 IV=1,2
      TOT=CURING+FLOAT(MAXMOW(IV))
      IF (TOT.GT.ALLWD) THEN
      IMAX=IFIX(ALLWD-CURING)
      MAXMOW(IV)=MAX0(0,IMAX)
      ENDIF
5     CONTINUE
      I=NTHCUT
C    NO PLOTS ARE MOWED TODAY IF
C       1.  THERE IS MORE THAN 2 MM OF RAIN
C       2.  MORE THAN 1/2 THE TOTAL AREA IS FIELD CURING
C       3.  TWO PLOTS ARE BEING HARVESTED AND MOWING CANNOT BE
C             SIMULTANEOUS WITH HARVEST
      IF (RAIN.GT.2.) RETURN
      IF (NHTDAY.GE.2.AND.CRTR(I,1,1).NE.1.) RETURN
C    NBMW IS THE RELATIVE MOWING TIME IN A DAY (0 IS NO TIME, 1 IS A
C    HALF-DAY, 2 IS A FULL DAY)
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C   HOW MUCH MOWING MAY BE DONE TODAY IS DETERMINED AS FOLLOWS
C   NORMALLY IF 2 PLOTS ARE HARVESTED TODAY, NO MOWING IS DONE
C            IF 1 PLOT IS HARVESTED TODAY, HALF A DAY IS SPENT MOWING
C            IF 0 PLOT IS HARVESTED TODAY, ALL DAY IS SPENT MOWING
C   THE FOLLOWING EXCEPTIONS ARE CONSIDERED
C      1.  IF MOWING MAY BE SIMULTANEOUS WITH HARVEST, THEN MOWING MAY
C          BE CARRIED  OUT ALL DAY
C      2.  IF TEDDING IS REQUIRED AND CANNOT BE SIMULTANEOUS WITH MOWING
C          THE MOWING PERIOD IS REDUCED BY HALF A DAY
C      3.  IF RAKING IS REQUIRED AND CANNOT BE SIMULTANEOUS WITH HARVEST
C          THE MOWING PERIOD IS REDUCED BY HALF A DAY
C      4.  IF CRTR(1,4,1) SPECIFIES THAT THE MAXIMUM PERIOD IS HALF A
C          DAY, THEN ANY TIME A FULL MOWING DAY IS SPECIFIED IT MUST BE
C          REDUCED.
      NBMW=0
      NRK=0
      IF (NHTDAY.EQ.0) NBMW=2
      IF (NHTDAY.EQ.1) NBMW=1
      IF (CRTR(1,1,1).EQ.1.) NBMW=2
      IF (NOPSQ(1,2).EQ.0) GO TO 10
      IF (CRTR(1,1,2).EQ.0.) NBMW=NBMW-1
   10 IF (NOPSQ(1,3).EQ.0) GO TO 20
      IF (CRTR(1,1,3).EQ.1.) GO TO 20
      IF (NHTDAY.NE.0) NRK=1
   20 NBMW=NBMW-NRK
      IF (NBMW.LE.0) RETURN
      IF (NBMW.EQ.2.AND.CRTR(1,4,1).EQ.1.) NBMW=1
      NMTDAY=MAXMOW(NBMW)
C     WRITE(10,101)NMTDAY
C 101   FORMAT(5X,'WITHIN MOWQ, NMTDAY= ',I4)
C   INITIALIZE EACH NEW MOWED PLOT
      IA=NMOW+1
      IB=NMOW+NMTDAY
      TIMEMW=TPL(1)*0.5
      IF (IB.LE.NPLOTS) GO TO 25
      IB=NPLOTS
      NMTDAY=NPLOTS-NMOW
25    DO 30 J=IA,IB
      HARMAT(J,1)=1.
      HARMAT(J,2)=XLEAF*10.
      HARMAT(J,3)=STEM*10.
      HARMAT(J,4)=QUAL(1,2)
      HARMAT(J,5)=QUAL(2,2)
      HARMAT(J,6)=QUAL(1,3)
      HARMAT(J,7)=QUAL(2,3)
      HARMAT(J,8)=QUAL(1,4)
      HARMAT(J,9)=QUAL(2,4)
      HARMAT(J,10)=XINMC(NDAYHR,TIMEMW,NTHCUT)
      HARMAT(J,14)=1.
      HARMAT(J,17)=CRTR(NTHCUT,2,1)
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      HARMAT(J,19)=CRTR(NTHCUT,3,1)
      HARMAT(J,20)=CRTR(NTHCUT,3,2)
      HARMAT(J,21)=1.
      HARMAT(J,22)=1.
      IF (NOPSQ(1,5).LT.140.OR.NOPSQ(1,5).GT.169) GO TO 35
C   HERE WE HAVE HAYLAGE OR DIRECT CUT AS FIRST PRIORITY HARVEST
      HARMAT(J,21)=HARDEX
C   IF HARDEX IS 3., WE HAVE THE FORCED HAY HARVEST OPTION SINCE SILOS
C   ARE FULL.
      IF (HARDEX.GE.3.) GO TO 35
      HARMAT(J,22)=2.
   35 HARMAT(J,24)=1.
      HARMAT(J,25)=1.
      HARMAT(J,26)=1.
      HARMAT(J,28)=TIMEMW
      HARMAT(J,29)=HARMAT(J,10)
      TIMEMW=TIMEMW+TPL(1)
C   CHECK IF THE CRUDE PROTEIN CRITERION IS SATISFIED AT MOWING TIME
      IF (HARMAT(J,21).GT.1.) GO TO 34
      IF (QUAL(3,2).LT.CRTR(NTHCUT,2,5).AND.TMSTO(2).LT.SILO(2)) THEN
      HARMAT(J,21)=2.
      ENDIF
   34 CONTINUE
      CALL QUANTC (J,1)
      OPUSE(NTHCUT,1)=OPUSE(NTHCUT,1)+TPL(1)
      IF (NOPSQ(NTHCUT,2).EQ.0) GO TO 30
C   NOW WE CONSIDER AN EXTRA TREATMENT (TEDDING)
      HARMAT(J,17)=CRTR(NTHCUT,2,2)
      HARMAT(J,18)=1.
      CALL QUANTC(J,2)
      OPUSE(NTHCUT,2)=OPUSE(NTHCUT,2)+TPL(2)
   30 CONTINUE
      RETURN
      END
C
C *********************************************************************
      FUNCTION XINMC (NDAYHR,TIMEMW,NTHCUT)
C *********************************************************************
C   THIS IS A SIMPLIFIED APPROXIMATION OF INITIAL MOISTURE CONTENT OF
C   ALFALFA.
C   THE MAXIMUM MOISTURE CONTENT IS 4.5 ON THE FIRST DAY OF HARVEST OF
C   FIRST AND FOURTH CUTS AT 8AM.  IT IS 4.0 FOR THE SECOND AND THIRD
C   CUTS.
C   THE MOISTURE DECREASES BY 0.05 PER HOUR FOR MOWING OCCURRING AFTER
C   8AM ON A GIVEN DAY.
C   IT IS FURTHER DECREASED BY 0.05 PER DAY FOR EACH CALENDAR
C   DAY AFTER THE BEGINNING OF HARVEST.
      XINMC=4.5
      IF (NTHCUT.EQ.2.OR.NTHCUT.EQ.3) XINMC=4.0
      IF (TIMEMW.GT.10.) TIMEMW=10.
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      XINMC=XINMC-0.05*TIMEMW
      XINMC=XINMC-0.05*FLOAT(NDAYHR)
      RETURN
      END
C
C *******************************************************************
      SUBROUTINE QUANTC(J,N)
C *******************************************************************
      COMMON /W1/ NPLOTS,NMOW,NHRV,NSTO,AREAPL,HARMAT(40,29),ZRT(9,5)
      COMMON /W2/ TPL(9),RAIN,JJDAY,NDAYHR
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
      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 /Y7/ NBOP(18),NBMACH(18,7),XNBM(18,7)
C   THIS SUBROUTINE ESTIMATES LEAF AND STEM LOSSES DUE TO MECHANICAL
C   TREATMENT.
C   THERE ARE 11 TYPES OF LOSS.  NB STANDS FOR THE MACHINE TREATMENT.
C     1.  MOWER
C     2. MOWER-CONDITIONER
C     3.  RAKE
C     4.  TEDDER
C     5.  BALER (CONVENTIONAL, RECTANGULAR BALES)
C     6.  BALER-EJECTOR
C     7.  ROUND BALER
C     8.  STACK WAGON
C     9.  CHOPPER (WILTED ALFALFA)
C     10.  CHOPPER (DIRECT-CUT ALFALFA)
C     11.  CHOPPER (DIRECT-CUT CORN SILAGE)
C   XLL REPRESENTS LEAF LOSS
C   XSL REPRESENTS STEM LOSS
C   FIRST WE HAVE TO IDENTIFY WHICH OPERATION WE ARE DEALING WITH.
      DIMENSION XLL(11),XSL(11)
      DIMENSION VAL(7),ARG(7)
      DATA XLL /.02,.04,0.,0.,.05,.075,.19,.24,.09,.04,.05/
      DATA XSL /.005,.01,.02,0.,.02,.02,.04,.05,.02,.01,.05/
      DATA VAL /.21,.14,.08,.045,.028,.023,.020/
      DATA ARG /.25,.40,.67,1.0,1.5,2.0,2.5/
      I=NTHCUT
      KK=7
      NB=11
      IF (NOPSQ(I,N).LE.0019) NB=1
      IF (NOPSQ(I,N).GE.20.AND.NOPSQ(I,N).LE.39) NB=2
      IF (NOPSQ(I,N).GE.40.AND.NOPSQ(I,N).LE.69) GO TO 10
      IF (NOPSQ(I,N).GE.70.AND.NOPSQ(I,N).LE.79) NB=5
      IF (NOPSQ(I,N).GE.80.AND.NOPSQ(I,N).LE.89) NB=7
      IF (NOPSQ(I,N).GE.90.AND.NOPSQ(I,N).LE.99) NB=8
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       IF (NOPSQ(I,N).GE.0140.AND.NOPSQ(I,N).LE.149) NB=11
      IF (NOPSQ(I,N).GE.150.AND.NOPSQ(I,N).LE.159) NB=9
      IF (NOPSQ(I,N).GE.160.AND.NOPSQ(I,N).LE.169) NB=10
      IF (NOPSQ(I,N).GE.170.AND.NOPSQ(I,N).LE.179) GO TO 30
      GO TO 40
C   HERE WE CONSIDER RAKING AND TEDDING
   10 XMC=HARMAT(J,10)
      IF (RAIN.GT.2.) XMC=HARMAT(J,29)
C   IN THE CASE OF RAKING AND TEDDING, LEAF LOSS IS A FUNCTION OF
C MOISTURE CONTENT.
      NB=3
      IF (NOPSQ(I,N).GE.60.AND.NOPSQ(I,N).LE.69) NB=4
      XLL(NB)=TABLI(VAL,ARG,XMC,KK)
      GO TO 40
C   CHECK IF THERE IS AN EJECTOR
   30 NB=5
      II=0
    1 II=II+1
      IF (NOPSQ(I,N).NE.NBOP(II).AND.II.LT.18) GO TO 1
      IF (NBMACH(II,3).NE.0) NB=6
   40 HARMAT(J,24)=HARMAT(J,24)*(1.-XLL(NB))
      HARMAT(J,25)=HARMAT(J,25)*(1.-XSL(NB))
      RETURN
      END
C
C ********************************************************************
      SUBROUTINE ENDHRV
C ********************************************************************
      COMMON /W1/ NPLOTS,NMOW,NHRV,NSTO,AREAPL,HARMAT(40,29),ZRT(9,5)
      COMMON /W2/ TPL(9),RAIN,JJDAY,NDAYHR
      COMMON /W3/ HFEED(4,160,5)
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
      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 /Z3/ HARDEX,TMSTO(4),NPST(5,5),NCUM(5),OPUSE(5,9)
      COMMON /Z4/FDLABR,FDENER,HRLABR,HRFUEL,HRELEC
      COMMON /Z5/ IPR2,IPR3,IPR4
      COMMON /Z7/ ALHRFD(26,15),AFEED(26,23)
      COMMON /YY1/ USEMCH(100),UNITS(100)
      COMMON /Y1/ XINFO(7),MCODE(100),XMDATA(100,13)
      COMMON /Y3/ NMDATA,NOPER,IN,IO
      COMMON /Y7/ NBOP(18),NBMACH(18,7),XNBM(18,7)
      COMMON /Z21/ ADATES(26,12),SDATES(4,12)
      COMMON /Z22/ DELAY(26,12),SDELAY(4,12)
      DATA DELAY /312*0.0/
      DATA NDAYHR /0/
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C   SUBROUTINE ENDHRV PROVIDES A SUMMARY OF HOW PLOTS WERE HARVESTED
C   THE END OF EACH CUT AND A DETAILED OUTPUT AT THE END OF EACH YEAR ON
C   QUANTITY AND QUALITY.
      K=(NTHCUT-1)*3+2
      ADATES(NTHYR,K)=FLOAT(JJDAY)
      ADATES(NTHYR,K+1)=ADATES(NTHYR,K)-ADATES(NTHYR,K-1)
      I=NTHCUT
      IF (NDAYHR.LT.39) GO TO 10
      NLM=NPLOTS-NMOW
      NLH=NPLOTS-NHRV
      OPUSE(I,1)=OPUSE(I,1)+NLM*TPL(1)
      OPUSE(I,8)=OPUSE(I,8)+NLH*TPL(8)
      IF (CRTR(I,3,8).EQ.1.) OPUSE(I,9)=OPUSE(I,9)+NLH*TPL(9)
      NCUM(5)=NCUM(5)+NLH
      NPST(I,5)=NPST(I,5)+NLH
10    CONTINUE
      NMOW=NPLOTS
      NHRV=NPLOTS
C   AT THE END OF EACH CUT, SUM UP LABOR,FUEL AND ELECTRICITY REQUIRED
C   FOR HARVEST.
      DO 50 J=1,9
      HRLABR=HRLABR+OPUSE(I,J)*ZRT(J,4)
      HRFUEL=HRFUEL+OPUSE(I,J)*ZRT(J,2)
      HRELEC=HRELEC+OPUSE(I,J)*ZRT(J,3)
   50 CONTINUE
C   JLALHR IS THE LAST ALFALFA HARVEST DAY DURING THE THIRD HARVEST.
C   IT WILL BE USED TO ESTABLISH ANY TIME CONFLICT BETWEEN ALFALFA
C   HARVEST AND CORN SILAGE HARVEST.
      IF (NTHCUT.EQ.3) JLALHR=JJDAY
C   CHECK IF THIS IS THE LAST CUT OF TH E YEAR
      NDAYHR=-40
      IF (NTHCUT.LT.NCUTS) RETURN
C   AT THE END OF EACH YEAR, SUM UP MACHINE USE FOR EACH OPERATION
C   AND FOR EACH INDIVIDUAL MACHINE.
      DO 60 I=1,5
      DO 60 J=1,9
      IF (OPUSE(I,J).LE.O.) GO TO 60
      II=0
    1 II=II+1
      IF (NOPSQ(I,J).NE.NBOP(II)) GO TO 1
      DO 65 K=1,7
      IF (NBMACH(II,K).EQ.O) GO TO 65
      IJ=0
    2 IJ=IJ+1
      IF (NBMACH(II,K).NE.MCODE(IJ)) GO TO 2
      UNITS(IJ)=AMAX1(UNITS(IJ),XNBM(II,K))
      USEMCH(IJ)=USEMCH(IJ)+OPUSE(I,J)*XNBM(II,K)
   65 CONTINUE
   60 CONTINUE
C   AT THE END OF EACH YEAR, SUMMARIZE THE TOTAL FEED HARVESTED
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C   MATRIX ALHRFD(26,15) CONTAINS DM ,T/HA), CP (DEC), AND TDN (DEC)
C   FOR EACH ALFALFA HARVEST FOR EACH YEAR.  COLUMNS 1 TO 12 CONTAIN
C DM, CP AND TDN FOR UP TO 4 ALFALFA HARVESTS.  COLUMNS U0 TO 15
C   CONTAIN ANNUAL AGGREGATE INFORMATION.
      TCP=0.
      TDIG=0.
      TDMA=0.
      TDM=0.
      DO 55 K=1,4
      KK=(K-1)*3+1
      DM=ALHRFD(NTHYR,KK)
      IF (DM.LE.0.) GO TO 55
      CP=ALHRFD(NTHYR,KK+1)/DM
      DIG=ALHRFD(NTHYR,KK+2)/DM
      ALHRFD(NTHYR,KK+1)=CP
      ALHRFD(NTHYR,KK+2)=DIG
      ALHRFD(NTHYR,KK)=DM/AREA(K)
      TDM=TDM+DM
      TDMA=TDMA+DM/AREA(K)
      TDIG=TDIG+DM*DIG
      TCP=TCP+CP*DM
   55 CONTINUE
      ALHRFD(NTHYR,13)=TDMA
      ALHRFD(NTHYR,14)=TCP/TDM
      ALHRFD(NTHYR,15)=TDIG/TDM
      IF (TDM.LE.0.) THEN
      ALHRFD(NTHYR,14)=0.
      ALHRFD(NTHYR,15)=0.
      ENDIF
C   MATRIX AFEED(26,23) CONTAINS DM (TOTAL T), CP (DEC), STANDARD DEV.
C   OF CRUDE PROTEIN, TDN (DEC) AND STANDARD DEVIATION OF TDN FOR ALL
C   4 STORAGE LOCATIONS.  LOCATION 1 IS FIRST SILO, 2 IS SECOND SILO,
C   3 IS HIGH QUALITY HAY, 4 IS LOW QUALITY HAY.
C   THE LAST THREE COLUMNS ARE RESERVED FOR DRY MATTER OF HARVESTED
C   CORN:  CORN SILAGE, HIGH MOISTURE CORN AND DRY CORN GRAIN.
      DO 35 NS=1,4
      NPSS=NCUM(NS)
      IF (NPSS.LE.0) GO TO 35
C CALCULATE TOTAL DM, AVERAGE CP, BIASED STANDARD ERROR OF CP, AVERAGE
C   DIG AND BIASED STANDARD ERROR OF DIG.
      SDM=0.
      SCP=0.
      SDIG=0.
      SSCP=0.
      SSDIG=0.
      DO 36 J=1,NPSS
      SDM=SDM+HFEED(NS,J,1)
      SCP=SCP+HFEED(NS,J,2)
      SSCP=SSCP+HFEED(NS,J,2)*HFEED(NS,J,2)
      SDIG=SDIG+HFEED(NS,J,3)
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      SSDIG=SSDIG+HFEED(NS,J,3)*HFEED(NS,J,3)
   36 CONTINUE
      KK=5*NS-4
      AFEED(NTHYR,KK)=SDM
      AFEED(NTHYR,KK+1)=SCP/NPSS
      AFEED(NTHYR,KK+3)=SDIG/NPSS
      VARCP=(SSCP-SCP*SCP/NPSS)/NPSS
      VARDIG=(SSDIG-SDIG*SDIG/NPSS)/NPSS
      IF(VARCP.LT.0.) VARCP=0.
      IF(VARDIG.LT.0.) VARDIG=0.
      AFEED(NTHYR,KK+2)=SQRT(VARCP)
      AFEED(NTHYR,KK+4)=SQRT(VARDIG)
   35 CONTINUE
      DO 81 NS=1,4
      TD=0.
      TDS=0.
      K=(NS-1)*3+1
      NPSS=NCUM(NS)
      IF (NPSS.LE.0) GO TO 81
      DO 82 NBPL=1,NPSS
      TD=TD+HFEED(NS,NBPL,5)
82    TDS=TDS+HFEED(NS,NBPL,5)*HFEED(NS,NBPL,5)
      XN=FLOAT(NPSS)
      DELAY(NTHYR,K)=XN
      AD=TD/XN
      SDD=(TDS-TD*TD/XN)/(XN-1.)
      IF (XN.LE.1.) SDD=0.
      IF (SDD.LT.0.) SDD=0.
      DELAY(NTHYR,K+1)=AD
      DELAY(NTHYR,K+2)=SQRT(SDD)
81    CONTINUE
      RETURN
      END
C ***********************************************************************
      SUBROUTINE DCALF
C ***********************************************************************
      COMMON /W1/ NPLOTS,NMOW,NHRV,NSTO,AREAPL,HARMAT(40,29),ZRT(9,5)
      COMMON /W2/ TPL(9),RAIN,JJDAY,NDAYHR
      COMMON /W3/ HFEED(4,160,5)
      COMMON /W4/ NPDCA,NDCTD,IDAH
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
      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 /Z3/ HARDEX,TMSTO(4),NPST(5,5),NCUM(5),OPUSE(5,9)
      COMMON /Z4/FDLABR,FDENER,HRLABR,HRFUEL,HRELEC
      COMMON /Z5/ IPR2,IPR3,IPR4
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      C
      C
      C
      C
      C
C  THI
C HARV
      D
      D

C   HA
      H
      H
      H
      I

      I
      P
      C
      D
      D
      N
      N
C   FI
    5 N
      I
      N
      I
C   IF
C   SI
C   INS
      N
   10 C
      N
      N
      N
      N
      N
      N
      N
      N
C   TOT
      H
      H
      H
      X
      H
      H
      T
      N
```

```
      COMMON /Z7/ ALHRFD(26,15),AFEED(26,23)
      COMMON /YY1/ USEMCH(100),UNITS(100)
      COMMON /Y1/ XINFO(7),MCODE(100),XMDATA(100,13)
      COMMON /Y3/ NMDATA,NOPER,IN,IO
      COMMON /Y7/ NBOP(18),NBMACH(18,7),XNBM(18,7)
C    THIS SUBROUTINE IS USED FOR ALFALFA GREEN CHOPPING (DIRECT CUT)
C   HARVEST WILL OCCUR IF RAIN IS LESS THAN 2 MM.
      DATA STOLS/0.07/,FDLS/0.11/
      DATA DCLL/0.04/,DCSL/0.01/
      IF (RAIN.GT.2.) RETURN
C    HARVEST LOSSES
      HLEAF=XLEAF*(1.-DCLL)
      HSTEM=STEM*(1.-DCSL)
      HDM=HLEAF+HSTEM
      PCL=HLEAF/HDM
      IF (PCL.LT.0.290) PCL=0.29
      IF (PCL.GT.0.50) PCL=0.50
      PCS=1.-PCL
      CP=PCL*QUAL(1,2)+PCS*QUAL(2,2)
      DIG=PCL*QUAL(1,3)+PCS*QUAL(2,3)
      DM=HDM/100.
      NDCTD=1
      NHPD=1
C    FIND THE STORAGE STRUCTURE IN WHICH THE ALFALFA WILL BE STORED
    5 NS=1
      IF (CP.GE.CRTR(NTHCUT,2,5).AND.TMSTO(1).LT.SILO(1)) GO TO 10
      NS=2
      IF (TMSTO(2).LT.SILO(2)) GO TO 10
C    IF QUALITY DICTATES TO STORE IN SILO 2 AND SILO 2 IS FULL WHILE
C    SILO 1 IS NOT, THEN STORE THE LOW QUALITY SILAGE IN SILO 1 (HIGH QL)
C    INSTEAD OF FORCING HAY HARVEST
      NS=1
   10 CONTINUE
      NMTDAY=NMTDAY+1
      NHTDAY=NHTDAY+1
      NHRV=NHRV+1
      NMOW=NMOW+1
      NPST(NTHCUT,NS)=NPST(NTHCUT,NS)+1
      NCUM(NS)=NCUM(NS)+1
      NPDCA=NPDCA+1
      NBPL=NCUM(NS)
C    TOTAL DRY MATTER AFTER STORAGE AND FEEDING LOSSES
      HFEED(NS,NBPL,1)=DM*AREAPL*NHPD*(1.-FDLS)*(1.-STOLS)
      HFEED(NS,NBPL,2)=CP
      HFEED(NS,NBPL,3)=DIG
      XMCI=XINMC(NDAYHR,5,NTHCUT)
      HFEED(NS,NBPL,4)=XMCI
      HFEED(NS,NBPL,5)=0.
      TMSTO(NS)=TMSTO(NS)+DM*AREAPL*NHPD
      NBHR=4+NS
```

```
      OPUSE(NTHCUT,NBHR)=OPUSE(NTHCUT,NBHR)+TPL(NBHR)*NHPD
      KK=(NTHCUT-1)*3+1
      ALHRFD(NTHYR,KK)=ALHRFD(NTHYR,KK)+HFEED(NS,NBPL,1)
      ALHRFD(NTHYR,KK+1)=ALHRFD(NTHYR,KK+1)
     + +HFEED(NS,NBPL,1)*HFEED(NS,NBPL,2)
      ALHRFD(NTHYR,KK+2)=ALHRFD(NTHYR,KK+2)
     + +HFEED(NS,NBPL,1)*HFEED(NS,NBPL,3)
      IF (TMSTO(1).LT.SILO(1)) GO TO 15
      HARDEX=2.
      IF (TMSTO(2).LT.SILO(2)) GO TO 15
      IF (NOPSQ(NTHCUT,1).EQ.0) GO TO 15
C    IF BOTH SILOS ARE FULL, SHIFT FROM DIRECT CUT HARVEST TO DRY HAY
C    HARVEST AS LONG AS THE EQUIPMENT IS AVAILABLE.
C    THE FIRST HAY HARVEST DAY WILL NOT START UNTIL TOMORROW
      HARDEX=3.
      IDAH=9
      RETURN
   15 NLEFT=NPLOTS-NHRV
      IF (NLEFT.GE.1) GO TO 25
      NHRV=NPLOTS
      NMOW=NPLOTS
      RETURN
C    CHECK IF A SECOND PLOT MAY BE HARVESTED TODAY AS DIRECT CUT ALFALFA
   25 IF (NDCTD.GE.2) RETURN
      IF (CRTR(NTHCUT,4,1).EQ.1.) RETURN
      NDCTD=NDCTD+1
      GO TO 5
      END
C
C **********************************************************************
      SUBROUTINE WRITAL(ILINE)
C **********************************************************************
      COMMON /W1/ NPLOTS,NMOW,NHRV,NSTO,AREAPL,HARMAT(40,29),ZRT(9,5)
      COMMON /W2/ TPL(9),RAIN,JJDAY,NDAYHR
      COMMON /W3/ HFEED(4,160,5)
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
      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 /Z3/ HARDEX,TMSTO(4),NPST(5,5),NCUM(5),OPUSE(5,9)
      COMMON /Z4/FDLABR,FDENER,HRLABR,HRFUEL,HRELEC
      COMMON /Z5/ IPR2,IPR3,IPR4
      COMMON /Z6/ CSLABR,CSFUEL,CSELEC,CSFDLB,CSFDEN,DMCS
      COMMON /Z7/ ALHRFD(26,15),AFEED(26,23)
      COMMON /Z21/ ADATES(26,12),SDATES(4,12)
      COMMON /YY1/ USEMCH(100),UNITS(100)
      COMMON /Y1/ XINFO(7),MCODE(100),XMDATA(100,13)
```

```
      COMMON /Y3/ NMDATA,NOPER,IN,IO
      COMMON /Y7/ NBOP(18),NBMACH(18,7),XNBM(18,7)
      COMMON /Z22/ DELAY(26,12),SDELAY(4,12)
      DIMENSION STALHR(4,15),STFEED(4,23)
      DATA STALHR,STFEED /60*0.,92*0./
C   THIS SUBROUTINE CONTAINS ALL THE WRITE STATEMENTS FOR THE ALFALFA
C   HARVEST.  THE ARGUMENT ILINE REFERS TO 3 PRINTOUT LEVELS.
C       ILINE=1 IS FOR DAILY AND SEASONAL OUTPUT.
C       ILINE=2 IS FOR YEARLY OUTPUT.
C       ILINE=3 IS FOR END-OF-SIMULATION OUTPUT.
C   DAILY AND YEARLY PRINTOUTS WILL APPEAR ONLY IF INPUT DATA IPR2,
C   IPR3 OR IPR4 ARE EQUAL TO 1.
      GO TO (1,2,3) ILINE
C   DAILY PRINTOUT
1     IF (IPR2.NE.1) RETURN
      IF (NTHCUT.EQ.1.AND.NDAYHR.EQ.1) WRITE (IO,102) NTHYR,JYEAR
102   FORMAT (//,5X,'DETAILED OUTPUT FOR YEAR ',I2,' (',I4,')',//)
      NHD=NDAYHR-1
      IF (NHD.EQ.1) WRITE (IO,101)
101   FORMAT (/,6X,'DAILY ALFALFA HARVEST INFORMATION',/,6X,'JDAY',6X,
     + 'PLOTS      NMOW      NHRV          PPT      TOPS',
     + 8X,'CP       DIG',/)
      WRITE (IO,100) JJDAY,NPLOTS,NMOW,NHRV,PPT,TOPS,QUAL(3,2),QUAL(3,3)
  100 FORMAT (5X,4(I5,5X),F10.2,F10.0,2F10.3)
      IF (NHRV.NE.NPLOTS) RETURN
      I=NTHCUT
C   A WARNING IS GIVEN IF THE END OF THE ALFALFA HARVEST WAS CAUSED
C   BY NDAYHR BEING GREATER THAN 39.
      IF (NDAYHR.LT.39) GO TO 10
      NLM=NPLOTS-NMOW
      NLH=NPLOTS-NHRV
      WRITE (IO,105) I,NLM,NLH
  105 FORMAT (5X,'WARNING---  THE HARVEST RATE MAY BE UNREALISTICALLY LO
     +W FOR THE GIVEN AREA',/,5X,'DURING CUT',I4,',',I4,' PLOTS WERE UNM
     +OWED AND',I4,' PLOTS WERE UNHARVESTED FOR LACK OF TIME',/,5X,'MORE
     + THAN 39 DAYS WOULD BE REQUIRED TO HARVEST THE WHOLE AREA')
   10 IF (IPR2.NE.1) GO TO 15
      WRITE (IO,110) I,AREA(I),NPLOTS,(NPST(I,J),J=1,5)
  110 FORMAT (5X,'DURING CUT',I4,', AN AREA OF',F8.2,' HA WAS DIVIDED IN
     +TO',I4,' PLOTS.  PLOTS WERE HARVESTED AND STORED AS FOLLOWS',/,10X
     +,I4,' PLOTS AS HIGH QUALITY HAYLAGE', /,10X,I4,' PLOTS AS LOW QUAL
     +ITY HAYLAGE',/,10X,I4,' PLOTS AS HIGH QUALITY HAY',/,10X,I4, ' PLO
     +TS AS LOW QUALITY HAY',/10X,I4,' PLOTS DESTROYED BECAUSE OF OVEREX
     +POSURE')
      WRITE (IO,115) (OPUSE(NTHCUT,J),J=1,9)
  115 FORMAT (/,5X,'THE NINE OPERATIONS WERE EACH CONDUCTED FOR THE FOLL
     +OWING AMOUNT OF TIME (H) DURING THE PRESENT HARVEST',/,5X,9F10.2)
   15 CONTINUE
      RETURN
C   YEARLY PRINTOUT.  IF IPR3 IS 1, A DETAILED DESCRIPTION OF THE VALUE
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C   VALUE OF ALL ALFALFA PLOTS HARVESTED IN THE YEAR IS PROVIDED.
C   IF IPR4 IS 1, A DETAILED DESCRIPTION OF ALL MACHINERY USE AND
C   RESOURCE REQUIREMENT IS PROVIDED.
2     CALL ANCOST(NTHYR)
      IF (IPR3.NE.1) GO TO 25
      WRITE (10,102) NTHYR,JYEAR
      WRITE (10,150)
  150 FORMAT (/,5X,'THE PRESENT CUT IS APPARENTLY THE LAST OF THE YEAR',
     +/,5X,'THE FEEDING VALUE OF ALL THE FORAGES HARVESTED IN THE YEAR I
     +S GIVEN BELOW')
      DO 40 NS=1,4
      NPSS=NCUM(NS)
      IF (NPSS.LE.0) GO TO 20
      WRITE (10,120) NS
  120 FORMAT (5X,' IN STORAGE STRUCTURE NS = ',I4,', THE FOLLOWING PLOTS
     + WERE ACCUMULATED',/,9X,'DM (T)        CP        DIG        MC   DAY
     +S EXP.')
      DO 30 NBPL=1,NPSS
      WRITE (10,130) (HFEED(NS,NBPL,J),J=1,5)
  130 FORMAT (7X,4F10.3,F8.0)
   30 CONTINUE
      GO TO 40
   20 WRITE (10,140) NS
  140 FORMAT (5X,'NOT A SINGLE PLOT WAS STORED IN STORAGE STRUCTURE NS=
     +',I4, ' DURING THE CURRENT YEAR')
   40 CONTINUE
      WRITE (10,145) NCUM(5)
  145 FORMAT (5X,'THE NUMBER OF ALFALFA PLOTS DESTROYED BECAUSE OF OVERE
     +XPOSURE IN THE YEAR EQUALS ',I5)
   25 CONTINUE
      IF (IPR4.NE.1) RETURN
      WRITE (10,102) NTHYR,JYEAR
      DO 70 K=1,NMDATA
      IF (USEMCH(K).LE.0.) GO TO 70
      IF (UNITS(K).NE.1.) GO TO 71
      WRITE(10,170) MCODE(K),USEMCH(K)
  170 FORMAT (5X,'A SINGLE UNIT OF MACHINE',I6,' WAS USED',F10.2,' HOURS
     + DURING THE YEAR FOR FORAGE HARVEST')
      GO TO 70
   71 WRITE (10,171) UNITS(K),MCODE(K),USEMCH(K)
  171 FORMAT (5X,F4.0,' UNITS OF MACHINE',I6,' WERE USED ALLTOGETHER A T
     +OTAL OF',F10.2,' HOURS DURING THE YEAR FOR FORAGE HARVEST')
   70 CONTINUE
      WRITE (10,180) HRLABR,HRFUEL,HRELEC,FDLABR,FDENER
  180 FORMAT (/,5X,'THE TOTAL YEARLY RESOURCE REQUIREMENTS',
     +' FOR ALFALFA HARVEST AND FEEDING WERE',
     +/,10X,'FOR HARVESTING, ',F10.2,' MAN.HOURS',/,26X,F10.2,' LITERS',
     + ' OF FUEL',/,26X,F10.2,' KW.H OF ELECTRICITY',/,10X,'FOR FEEDING,
     + ',F13.2,' MAN.HOURS',/26X,F10.2,' LITERS OF FUEL OR ELECTRICAL EQ
     +UIVALENT')
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      WRITE (10,190) CSLABR,CSFUEL,CSELEC,CSFDLB,CSFDEN
190   FORMAT (/,5X,'THE TOTAL YEARLY RESOURCE REQUIREMENTS',
     +' FOR CORN SILAGE HARVEST AND FEEDING WERE',
     +/,10X,'FOR HARVESTING, ',F10.2,' MAN.HOURS',/,26X,F10.2,' LITERS',
     + ' OF FUEL',/,26X,F10.2,' KW.H OF ELECTRICITY',/,10X,'FOR FEEDING,
     + ',F13.2,' MAN.HOURS',/26X,F10.2,' LITERS OF FUEL OR ELECTRICAL EQ
     +UIVALENT')
      RETURN
C   END-OF-SIMULATION PRINTOUT.
3     CONTINUE
      WRITE (10,125)
125   FORMAT ('1',////,
     +        /, 5X,'AVERAGE ALFALFA DM YIELD AVAILABLE AS FEED (T/HA),
     +AVERAGE CRUDE PROTEIN (DEC) AND AVERAGE DIGESTIBILITY (DEC)',/, 5X
     +,'FOR UP TO 4 HARVESTS AND THE ANNUAL TOTAL',//,' YR',7X,'HARVEST
     +1',12X,
     +'HARVEST 2',12X,'HARVEST 3',12X,'HARVEST 4',12X,'TOTAL YEARLY',/,
     +10X,'DM    CP    DIG      DM    CP    DIG      DM    CP    DIG
     + DM    CP    DIG      DM    CP    DIG',//)
      DO 32 I=1,NYRS
      WRITE (10,131) I, (ALHRFD(I,J),J=1,15)
131   FORMAT (2X,I2,5(F9.2,2F6.3))
   32 CONTINUE
      WRITE (10,134)
134   FORMAT (9X,'----------------    ----------------    ----------',
     +'------    ----------------    ----------------',//)
      CALL SSTAT (15,ALHRFD,NYRS,STALHR)
      WRITE (10,133)
133   FORMAT (///,5X,'SAMPLE STATISTICS FOR SIMULATION OUTPUT.  ',
     + 'ROW 1=MEAN, ROW 2=STANDARD DEVIATION, ROW 3=COEF. OF ',
     + 'VARIATION',/)
      DO 73 I=1,3
73    WRITE (10,131) I,(STALHR(I,J),J=1,15)
      WRITE (10,134)
      WRITE (10,132)
132   FORMAT ('1',////,
     +        /,15X,'TOTAL ALFALFA FEED AVAILABLE FROM FOUR STORAGE LOCA
     +TIONS',/,15X,'THE INFORMATION INCLUDES TOTAL DM (T), AVERAGE CP, B
     +IASED STANDARD DEVIATION OF CP',/,15X,
     +'AVERAGE DIG AND BIASED STANDARD DEVIATION',
     +   ' OF DIG',//,' YR',7X,'ALFALFA IN FIRST SILO',10X,'ALFALFA',
     +   ' IN SECOND SILO',11X,'HIGH QUALITY HAY',13X,'LOW QUALITY HAY',
     +/,8X,'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)',
     +//)
      DO 34 I=1,NYRS
      WRITE (10,135) I, (AFEED(I,J),J=1,20)
135   FORMAT (1X,I2,2X,4(F7.1,2X,4(F4.3,1X),1X))
   34 CONTINUE
      WRITE(10,137)
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      CALL SSTAT (23,AFEED,NYRS,STFEED)
      WRITE (10,133)
      DO 74 I=1,2
74    WRITE (10,135) I,(STFEED(I,J),J=1,20)
      WRITE (10,136) (I,(STFEED(I,J),J=1,20),I=3,3)
136   FORMAT(1X,I2,2X,4(F7.2,2X,4(F4.3,1X),1X))
      WRITE(10,137)
137   FORMAT (7X,'-------------------------    --------------------',
     +'------    -------------------------    --------------------',
     + '------',//)
      WRITE (10,201)
201   FORMAT ('1',//,5X,'STARTING AND ENDING HARVEST DATES OF',
     +       ' ALFALFA FOR THE WHOLE SIMULATION',//,2X,'YR',4X,
     +       'HARVEST 1',21X,'HARVEST 2',21X,'HARVEST 3',21X,'HARVEST 4',
     +       /,8X,'STARTING  ENDING    SPAN      STARTING  ENDING    ',
     +       'SPAN      STARTING  ENDING    SPAN      STARTING  ',
     +       'ENDING    SPAN',/,8X,'DATE',6X,'DATE',16X,'DATE',6X,
     +       'DATE',16X,'DATE',6X,'DATE',16X,'DATE',6X,'DATE',/,8X,
     +       '------------------------',6X,'------------------------',
     +       6X,'------------------------',6X,'--------------------',
     +       '----',//)
      DO 36 I=1,NYRS
      WRITE (10,202) I,(ADATES(I,J),J=1,12)
202   FORMAT (2X,I2,1X,F7.0,11(3X,F7.0))
36    CONTINUE
      CALL SSTAT (12,ADATES,NYRS,SDATES)
      WRITE (10,133)
      DO 38 I=1,3
38    WRITE (10,204) I,(SDATES(I,J),J=1,12)
204   FORMAT (2X,I2,3X,F7.2,11(3X,F7.2))
      WRITE (10,207)
207   FORMAT ('1',//,5X,'THE AVERAGE NUMBER OF DAYS ALFALFA WAS',
     +       ' FIELD CURING BEFORE GOING INTO STORAGE',//,1X,'YR',
     +       10X,'FIRST SILO',19X,'SECOND SILO',17X,'HIGH QUALITY HAY',
     +       14X,'LOW QUALITY HAY',/,
     +       6X,'PLOTS',4X,'DAYS',5X,'S(DAY)',
     +       6X,'PLOTS',4X,'DAYS',5X,'S(DAY)',
     +       6X,'PLOTS',4X,'DAYS',5X,'S(DAY)',
     +       6X,'PLOTS',4X,'DAYS',5X,'S(DAY)',
     +       //)
      DO 209 I=1,NYRS
209   WRITE (10,208) I,(DELAY(I,J),J=1,12)
208   FORMAT (1X,I2,3X,4(F4.0,5X,F5.2,4X,F6.3,6X))
      CALL SSTAT (12,DELAY,NYRS,SDELAY)
      WRITE (10,133)
      DO 210 I=1,3
210   WRITE (10,211) I,(SDELAY(I,J),J=1,12)
211   FORMAT (1X,I2,3X,4(F6.2,3X,F6.3,3X,F6.3,6X))
      RETURN
      END
```

```
C
C ************************************************************************
      FUNCTION CSRATE (YDM,NOPCS)
C ************************************************************************
      COMMON /W1/ NPLOTS,NMOW,NHRV,NSTO,AREAPL,HARMAT(40,29),ZRT(9,5)
      COMMON /W2/ TPL(9),RAIN,JJDAY,NDAYHR
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
      COMMON /Z6/ CSLABR,CSFUEL,CSELEC,CSFDLB,CSFDEN,DMCS
      COMMON /Z9/ NBOPCS,ZRTCS(5)
      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 /Y3/ NMDATA,NOPER,IN,IO
      COMMON /Y6/ RATES(108,8),YAR(6)
      COMMON /Y7/ NBOP(18),NBMACH(18,7),XNBM(18,7)
      COMMON /W4/ NPDCA,NDCTD,IDAH
C   THIS FUNCTION ESTIMATES THE HARVEST RATE (HA/H) FOR THE CORN SILAGE
C   OPERATION.
C   RETAIN CURRENT VALUES OF TOPS,NTHCUT,IDAH AND NOPSQ(1,1).
C   THESE VALUES MUST BE CHANGED BEFORE CALLING INHRV FOR CORN SILAGE.
C   AFTER THE CORN SILAGE HARVEST RATE IS ESTIMATED, THE ORIGINAL
C   VALUES WILL BE REASSIGNED TO THE 4 VARIABLES.
      DMCS=YDM
      NBOPCS=NOPCS
      ATOPS=TOPS
      JCUT=NTHCUT
      JAH=IDAH
      NALFM=NOPSQ(1,1)
C   CHANGE THE VARIABLES FOR CORN SILAGE HARVEST.
      TOPS=YDM*100./1.1
      NTHCUT=1
      IDAH=1
      NOPSQ(1,1)=NOPCS
      CALL INHRV
      CSRATE=ZRT(1,1)
      ZRTCS(1)=ZRT(1,1)
      ZRTCS(2)=ZRT(1,2)
      ZRTCS(3)=ZRT(1,3)
      ZRTCS(4)=ZRT(1,4)
      ZRTCS(5)=ZRT(1,5)
C        WRITE (10,152) NOPCS,((ZRT(I,J),J=1,5),I=1,9)
C 152    FORMAT (5X,'ZRT MATRIX FOR CORN SILAGE.  NOPCS=',I4,/,
C       + 9(10X,5F10.2,/))
C   REASSIGN THE ORIGINAL VALUES.
      TOPS=ATOPS
      NTHCUT=JCUT
      IDAH=JAH
```

```
      NOPSQ(1,1)=NALFM
      RETURN
      END
C
C ********************************************************************
      SUBROUTINE ENDCS (CSAREA,CSFED)
C ********************************************************************
      COMMON /W1/ NPLOTS,NMOW,NHRV,NSTO,AREAPL,HARMAT(40,29),ZRT(9,5)
      COMMON /W2/ TPL(9),RAIN,JJDAY,NDAYHR
      COMMON /W3/ HFEED(4,160,5)
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
      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 /Z3/ HARDEX,TMSTO(4),NPST(5,5),NCUM(5),OPUSE(5,9)
      COMMON /Z4/FDLABR,FDENER,HRLABR,HRFUEL,HRELEC
      COMMON /Z5/ IPR2,IPR3,IPR4
      COMMON /Z6/ CSLABR,CSFUEL,CSELEC,CSFDLB,CSFDEN,DMCS
      COMMON /Z9/ NBOPCS,ZRTCS(5)
      COMMON /YY1/ USEMCH(100),UNITS(100)
      COMMON /Y1/ XINFO(7),MCODE(100),XMDATA(100,13)
      COMMON /Y3/ NMDATA,NOPER,IN,IO
      COMMON /Y7/ NBOP(18),NBMACH(18,7),XNBM(18,7)
C    THIS SUBROUTINE  ACCOUNTS FOR THE USE OF ALL MACHINES INVOLVED IN
C    THE CORN SILAGE OPERATION AND ESTIMATES LABOR AND ENERGY REQUIREMENT
C    LABOR AND ENERGY REQUIRED FOR FEEDING CORN SILAGE ARE
C    APPROXIMATED AS 0.8 MAN.H/TDM AND 0.45 L FUEL EQUIVALENT
C    PER TON OF DRY MATTER.
      DATA FDLB,FDEN /0.8,0.45/
      CSUSE=CSAREA/ZRTCS(1)
C        WRITE (10,101)  (ZRT(1,JJ),JJ=1,5),CSAREA,DMCS,CSUSE
C 101    FORMAT (5X,'PRINTOUT TO CHECK THE SOURCE OF CORN SILAGE ',
C       + ' ERROR',/,5X,'ZRT = ',5F10.2,/,5X,'CSAREA = ',F10.2,' DMCS=',
C       + F10.2,' CSUSE=',F10.2)
      II=0
    1 II=II+1
      IF (NBOPCS.NE.NBOP(II)) GO TO 1
      DO 65 K=1,7
      IF (NBMACH(II,K).EQ.0) GO TO 65
      IJ=0
    2 IJ=IJ+1
      IF (NBMACH(II,K).NE.MCODE(IJ)) GO TO 2
      UNITS(IJ)=AMAX1(UNITS(IJ),XNBM(II,K))
      USEMCH(IJ)=USEMCH(IJ)+CSUSE*XNBM(II,K)
   65 CONTINUE
      CSLABR=CSUSE*ZRTCS(4)
      CSFUEL=CSUSE*ZRTCS(2)
```

```
      CSELEC=CSUSE*ZRTCS(3)
      CSFDLB=FDLB*CSFED
      CSFDEN=FDEN*CSFED
      RETURN
      END
C ********************************************************************
      SUBROUTINE ANCOST(NTHYR)
C ********************************************************************
      COMMON /Z3/ HARDEX,TMSTO(4),NPST(5,5),NCUM(5),OPUSE(5,9)
      COMMON /Z4/FDLABR,FDENER,HRLABR,HRFUEL,HRELEC
      COMMON /Z6/ CSLABR,CSFUEL,CSELEC,CSFDLB,CSFDEN,DMCS
      COMMON /Z8/ ALFSIL(2),HAYST(3)
      COMMON /Z10/ TCOSTS(26,20),TRESS(26,20)
      COMMON /YY1/ USEMCH(100),UNITS(100)
      COMMON /Y1/ XINFO(7),MCODE(100),XMDATA(100,13)
      COMMON /Y3/ NMDATA,NOPER,IN,IO
      COMMON /PRICE/PLABOR,PFUELD,PFUELG,RATEIM,PDRYCG,PHRVCG,COEFSV(3),
     +       PFSCA1,PFSCA2,PFSCCS,PFSCHM,ALFYRS,RATEIS,RATEIL,XLIFE(3)
      DIMENSION RMCOEF(27)
      DATA RMCOEF /2*1.2,4*12.,3*7.,3*3.1,4*2.9,3.1,1.8,5*3.0,2.5,
     + 3.0,0.,0./
      DATA TCOSTS,TRESS/520*0.,520*0./
C   THIS SUBROUTINE ESTIMATES THE ANNUAL USE OF RESOURCES AND THE
C   ANNUALIZED COSTS FOR ALFALFA AND CORN SILAGE OPERATIONS.
C   L. PARSCH HAS WRITTEN ANOTHER SUBROUTINE THAT ESTIMATES COSTS
C   FOR HIGH MOISTURE CORN AND GRAIN CORN OPERATIONS.
C   ALL THESE COSTS ARE MERGED IN SUBROUTINE REPORT AT THE END
C   OF THE SIMULATION.
C
C   IN THE FIRST YEAR ONLY, THE FIXED COSTS OF MACHINERY AND OF
C   ALFALFA STORAGE STRUCTURES ARE ESTIMATED.
C
      IF(NTHYR.NE.1) GO TO 20
C
C   TOTAL CAPITALIZATION OF MACHINERY IS CALACULATED.
C
      TMCAP=0.
      DO 10 K=1,NMDATA
      IF (USEMCH(K).LE.0.) GO TO 10
      IF (MCODE(K).GE.260.AND.MCODE(K).LE.279) GO TO 10
      TMCAP=TMCAP+XMDATA(K,3)*UNITS(K)
10    CONTINUE
C
C   TOTAL CAPITALIZATION OF ALFALFA SILOS AND HAY BARN.
C
      TSCAP=ALFSIL(1)+ALFSIL(2)+HAYST(2)
C
C   ESTIMATE THE ANNUALIZED FIXED COSTS FOR MACHINERY AND SILOS.
C
      ANMACH=ANPV(TMCAP,COEFSV(2),XLIFE(2),RATEIM)
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```
      ANSILO=ANPV(TSCAP,COEFSV(1),XLIFE(1),RATEIL)
      DO 15 K=1,26
      TRESS(K,1)=TMCAP
      TCOSTS(K,1)=ANMACH
      TRESS(K,2)=TSCAP
      TCOSTS(K,2)=ANSILO
15    CONTINUE
20    CONTINUE
C
C   ANNUAL VARIABLE COSTS:  FUEL, LABOR AND REPAIR AND MAINTENANCE.
C   ESTIMATE FUEL REQUIREMENTS AND COSTS FIRST.
C
      TFUEL=HRFUEL+FDENER+CSFDEN+CSFUEL+HRELEC/6.
      TRESS(NTHYR,3)=TFUEL
      TCOSTS(NTHYR,3)=TFUEL*PFUELD
C
C   LABOR REQUIREMENTS AND COSTS.
C
      TLABHR=HRLABR+CSLABR
      TLABFD=FDLABR+CSLABR
      TRESS(NTHYR,5)=TLABHR
      TRESS(NTHYR,6)=TLABFD
      TCOSTS(NTHYR,5)=TLABHR*PLABOR
      TCOSTS(NTHYR,6)=TLABFD*PLABOR
C
C   REPAIR AND MAINTENANCE COSTS.
C
      TRMC=0.
      DO 30 K=1,NMDATA
      IF (USEMCH(K).LE.0.) GO TO 30
      KRM=MCODE(K)/10
      TRMC=TRMC+XMDATA(K,2)*USEMCH(K)*RMCOEF(KRM)*0.0001
30    CONTINUE
      TRESS(NTHYR,4)=TRMC
      TCOSTS(NTHYR,4)=TRMC
C
C   THERE MAY ALSO BE A VARIABLE STORAGE COST FOR DRY HAY IF THE
C   VOLUME HARVESTED EXCEEDS THE NOMINAL STORAGE CAPACITY.
C
      TOTHAY=TMSTO(3)+TMSTO(4)
      IF (TOTHAY.LE.HAYST(3)) RETURN
      VARSTO=(TOTHAY-HAYST(3))*HAYST(1)
      TCOSTS(NTHYR,2)=TCOSTS(NTHYR,2)+VARSTO
      RETURN
      END
C ***********************************************************************
      SUBROUTINE COWFD (NYRS,XLCOWS,HERD)
C ***********************************************************************
C
C   THIS SUBROUTINE ESTIMATES MILK PRODUCTION, THE SALE OF
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C     EXCESS FORAGES AND THE PURCHASE OF SUPPLEMENTAL FEEDS.
C     IT WAS WRITTEN BY PHILIPPE SAVOIE, APRIL 1982
C     THE ARRAY HERD CONTAINS THE DISTRIBUTION OF ANIMALS
C     WITHIN THE DAIRY HERD INTO THE SIX GROUPS SPECIFIED
C     BELOW.  TYPICAL VALUES COULD BE:
C        DATA HERD /0.30,0.30,0.00,0.00,0.10,0.30/
C     XLCOWS IS THE TOTAL NUMBER OF LACTATING COWS REPRESENTING
C     HERD(1) + HERD(2) + HERD(3) + HERD(4).
C
C     LACTATING AND DRY COWS ARE ASSUMED TO WEIGH 650 KG.
C     THE HERD IS DIVIDED INTO SIX GROUPS OF ANIMALS:
C        1.  LACTATING COWS PRODUCING 35 KG MILK PER DAY
C        2.  LACTATING COWS PRODUCING 30 KG MILK PER DAY
C        3.  LACTATING COWS PRODUCING 25 KG MILK PER DAY
C        4.  LACTATING COWS PRODUCING 20 KG MILK PER DAY
C        5.  DRY COWS
C        6.  HEIFERS (AVERAGE 300 KG LIVE WEIGHT)
C
C     A FEW PRINTOUTS ARE AVAILABLE TO SHOW DETAILS OF THE RATION
C     FORMULATIONS AND HOW COWS ARE FED.  THESE ARE PRESENTLY DISACTIVATED
C     BY COMMENT SIGNS IN THE FIRST COLUMN.  THEY ARE LOCATED JUST
C     ABOVE THE DO 60 STATEMENT (4 LINES), ABOVE THE 50 CONTINUE
C     STATEMENT (2 LINES) AND BELOW THE DO 80 STATEMENT (3 LINES).
C
      COMMON /Z7/ ALHRFD(26,15),AFEED(26,23)
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
      COMMON /SUMRY2/ TRESP(26,20),TCOSTP(26,20),TCOST(26,20),
     +      STCOST(4,20),TRES(26,20),SRES(4,20)
      COMMON /Y3/ NMDATA,NOPER,IN,IO
      DIMENSION HERD(6),CNEL(6),CCP(6),TNEL(6),TCP(6),CS(3)
      DIMENSION HMC(3),SBM(3),YFR(6),PURALF(5),ADUMMY(4,6)
      DIMENSION ALFM(5,6),FR(5),ALFNEL(5),RATION(5,6,5)
      DIMENSION XMILK(4),FEEDUT(26,12),SFDUT(4,12),STTCST(4,20)
      DIMENSION TC10(26),TC13(26),TC15(26),TCUA(26),TNRUA(26)
C
C     CNEL AND CCP ARE THE MINIMUM CONCENTRATIONS OF NET ENERGY
C     (LACTATION) AND CRUDE PROTEIN REQUIRED IN THE RATION FOR EACH
C     OF THE FIVE GROUPS OF COWS (MCAL/KG AND DEC. CP)
C
      DATA CNEL/1.656,1.590,1.514,1.426,1.35,1.35/
      DATA CCP/0.163,0.153,0.141,0.128,0.11,0.12/
C
C     TNEL AND TCP ARE THE TOTAL NET ENERGY OF LACTATION (MCAL) AND
C     TOTAL CRUDE PROTEIN (KG) REQUIRED PER ANIMAL PER DAY FOR
C     EACH OF THE FIVE GROUPS OF COWS.
C
      DATA TNEL/34.45,31.00,27.55,24.10,13.39,7.25/
      DATA TCP/3.385,2.975,2.565,2.155,0.984,0.746/
C
C     THE STANDARD QUALITY OF FEEDSTUFFS USED IN THE RATION IS
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C   CHARACTERIZED BY 1=NET ENERGY OF LACTATION (MCAL/KG),
C   2=CRUDE PROTEIN (DEC), 3=TDN (DEC).
C   FIVE TYPES OF FEED ARE CONSIDERD IN THE RATION:
C   ALFALFA, CORN SILAGE, HIHGGH MOISTURE GRAINCORN, DRY CORN GRAIN
C   AND SOYBEAN MEAL.  DHE FIRST THREE ARE FARM GROWN AND ARE
C   ALWAYS INCLUDED IN THE RATION.  THE LAST TWO ARE ADDED
C   ONLY WHEN WE MUST INCREASE EITHER THE NET ENERGY
C   CONCENTRATION (ADD PURCHASED CORN GRAIN) OR THE CRUDE
C   PROTEIN CEONCENTRATION (ADD SOYBEAN MEAL).
C   NOTE THAT NO STANDARD VALUE IS USED FOR ALFALFA, BUT RATHER
C   VALUES OF QUALITY FROM THE AFEED MATRIX WILL BE USED.
C
      DATA CS/1.589,0.08,0.70/
      DATA HMC/1.84,0.10,0.80/
      DATA SBM/1.86,0.496,0.81/
      DATA PURALF/10000.,.13,0.,.52,0./
      DATA XMILK,PMILK,PSOYM,PCORN,PALF/35.,30.,25.,20.,286.,248.,139.,8
     +3./
      DATA SCG,SHMC,SALF,SCS/129.,90.,69.,70./
      DATA RATION/150*0./
1     READ (2,99) XLCOWS,(HERD(I),I=1,6)
99    FORMAT (7F10.3)
      DO 5 NTHYR=1,NYRS
      TCORN=0.
      TSOYM=0.
      TALF=AFEED(NTHYR,1)+AFEED(NTHYR,6)+AFEED(NTHYR,11)
     + +AFEED(NTHYR,16)
      TALF1=TALF
      TCS=AFEED(NTHYR,21)
      TCS1=TCS
      THMC=AFEED(NTHYR,22)
      THMC1=THMC
      TCG=AFEED(NTHYR,23)
      TCG1=TCG
C
C   THE YFR ARRAY CONTAINS THE TOTAL YEARLY FEED REQUIREMENT
C   (TONS OF DRY MATTER) FOR EACH GROUP OF COWS.
C   XLCOWS IS THE TOTAL NUMBER OF LACTATING COWS.
C   TCOWS IS THE TOTAL NUMBER OF COWS IN THE HERD, INCLUDING
C   DRY COWS AND HEIFERS.
C
      FRLACT=HERD(1)+HERD(2)+HERD(3)+HERD(4)
      TFRAC=FRLACT+HERD(5)+HERD(6)
      IF (FRLACT.LE.0.0.OR.TFRAC.NE.1.) THEN
      WRITE (10,111)
111   FORMAT ('1',///,5X,'***WARNING***',/,5X,'THE TOTAL FRACTION',
     +      ' OF LACTATING COWS WITH RESPECT TO ALL COWS IN THE HERD',
     +      ' WAS LESS OR EQUAL TO 0. ACCORDING TO INPUT',5X,/,
     +   5X,'OR THE TOTAL OF ALL FRACTIONS WAS NOT EQUAL TO 1',5X,/,
     +      5X,'THE FOLLOWING DEFAULT VALUES WERE GIVEN TO THE SIX',
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```
     +      ' COW GROUPS:  0.30, 0.30, 0.00, 0.00, 0.10 AND 0.30.',//)
      HERD(1)=0.30
      HERD(2)=0.30
      HERD(3)=0.00
      HERD(4)=0.00
      HERD(5)=0.10
      HERD(6)=0.30
      FRLACT=HERD(1)+HERD(2)+HERD(3)+HERD(4)
      ENDIF
      TCOWS=XLCOWS/FRLACT
      DO 7 JCOW=1,6
7     YFR(JCOW)=TCOWS*HERD(JCOW)*TNEL(JCOW)*365./(CNEL(JCOW)*1000.)
      FEEDUT(NTHYR,12)=YFR(1)+YFR(2)+YFR(3)+YFR(4)+YFR(5)+YFR(6)
      DO 10 NS=1,4
      K=(NS-1)*5+1
      ADUMMY(NS,1)=AFEED(NTHYR,K)
      ADUMMY(NS,2)=AFEED(NTHYR,K+1)
      ADUMMY(NS,3)=AFEED(NTHYR,K+2)
      ADUMMY(NS,4)=AFEED(NTHYR,K+3)
      ADUMMY(NS,5)=AFEED(NTHYR,K+4)
10    CONTINUE
C
C    FOR WET ALFALFA, A 5 PERCENT REDUCTION OF CRUDE PROTEIN AND OF
C    DIGESTIBILITY IS ASSUMED TO REFLECT THE REDUCED INTAKE WHEN
C    COMPARED WITH DRY ALFALFA.
C
      DO 12 NS=1,2
      ADUMMY(NS,2)=ADUMMY(NS,2)*0.95
12    ADUMMY(NS,4)=ADUMMY(NS,4)*0.95
C
C    RANK THE FOUR ALFALFA STORAGE LOCATIONS BY QUALITY, THE HIGHEST
C    CRUDE PROTEIN BEING THE FIRST ROW IN ALFM MATRIX.
C    A FIFTH ROW IS INCLUDED FOR PURCHASED ALFALFA IN CASE NOT ENOUGH
C    ROUGHAGE IS PRODUCED ON THE FARM.  THE QUALITY OF PURCHASED
C    ALFALFA IS DEFINED IN A DATA STATEMENT FOR PURALF(5).
C    THE FIVE COLUMNS IN MATRIX ALFM REPRESENT:  TOTAL DM (METRIC
C    TONS), CRUDE PROTEIN (DEC), BIASED STANDARD DEV. OF CP,
C    DIGESTIBILITY (DEC) AND BIASED STANDARD DEVIATION OF DIG.
C
      DO 30 I=1,4
      KMAX=1
      XCP=ADUMMY(1,2)
      DO 20 NS=2,4
      IF(XCP.GT.ADUMMY(NS,2)) GO TO 20
      XCP=ADUMMY(NS,2)
      KMAX=NS
20    CONTINUE
      ALFM(I,1)=ADUMMY(KMAX,1)
      ALFM(I,2)=ADUMMY(KMAX,2)
      ALFM(I,3)=ADUMMY(KMAX,3)
```

```
      ALFM(1,4)=ADUMMY(KMAX,4)
      ALFM(1,5)=ADUMMY(KMAX,5)
      ADUMMY(KMAX,2)=-1.
30    CONTINUE
      ALFM(5,1)=10000.
      ALFM(5,2)=PURALF(2)
      ALFM(5,3)=PURALF(3)
      ALFM(5,4)=PURALF(4)
      ALFM(5,5)=PURALF(5)
      TDM=TALF+TCS+THMC
C   THE NET ENERGY FOR LACTATION IS CALCULATED FOR ALL FIVE ALFALFA
C   SOURCES.  NE IS A FUNCTION OF DIGESTIBILITY.
      DO 40 NS=1,5
      TDN=ALFM(NS,4)
      ALFNEL(NS)=1.15+(TDN-0.52)*2.5
      IF (TDN.LT.0.52) ALFNEL(NS)=1.15
      IF (TDN.GT.0.68) ALFNEL(NS)=1.55
40    CONTINUE
C
C   THE FOLLOWING DO LOOPS (60 AND 50) ESTABLISH BALANCED RATIONS
C   FOR ALL COMBINATIONS OF FARM GROWN ROUGHAGES (5 DISTINCT ALFALFA
C   GROUPS) AND OF FIVE ANIMAL GROUPS.
C
C        WRITE (10,136)
C 136    FORMAT (//,5X,'THE RATION FORMULATIONS FOR ALL COMBINATIONS',
C      +       /,5X,'NS    JCOW      ALF       CS       HMC       CG     SBM',
C      +      '       NEL       CP',/)
      DO 60 NS=1,5
      IF (ALFM(NS,1).LE.0.) GO TO 60
      DO 50 JCOW=1,6
      FR(1)=TALF/TDM
      FR(2)=TCS/TDM
      FR(3)=THMC/TDM
      FR(4)=0.
      FR(5)=0.
      FR1=1.
      FR4=0.
      FR5=0.
      AVENEL=ALFNEL(NS)*FR(1)+CS(1)*FR(2)+HMC(1)*FR(3)
      AVECP=ALFM(NS,2)*FR(1)+CS(2)*FR(2)+HMC(2)*FR(3)
      IF (NS.EQ.5) THEN
      AVENEL=ALFNEL(NS)
      AVECP=ALFM(NS,2)
      ENDIF
      IF (AVENEL.GE.CNEL(JCOW)) GO TO 55
C
C   HERE WE MUST INCREASE THE CONCENTRATION OF NET ENERGY BY ADDING
C   MORE CORN GRAIN.
C   THE NEW CONCENTRATIONS IN THE RATION ARE CALCULATED
C
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```
      R=(CNEL(JCOW)-AVENEL)/(HMC(1)-CNEL(JCOW))
      FR(4)=R/(1.+R)
      FR(3)=FR(3)/(1.+R)
      FR(2)=FR(2)/(1.+R)
      FR(1)=FR(1)/(1.+R)
      AVECP=ALFM(NS,2)*FR(1)+CS(2)*FR(2)+HMC(2)*(FR(3)+FR(4))
      IF (NS.EQ.5) THEN
      FR1=1./(1.+R)
      FR4=R/(1.+R)
      AVECP=ALFM(NS,2)*FR1+HMC(2)*FR4
      ENDIF
      IF (AVECP.GE.CCP(JCOW)) GO TO 51
C
C   HERE WE NEED TO ADD BOTH CG AND SBM.
C   RECALCULATE PROPORTIONS OF FEEDS BY SOLVING TWO EQUATIONS
C   SIMULTANEOUSLY FOR CCP AND CNEL.  BALANCE THE FOLLOWING
C   EQUATIONS:
C   AVENEL+HMC(1)*RC+SBM(1)*RS=CNEL(JCOW)
C   AVECP +HMC(2)*RC +SBM(2)*RS=CCP(JCOW)
C
C       X1=CCP(JCOW)-(AVECP+HMC(2)*(CNEL(JCOW)-AVENEL)/HMC(1))
C       X2=SBM(2)-HMC(2)*SBM(1)/HMC(1)
C       RS=X1/X2
C       RC=(CNEL(JCOW)-(AVENEL+SBM(1)*RS))/HMC(1)
C       X3=1./(1.+RS+RC)
C       FR(1)=FR(1)*X3
C       FR(2)=FR(2)*X3
C       FR(3)=FR(3)*X3
C       FR(4)=RC*X3
C       FR(5)=RS*X3
C       IF (NS.EQ.5) THEN
C       FR1=FR1*X3
C       FR4=RC*X3
C       FR5=RS*X3
C       ENDIF
C       GO TO 51
55    IF (AVECP.GE.CCP(JCOW)) GO TO 51
C
C   HERE WE MUST INCREASE THE CONCENTRATION OF CRUDE PROTEIN
C   BY ADDING SOME SOYBEAN MEAL.
C   THE NEW CONCENTRATIONS IN THE RATION ARE CALCULATED.
C
      R=(CCP(JCOW)-AVECP)/(SBM(2)-CCP(JCOW))
      FR(5)=R/(1.+R)
      FR(4)=FR(4)/(1.+R)
      FR(3)=FR(3)/(1.+R)
      FR(2)=FR(2)/(1.+R)
      FR(1)=FR(1)/(1.+R)
      IF (NS.EQ.5) THEN
      FR1=FR1/(1.+R)
```

```
      FR4=FR4/(1.+R)
      FR5=R/(1.+R)
      ENDIF
51    DO 58 II=1,5
58    RATION(NS,JCOW,II)=FR(II)
      IF (NS.EQ.5) THEN
      RATION(NS,JCOW,1)=FR1
      RATION(NS,JCOW,2)=0.
      RATION(NS,JCOW,3)=0.
      RATION(NS,JCOW,4)=FR4
      RATION(NS,JCOW,5)=FR5
      ENDIF
      AVENEL=ALFNEL(NS)*RATION(NS,JCOW,1)+CS(1)*RATION(NS,JCOW,2)
     +  +HMC(1)*(RATION(NS,JCOW,3)+RATION(NS,JCOW,4))+SBM(1)*
     +   RATION(NS,JCOW,5)
      AVECP=ALFM(NS,2)*RATION(NS,JCOW,1)+CS(2)*RATION(NS,JCOW,2)
     +   +HMC(2)*(RATION(NS,JCOW,3)+RATION(NS,JCOW,4))
     +   +SBM(2)*RATION(NS,JCOW,5)
C        WRITE(10,137) NS,JCOW,(RATION(NS,JCOW,I),I=1,5),AVENEL,AVECP
C 137    FORMAT (5X,I2,I7,7F8.3)
50    CONTINUE
60    CONTINUE
C
C   FEED EACH GROUP OF COWS ONE AFTER THE OTHER STARTING WITH LACTATING
C   COWS.  THE BALANCED FEEDS WILL BE ALLOCATED STARTING WITH THE
C   HIGHEST QUALITY ALFALFA UNTIL THE YEARLY FEED REQUIREMENT IS MET.
C
      DO 70 JCOW=1,6
      IF (HERD(JCOW).LE.0.) GO TO 70
      DO 80 NS=1,5
C        WRITE (10,126) JCOW,NS,ALFM(NS,1),ALFM(NS,2),YFR(JCOW)
C 126    FORMAT (5X,'FEEDING THE COWS:  JCOW  NS  ALFDM  ALFCP  YFR',
C      +        /,5X,20X,I3,I4,F7.1,F7.3,F7.1)
      IF (ALFM(NS,1).LE.0.) GO TO 80
      ALFRQ=YFR(JCOW)*RATION(NS,JCOW,1)
      IF (ALFM(NS,1).GT.ALFRQ) THEN
C   THE FEED REQUIREMENT FOR JCOW IS COMPLETELY MET.
C   REDUCE THE FEED LEFT IN STORAGE LOCATION NS.
      ALFM(NS,1)=ALFM(NS,1)-ALFRQ
      TALF=TALF-ALFRQ
      THMC=THMC-YFR(JCOW)*RATION(NS,JCOW,3)
      TCS=TCS-YFR(JCOW)*RATION(NS,JCOW,2)
      TCORN=TCORN+YFR(JCOW)*RATION(NS,JCOW,4)
      TSOYM=TSOYM+YFR(JCOW)*RATION(NS,JCOW,5)
      GO TO 70
      ENDIF
C
C   HERE ALL THE FEED IN NS IS NOT ENOUGH TO SATISFY THE FEED
C   REQUIRED BY COW GROUP JCOW.
C   USE ALL NS.  REDUCE YFR(JCOW) BY EMPTYING ALL THE FEED
```

```
C   IN STORAGE LOCATION NS.
C
      TDMNS=ALFM(NS,1)/RATION(NS,JCOW,1)
      YFR(JCOW)=YFR(JCOW)-TDMNS
      TALF=TALF-ALFM(NS,1)
      ALFM(NS,1)=0.
      THMC=THMC-TDMNS*RATION(NS,JCOW,3)
      TCS=TCS-TDMNS*RATION(NS,JCOW,2)
      TCORN=TCORN+TDMNS*RATION(NS,JCOW,4)
      TSOYM=TSOYM+TDMNS*RATION(NS,JCOW,5)
80    CONTINUE
70    CONTINUE
C
C   MILK PRODUCTION, INCOME FROM MILK, INCOME FROM THE SALE OF EXCESS
C   CROPS AND COST OF PURCHASED FEEDS ARE ESTIMATED BELOW.
C
      TMILK=(TCOWS*(HERD(1)*XMILK(1)+HERD(2)*XMILK(2)
     +    +HERD(3)*XMILK(3)+HERD(4)*XMILK(4)))*365./1000.
      VMILK=TMILK*PMILK
      CSOYM=TSOYM*PSOYM
C   IN THE CASE OF CORN PURCHASES (TCORN), CHECK IF ANY FARM HARVESTED
C   CORN IS LEFT AS HMC OR AS DRY GRAIN BEFORE MAKING OUTSIDE PURCHASES
      IF (TCORN.GT.THMC) THEN
      TCORN=TCORN-THMC
      THMC=0.
      ELSE
      THMC=THMC-TCORN
      TCORN=0.
      ENDIF
      IF (TCORN.GT.TCG) THEN
      TCORN=TCORN-TCG
      TCG=0.
      ELSE
      TCG=TCG-TCORN
      TCORN=0.
      ENDIF
      CCORN=TCORN*PCORN
      VCG=TCG*SCG
      VHMC=THMC*SHMC
      IF (TALF.LT.0.) THEN
      VALF=0.
      CALF=(-TALF)*PALF
      ELSE
      VALF=TALF*SALF
      CALF=0.
      ENDIF
      VCS=TCS*SCS
      TT=0.
      DO 85 I=1,9
85    TT=TT+TCOST(NTHYR,I)
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```
      TCOST(NTHYR,10)=TT
C    NET COST OF FEEDS:  SBM MINUS INCOME FROM EXCESS ALF, CS, HMC
      TCOST(NTHYR,11)=CSOYM+CALF-(VHMC+VALF+VCS)
C    NET COST OF CORN PURCHASES
      TCOST(NTHYR,12)=CCORN-VCG
      TCOST(NTHYR,13)=TCOST(NTHYR,10)+TCOST(NTHYR,11)+TCOST(NTHYR,12)
      TCOST(NTHYR,14)=VMILK
      TCOST(NTHYR,15)=TCOST(NTHYR,14)-TCOST(NTHYR,13)
C
C    MATRIX FEEDUT IS A FEED UTILIZATION MATRIX.
C
      FEEDUT(NTHYR,1)=TALF1
      FEEDUT(NTHYR,2)=TCS1
      FEEDUT(NTHYR,3)=THMC1
      FEEDUT(NTHYR,4)=TCG1
      FEEDUT(NTHYR,5)=TSOYM
      FEEDUT(NTHYR,6)=TCORN
      FEEDUT(NTHYR,7)=TALF
      FEEDUT(NTHYR,8)=TCS
      FEEDUT(NTHYR,9)=THMC
      FEEDUT(NTHYR,10)=TCG
      TT=0.
      DO 88 I=1,6
88    TT=TT+FEEDUT(NTHYR,I)
      DO 89 I=7,10
89    TT=TT-FEEDUT(NTHYR,I)
      FEEDUT(NTHYR,11)=TT
5     CONTINUE
      WRITE (10,101) XLCOWS,(HERD(I),I=1,6)
101   FORMAT ('1',//,5X,'SUMMARY OF HOW FEEDS WERE USED EACH YEAR',
     +      /,5X,'THE NUMBER OF LACTATING COWS IS ',F6.0,/,
     +      5X,'THE DAIRY HERD IS DIVIDED INTO SIX GROUPS IN THE',
     +      ' FOLLOWING PROPORTIONS:  ',6(F5.3,2X),
     +     /,5X,'UNITS ARE METRIC TONS OF DRY MATTER',/,5X,
     +   'RATIONS WERE FORMULATED BY SUBROUTINE COWFD',//,3X,'YR',
     +   10X,'FEEDS PRODUCED ON THE FARM',9X,'FEEDS PURCHASED',18X,
     +   'FEEDS SOLD',16X,'NET FED',3X,'MAXIMUM',/,
     +   11X,
     +   'ALF       CS        HMC       CG        SBM       CG',
     +   '         ALF       CS        HMC       CG',15X,'INTAKE')
      WRITE(10,103)
103   FORMAT(9X,'------------------------------------',5X,'----------',
     +      '-----',4X,'--------------------------------------',4X,
     +      '----------------',//)
      DO 95 I=1,NYRS
95    WRITE (10,102) I,(FEEDUT(I,J),J=1,12)
102   FORMAT (3X,I2,12F10.2)
      WRITE(10,103)
      CALL SSTAT(12,FEEDUT,NYRS,SFDUT)
      WRITE (10,133)
```

```
133
96
77
112
78
113
210
21
21
21
21
20
C *
C *
C
C
C
```

```
133   FORMAT (///,5X,'SAMPLE STATISTICS FOR SIMULATION OUTPUT.  ',
     + 'ROW 1=MEAN, ROW 2=STANDARD DEVIATION, ROW 3=COEF. OF ',
     + 'VARIATION',/)
      DO 96 I=1,3
96    WRITE (10,102) I,(SFOUT(I,J),J=1,12)
      WRITE (10,103)
      DO 77 I=1,NYRS
      TC10(I)=TCOST(I,10)
      TC13(I)=TCOST(I,13)
      TC15(I)=TCOST(I,15)
      TCUA(I)=TCOST(I,13)/AREA(I)
      TNRUA(I)=TCOST(I,15)/AREA(I)
77    IF(AREA(I).LE.0.) TCUA(I)=0.
      CALL RANK(TC10,NYRS)
      CALL RANK(TC13,NYRS)
      CALL RANK(TC15,NYRS)
      CALL RANK(TCUA,NYRS)
      CALL RANK(TNRUA,NYRS)
      WRITE (10,112)
112   FORMAT ('1',//,5X,'TOTAL COSTS RANKED IN INCREASING ORDER',/,
     +      5X,'TOTAL COST (1-9)',5X,'TOTAL COST (10-12)',5X,
     +      'NET RETURN',
     +      5X,'TC(10-12)/HA',5X,'TNR/HA',//)
      DO 78 I=1,NYRS
78    WRITE (10,113) TC10(I),TC13(I),TC15(I),TCUA(I),TNRUA(I)
113   FORMAT (5X,F10.0,2(11X,F10.0),2(6X,F10.0))
      WRITE (10,210)
210   FORMAT ('1',///,5X,'TOTAL COSTS IN THE ORIGINAL YEARLY',
     +      ' ORDER FOR THE HERD SPECIFIED ABOVE',//,3X,'YR',3X,
     +      '10=SUM(1-9)  11=FNET  12=CG    13=SUM(10-12)  14=',
     +      'MILK   15=NET RETURN',//)
      DO 211 I=1,NYRS
211   WRITE (10,212) I,(TCOST(I,J),J=10,15)
212   FORMAT (3X,I2,6F10.0)
      CALL SSTAT (20,TCOST,NYRS,STTCST)
      WRITE (10,133)
      DO 213 I=1,3
213   WRITE (10,214) I,(STTCST(I,J),J=10,15)
214   FORMAT (3X,I2,6F10.2)
      READ (2,201) IZZ
201   FORMAT (I10)
      IF (IZZ.EQ.1) GO TO 1
      RETURN
      END
C ***********************************************************************
      SUBROUTINE RANK(AR,KB)
C ***********************************************************************
C
C   THIS SUBROUTINE REORDERS NUMBERS IN A ONE-DIMENSIONAL ARRAY
C   AND RANKS THEM IN INCREASING ORDER.
```

```
C TH
C
1
C F
2
3
C *
C *
C
C
C
C
C
C
C
C
```

```
C   THERE ARE KB NUMBERS TO BE RANKED IN ARRAY AR.
C
      DIMENSION AR(26),DUM(26)
      IF (KB.LE.1) RETURN
      DO 1 I=1,KB
1     DUM(I)=AR(I)
C   FIND THE MINIMUM VALUE AND RANK IT.
      DO 3 J=1,KB
      IMIN=1
      VALMIN=DUM(1)
      DO 2 I=2,KB
      IF (VALMIN.GT.DUM(I)) THEN
      VALMIN=DUM(I)
      IMIN=I
      ENDIF
2     CONTINUE
      AR(J)=VALMIN
      DUM(IMIN)=9.E+20
3     CONTINUE
      RETURN
      END
C ***********************************************************************
      PROGRAM TEST
C ***********************************************************************
C
C   PROGRAM TEST IS A DUMMY PROGRAM USED TO TEST ALHARV.
C   IT ALLOWS TO RUN ALHARV AND FORHRV TOGETHER WITHOUT THE
C   CORN AND ALFALFA GROWTH MODELS BY ASSUMING FIXED YIELDS AND
C   WEATHER CONDITIONS.  IT SHOULD BE REPLACED BY THE BIGMOD PROGRAM,
C   ALFMOD AND CRNMOD WRITTEN BY PARSCH (1982) TO SIMULATE THE WHOLE
C   DYNAMIC FORAGE MODEL.
C
      COMMON /W1/ NPLOTS,NMOW,NHRV,NSTO,AREAPL,HARMAT(40,29),ZRT(9,5)
      COMMON /W2/ TPL(9),RAIN,JJDAY,NDAYHR
      COMMON /W3/ HFEED(4,160,5)
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),SILO(2)
      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 /Z3/ HARDEX,TMSTO(4),NPST(5,5),NCUM(5),OPUSE(5,9)
      COMMON /Z4/FDLABR,FDENER,HRLABR,HRFUEL,HRELEC
      COMMON /Z5/ IPR2,IPR3,IPR4
      COMMON /Z6/ CSLABR,CSFUEL,CSELEC,CSFDLB,CSFDEN,DMCS
      COMMON /Z7/ ALHRFD(26,15),AFEED(26,23)
      COMMON /Z10/ TCOSTS(26,20),TRESS(26,20)
      COMMON /YY1/ USEMCH(100),UNITS(100)
      COMMON /Y1/ XINFO(7),MCODE(100),XMDATA(100,13)
```

```
      COMMON /Y3/ NMDATA,NOPER,IN,IO
      COMMON /Y6/ RATES(108,8),YAR(6)
      COMMON /Y7/ NBOP(18),NBMACH(18,7),XNBM(18,7)
      COMMON /PRICE/PLABOR,PFUELD,PFUELG,RATEIM,PDRYCG,PHRVCG,COEFSV(3),
     +       PFSCA1,PFSCA2,PFSCCS,PFSCHM,ALFYRS,RATEIS,RATEIL,XLIFE(3)
      COMMON /SUMRY2/ TRESP(26,20),TCOSTP(26,20),TCOST(26,20),
     +      STCOST(4,20),TRES(26,20),SRES(4,20)
      DIMENSION HERD(6)
      OPEN(1,FILE='MACH')
      OPEN(2,FILE='MGTALF')
      OPEN (6,FILE='OUTPUT')
      DATA IN/5/,IO/6/
      DATA QUAL /.44,.56,1.,.28,.13,.196,.75,.60,.666,.14,.29,.224/
      DATA PLABOR,PFUELD /5.00,0.309/
      DATA RATEIM,RATEIL /0.15,0.13/
      DATA COEFSV,XLIFE /0.0,0.1,0.2,30.,10.,7./
      DO 28 I=1,26
      DO 26 J=1,20
   26 AFEED(I,J)=0.
      DO 28 J=1,15
   28 ALHRFD(I,J)=0.
      NTHCUT=1
      BGNCUT(1)=1.
      BGNCUT(2)=50.
      BGNCUT(3)=100.
      BGNCUT(4)=365
      NTHYR=1
      JDAYF=1
      JDAYL=150
      JYEARF=1
      JYEARL=2
      CPLANT=0.
      NYRS=JYEARL+1-JYEARF
      TMINC=15.
      TMAXC=25.
      SRADF=500.
      PPT=20.
      XLEAF=220.
      STEM=280.
      TOPS=500.
      IN=1
      CALL FORHRV
      IN=2
      CALL MGTINF
      YCS=10.
      CSAREA=100.
      DO 30 JYEAR=JYEARF,JYEARL
      CALL YRINIT
      DO 20 JDAY=JDAYF,JDAYL
      IF (JDAY.LT.BGNCUT(NTHCUT)) GO TO 20
```

```
      X1=FLOAT(JDAY)/4.
      I1=IFIX(X1)
      X2=X1-FLOAT(I1)
      IF (X2.EQ.0.) PPT=10.
      CALL ALHARV (REMCUT,REMHRV,ICUTON,JDAY)
C       IF (JDAY.EQ.1.OR.JDAY.EQ.50) GO TO 96
C       IF(JDAY.EQ.100) GO TO 96
C       IF(JDAY.GE.109.AND.JDAY.LE.111) GO TO 96
C       GO TO 97
C 96    WRITE(10,107) JYEAR,JDAY,NTHCUT,HARDEX,(TMSTO(J),J=1,4)
C       WRITE(10,108) (NPST(NTHCUT,J),J=1,5),(OPUSE(NTHCUT,J),J=1,9)
C       WRITE(10,109) (ZRT(J,1),J=1,9)
C 107   FORMAT(5X,'JYEAR=',I4,/,5X,'JDAY=',I4,/,5X,'NTHCUT=',
C      + I4,/,5X,'HARDEX=',F10.0,/,5X,'TMSTO=',4F10.2)
C 108   FORMAT(5X,'NPST=',5I10,/,5X,'OPUSE=',9F10.2)
C 109   FORMAT(5X,'ZRT=',9F10.2)
C 97    CONTINUE
      PPT=0.
      IF (REMHRV.EQ.0.) NTHCUT=NTHCUT+1
   20 CONTINUE
      CSHR=CSRATE(YCS,140)
      CSFED=YCS*CSAREA*0.8
      CALL ENDCS(CSAREA,CSFED)
      CALL WRITAL(2)
      WRITE (10,120) YCS,CSAREA,CSHR,CSLABR,CSFUEL,CSELEC
  120 FORMAT (//,10X,'CORN SILAGE HARVEST INFORMATION',/,10X, 6F12.2)
      XLEAF=132.
      STEM=168.
      TOPS=300.
      NTHCUT=1
      NTHYR=NTHYR+1
   30 CONTINUE
      CALL WRITAL(3)
      DO 53 I=1,NYRS
      DO 53 J=1,20
53    TCOST(I,J)=TCOSTS(I,J)
      CALL COWFD(NYRS,XLCOWS,HERD)
      WRITE (10,130)
130   FORMAT (//,5X,'PRINTOUT OF RESOURCES AND COSTS.  EACH',
     +'COLUMN REPRESENTS:',/,5X,'1=MACH INV.  2=SILO INV.  3=FUEL (L) '
     +'4=R&M ($)  5=FIEL LB (MAN.H)  6=FEDD LB',//)
      DO 40 K=1,NYRS
      WRITE (10,140) (TRESS(K,J),J=1,10)
140   FORMAT (5X,6(F10.1,1X),4F6.1)
40    CONTINUE
      WRITE (10,130)
      DO 50 K=1,NYRS
      WRITE (10,141) (TCOST(K,J),J=1,15)
141   FORMAT(1X,15(1X,F7.0))
50    CONTINUE
```

```
      STOP
      END
C
C ******************************************************************
      FUNCTION TABLI (VAL,ARG,DUMMY,K)
C ******************************************************************
      DIMENSION VAL(K),ARG(K)
      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 ANPV(PP,COEFSV,XLIFE,RATEI)
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
      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
```

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