This is to certify that the

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VALUE OF ALFALFA LOSSES IN THE DAIRY FORAGE SYSTEM

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VALUE OF ALFALFA LOSSES IN THE DAIRY FORAGE SYSTEM

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ABSTRACT

VALUE OF ALFALFA LOSSES IN THE DAIRY FORAGE SYSTEM

By

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Value lost because of dry matter loss and quality deterioration during production and utilization of forages was determined using a whole-farm simulation model (DAFOSYM). Improved submodels of dry matter loss and changes in neutral detergent fiber and crude protein during harvest, storage and feeding were developed. The silo storage model is comprehensive and describes the preseal, fermentation, infiltration and feedout phases. The animal model combines nutrient requirements with an intake function to predict animal response to forage quality.

Elimination of all losses on a representative, Midwestern, 100-cow dairy farm increases the annual net return by $12,448 when milk production is 8,000 kg/cow-y. Reduction of alfalfa value during harvest ($13.42/T DM) is larger than during storage ($7.87/T DM).

Rate of respiration loss during field curing was modeled as a function of moisture content and temperature, with the loss being non-protein, non-fiber material. The loss in alfalfa value due to respiration is relatively small ($1.32/T DM). Rain loss, modeled as a function of rainfall and alfalfa quality at the time of rain occurrence, decreases alfalfa value by $2.94/T DM.

Machinery-induced losses were modeled as functions of moisture

content and yield. Of these losses, raking loss reduces alfalfa value most ($7.01/T DM).

For a moderate milk production level, hay storage causes the greatest value reduction ($8.91/T DM); silo loss reduces value by $6.42/T DM.

The value of alfalfa losses depends greatly on the milk production potential of the dairy animals. At high milk production levels (production is limited only by forage quality), the value of all alfalfa losses combined is 2.2 times greater than the value at moderate (8,000 kg/cow-y) milk production. The ranking of the most costly losses changes as milk production increases. Hay storage ($19.58/T DM), silo storage ($28.93/T DM), raking ($10.00/T DM) and rain ($7.08/T DM) cause the largest value reductions at the high milk production level.

Improvement in feed allocation over a method typical of the better dairy farmers can increase net return by $3,271 to $11,059/y. The improvement in feed allocation has as much impact on net return as the elimination of all storage losses.

APPROVED BY ____________________
Major Professor

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Department Chairman

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NOMENCLATURE

Chapter 3: Harvest loss models

ATD	average temperature during daytime hours, ^oC
ATN	average temperature during nighttime hours, ^oC
BCL	baler chamber loss, fraction of dry matter
CP	crude protein content of leaves or stems, fraction
CSL	chopper spout loss, fraction of dry matter
DC	drying constant, 1/h
HDL	hours of daylight each day
l	fraction of loss material that is leaves
L	fraction of whole plant that is leaves
LL	leaf loss, fraction of leaf dry matter
LLR	leaf loss from raking, fraction of dry matter
m	moisture content, decimal wet basis
m_1	moisture content at 8 a.m. of next day
m_2	moisture content at 8 p.m. of current day
m_3	moisture content at 8 a.m. of next day
NDF	neutral detergent fiber content of leaves or stems, fraction of dry matter
RAIN	rainfall amount, mm
REL	respiration loss, fraction of dry matter
RL	raking loss, fraction of dry matter
RLR	respiration loss rate, fraction of dry matter/h
RNL	rain loss due to leaching, fraction of dry matter
RNLL	rain loss due to leaf shatter, fraction of leaf dry matter
s	fraction of loss material that is stems
S	fraction of whole plant that is stems
SL	stem loss, fraction of stem dry matter
SLR	stem loss from raking, fraction of dry matter
t	time, h
T	temperature, ^oC
TL	total loss, fraction of dry matter
Y	yield, T DM/ha

Subscripts

i	initial (before a given treatment)
f	final (after a given treatment)

NOMENCLATURE - continued

Chapter 4: Storage loss models

A	area of moving front, m^2
ADIP	acid detergent insoluble protein content, fraction of dry matter
ADIPCP	acid detergent insoluble protein content, fraction of crude protein
AL	accumulated dry matter loss in a section (summed from time 0 to date), kg
ASH	ash content, fraction of dry matter
B	depth to moving front, cm
CP	crude protein content, fraction of dry matter
D	diffusion coefficient for oxygen, cm^2/h
DF	depth of forage fed per day, cm/d
DM	dry matter content, decimal
f_C	relative respiration rate as dependent on carbon dioxide concentration, dimensionless
FR	feed rate out of the silo, kg DM/d
h	depth of plot or depth of bunker, cm
H	height of bunker, m
HC	soluble carbohydrate formed from acid and enzyme hydrolysis of hemicellulose, fraction of DM
HDD	heating, degree-days > 35°C
K_m	Michaelis-Menten constant, dimensionless
l	dry matter loss rate, g/h
L	dry matter loss, fraction of dry matter
L'	depth at which oxygen concentration gradient is zero, cm
LI	infiltration loss, kg/10 d
m	moisture content, decimal wet basis
M	initial mass of dry matter in the plot (tower silo) or the vertical section (bunker silo), kg
NDF	neutral detergent fiber content, fraction of dry matter
NH3	ammonia content, fraction of dry matter
NPN	non-protein nitrogen, fraction of total nitrogen
PH	silage pH after fermentation
q	rate of oxygen reaching the front, cm^3/h
Q	total sensible heat production, kJ/kg DM-6 months
R	radius, m
RS	respirable substrate, fraction of dry matter
t	time, d
T	temperature, °C
U	permeability, cm/h
x	depth, cm

α	approximation variable, cm
	$\approx (K_m+\psi)/\gamma$
ψ	oxygen concentration, decimal
ϕ	forage porosity, decimal
μ	respiration rate, $cm^3 O_2$/g silage-h
ρ	forage density, g/cm^3
γ	constant incorporating density, respiration and diffusion parameters, $1/cm^2$
τ	tortuosity of diffusional paths in silage (2/3), dimensionless

Subscripts

a	in air
eff	effective
f	front
i	initial
inf	infiltration
j	time increment, multiples of 10d
s	silo
td	to date
1	phase 1
2	phase 2
3	phase 3
4	phase 4
4a	phase 4, in-silo
4b	phase 4, in-bunk

Chapter 5: Animal utilization model

$AESCP_{diet}$	available escape protein of the diet, kg/d
$AESCP_i$	available escape protein content of feed i, kg/d
ALFSIL	amount of alfalfa silage in the diet, kg DM/d
$ANDF_i$	adjusted NDF content of feed i, fraction of DM
$ANDF_{diet}$	adjusted NDF content of the diet, fraction of DM
AP^r	absorbed protein requirement, kg/d
ARV_j	annual roughage value requirement for group j, kg/y
ARVH	annual roughage value requirement for the herd, kg/y
ASRV	amount of alfalfa silage roughage value in storage, kg/y
ATDN	adjusted total digestible nutrient content of diet, fraction of DM
BASEMP	average milk production of a mature cow in the herd, kg/y
BASEWT	average weight of a mature cow during the second stage of lactation indicating size of animals in the herd, kg

BCP_{diet}	bacterial crude protein yield of the diet, kg/d
$BTDN_{diet}$	baseline total digestible nutrient content of the diet, fraction of DM
$BTDN_i$	baseline total digestible nutrient content of feed i, fraction of DM
BW	body weight, kg
ΔBW	change in body weight, kg/d
C	daily intake capacity of the animal
C_{ic}	ingestive capacity coefficient, kg ANDF/d per kg BW
CP_i	crude protein content of feed i, fraction of dry matter
CP_{diet}	crude protein content of the diet, fraction of dry matter
CS	amount of corn silage in the diet, kg DM/d
CSRV	amount of corn silage roughage value in storage, kg
DE_{diet}	digestible energy content of the diet, Mcal/kg DM
$DEGR_i$	protein degradation rate of feed i, fraction of crude protein
DMI	dry matter intake, kg DM/d
DMI_m	dry matter intake reserved for maintenance, kg DM/d
DMI_g	dry matter intake reserved for gain, kg DM/d
DPA	difference protein absorbed, kg/d
F	fill effect of diet
FAIF	fraction of alfalfa in the forage
FFC	fraction of cows experiencing first lactation
FFID	fraction of the diet that is forage
FHAYIA	fraction of the alfalfa in the diet that is hay
FPN	absorbed protein requirement for fecal output, kg/d
GR	grain to total dry matter ratio in corn silage
HAY	amount of alfalfa hay in the diet, kg DM/d
I	daily intake
IC	ingestive capacity, kg ANDF/d
IDM	indigestible dry matter intake, kg DM/d
LPN	absorbed protein requirement for lactation, kg/d
ME_{diet}	metabolizable energy content of the diet, Mcal/kg DM
ME_i	metabolizable energy content of feed i, Mcal/kg DM
ME^r	metabolizable energy requirement, Mcal/d
MMNT	multiples of maintenance
MNTP	absorbed protein requirement for maintenance, kg/d
MPD	milk production, kg/d
MPD_{min}	minimum basis of milk production for determining net energy concentration of approximate diet, kg/d
NDF	neutral detergent fiber content, fraction of dry matter
$NE_{g,diet}$	net energy for gain of the diet, Mcal/kg DM
NE_g^r	net energy for gain requirement, Mcal/d
$NE_{l,i}$	net energy for lactation of feed i, Mcal/kg DM
$NE_{l,i,adjusted}$	net energy for lactation of feed i, adjusted for

	multiples of maintenance, Mcal/kg DM
$NE_{l,diet}$	net energy for lactation of the diet, Mcal/kg DM
$NE_{l,m}$	net energy for lactation requirement for maintenance, Mcal/d
$NE_{l,p}$	net energy for lactation requirement for pregnancy, Mcal/d
$NE_{l,g}$	net energy for lactation requirement for weight change, Mcal/d
$NE_{l,l}$	net energy for lactation requirement for lactation, Mcal/d
NE_l^r	net energy for lactation requirement, Mcal/d
$NE_{l,adjusted}^r$	net energy for lactation requirement adjusted for multiples of maintenance, Mcal/d
$NE_{m,diet}$	net energy for maintenance of the diet, Mcal/kg DM
NE_m^r	net energy for maintenance requirement, Mcal/d
$NH3_{diet}$	ammonia pool of the diet, kg/d
NPN	non-protein nitrogen content, fraction of crude protein
PDMI	approximate dry matter intake, kg DM/d
PFAT	milk fat, %
$PRICE_i$	relative price of feed i for LP solution of linear inequalities
RAP^r	rumen available protein requirement, kg/d
RAP_{diet}	rumen available protein in the diet, kg/d
RELLW	relative live weight
RELMBS	relative metabolic body size
RPN	absorbed protein requirement for retained protein, kg/d
RV_i	roughage value of feed i, fraction of DM
x_i	amount of feed i in the diet, kg DM/d
Y_j	animal characteristic in Table 5.11 for group j
YPN	absorbed protein requirement for pregnancy, kg/d

Chapter 6: Alfalfa value

AA	annual alfalfa used, kg/cow-y
ACS	annual corn silage used, kg/cow-y
ADF	acid detergent fiber content, fraction of dry matter
AMP	annual milk production, kg/cow-y
ASFC	annual supplemental feed cost, $/cow-y
CP	crude protein content, fraction of dry matter
L	fraction of milk income required to cover non-feed, variable costs
MPD	milk per day, kg/cow-d
NDF	neutral detergent fiber content, fraction of dry matter
P	price, $/kg
PMP	potential milk production, kg/cow-y
RFV	relative feed value
UAI	unallocated income, $/cow-y
V	alfalfa value, $/T dry matter

Subscript

ref	with respect to reference quality alfalfa

Chapter 7: Determining loss value

MP	milk production, kg/y
RTFC	reduction in total feed costs per unit of milk produced, %
TFC	total feed costs, $/y

1. INTRODUCTION

1.1 Background and motivation

Of the 141 million tonnes (T) of hay that U.S. farmers produced on 25 million hectares (ha) during 1986, 59 percent was alfalfa (USDA, 1987). In Michigan alone, the value of hay production exceeded $300 million (USDA, 1987). During the mid-1980s, annual hay production in the United States was valued at approximately $9.5 billion. This was nearly 53 percent of the value of U.S.-produced corn grain and 92% of the value of U.S.-produced soybeans. Dry matter loss and quality deterioration during forage production can vary among farms, but the typical loss of 22 percent during hay production implies an annual economic loss of $2.7 billion to American farmers. Forage losses during silage production result in additional economic losses.

Forages are an interdisciplinary topic. From the time of planting through growth, harvest and storage and eventually animal utilization, the processes in forage production are affected by agronomists, engineers, animal scientists and economists. Each of these disciplines has been involved in research to improve forage efficiency. The work of the agronomists has resulted in yields of high quality alfalfa that exceed 22.2 tonnes of dry matter per hectare (Tesar, 1982). The primary interest of the engineer has been to design machinery and processes that harvest, store and feed the animal. Animal scientists are increasing the efficiency with which forages and other feeds are converted into 65 million tonnes of milk per year (USDA, 1987). To the economists, who focus on overall efficiency, it must be satisfying to see the progress made in forage utilization over the past years, yet at the same time discouraging to recognize that national averages of forage production and utilization are consistently far below levels shown possible by research.

Some of the controllable factors in forage production that have significant impacts on farm net return are planting time and date, seeding rate, fertilization practices, soil conditions, length of growth period, date of harvest, machinery types and technologies used, labor availability, allocation of land and financial resources, rations as fed to the animals and allocation of produced feeds. To maximize production, all of these factors -- as well as some beyond the farmer's control, such as weather -- must be considered.

Interdisciplinary topics rely heavily on a common interest in improvement. It is obvious that, because numerous disciplines affect the production and utilization of forages, gains in efficiency should not be limited to any one or two fields. Improvement of forage quality during growth has no impact if the gain is lost during harvest and storage, or if the animal does not utilize the improved quality. Many times, researchers have fine-tuned one specific area while leaving another far less efficient area untouched or even inadvertently making it more inferior. Properly evaluating the various steps in the chain of forage production and utilization events can identify the weakest links, the processes in which large losses occur. A thrust of this present work was to connect some of the links between disciplines.

Determining the value of losses at each stage in the production and utilization chain enables researchers to direct studies to those areas with the greatest economic potential. Farmers could also use such information to make decisions about various technologies or management strategies. Perhaps the cheapest gains in efficiency can be achieved by informing farm operators that good management can minimize losses and increase profits.

1.2 Objectives

The primary goal of this work was to evaluate, in economic terms, the losses of dry matter and reduction of quality that occur during alfalfa harvest and storage. The specific objectives were:

1. To develop models of dry matter loss and quality change during harvest and storage of alfalfa and incorporate these models into DAFOSYM, a simulation model of the dairy forage system.

2. To develop and incorporate into DAFOSYM a model that determines feed value by predicting potential milk production from a given quantity of feeds of given quality.

3. To use DAFOSYM to determine the value of losses that occur at each stage of alfalfa production and utilization.

2. LITERATURE REVIEW

Minimizing losses has long been recognized as a way to improve forage systems. Total losses between crop growth and animal utilization vary widely as management practices and crop and weather conditions change. Total losses typically range from 5 to 26% of the initially available crop (Moser, 1980; Hundtoft, 1965), so the value of losses is of obvious importance. The intent of this chapter is to review data and models of losses, methods of determining feed value and several forage system models.

2.1 Forage losses

Losses of forage dry matter and quality begin during crop growth and continue to occur during harvest, storage and feeding. Losses in legumes differ from those in grasses, even though the processes may be identical. Under similar conditions and given identical treatments, legume loss between cutting and baling was 38.9% (Klinner, 1976); loss in grass hay was approximately half as much.

2.1.1 Field losses

For hay made under good conditions, total dry matter loss is typically 15 to 22% of the initial yield (Rotz and Abrams, 1988). For silage systems, field losses range from 5 to 18% (Hundtoft, 1965). When rain severely hampers field-curing conditions, the loss can reach 100%. Field losses are caused by improper timing of harvest, machinery treatment, rain or respiration during curing.

2.1.1.1 Losses during field curing

Respiration of the cut plant, the activity of microorganisms and rain can each contribute to dry matter and quality loss during field curing of forages. The dry matter lost during field curing is primarily non-structural carbohydrate; when rain occurs, some protein is lost (Rotz and Abrams, 1988).

Zimmer (1977) plotted dry matter loss vs. curing time for grass harvested under poor, moderate and good weather conditions. Loss per day ranged from 1 to 4%. Dry matter loss ranged from 2.5% (good weather and silage harvest) to 30% (poor weather and hay harvest). Honig (1980) plotted grass respiration loss per hour as a function of dry matter content and temperature. The respiration rate ranged from 0 to 0.35%/h, increased with increasing temperature and decreased with increasing dry matter content. Wood and Parker (1971) presented a model of grass respiration that includes the effects of moisture and temperature. The Honig and Wood models differ in that the Honig model allows for slight respiration at moistures as low as 20%, while the Wood and Parker model does not allow for respiration below 27.3% moisture. (Wood and Parker acknowledge that a small but insignificant amount of respiration occurs between 20 and 27% moisture.) Rees (1982) reviewed models and data of respiration loss and concluded that the models of Honig (1980) and Wood and Parker (1971) are in close agreement; however, Rees used an oversimplified drying model in his comparison. McGechan (1986) combined the functional forms of these two models and incorporated maturity effects (water soluble carbohydrate and digestibility) as well. The data of Greenhill (1959) show that the respiration of legumes is approximately 50% greater than that of grass (Dale et al., 1978).

Rotz and Abrams (1988) reported alfalfa curing loss to range from -8 to 19%, with an average of 3.2%. Because of large errors associated with the measurement of field curing loss, Rotz et al. (1987) did not measure a significant decrease in respiration loss as curing time decreased.

Rain is another environmental factor causing alfalfa loss. Rain-induced losses can reach 100% if crop quality deteriorates below a useful level. Experimental results on the effects of rewetting forage crops have been reported by Collins (1982, 1983, 1985) and Fonnesbeck et al. (1982). Rain-induced losses are affected by the amount of rainfall, the number of showers, the types of mechanical treatment and the moisture content when rain occurs (Collins, 1982). Although experimental conditions can be described accurately, it is difficult to identify the independent effects of these factors on rain-induced losses.

Alfalfa hay exposed to 25 mm of rain during a 3-day period had a combined leaching and respiration loss of 11.9% (Collins, 1985); the comparable loss without rain was 3.9%. Leaf loss (shatter during rain impact and simulated raking) was 9.8 and 2.4% for wetted and non-wetted alfalfa, respectively. The rain-induced loss of an additional 15.4% caused acid detergent fiber (ADF) and neutral detergent fiber (NDF) concentrations to increase, while in vitro dry matter digestiblity (IVDMD) and crude protein (CP) concentrations decreased. Total NDF, ADF and CP losses (as a fraction of initial amount) were -1, 1 and 9%, respectively, for non-wetted hay; for wetted hay these losses were 4, 6 and 31%, respectively. In these experiments, the curing time to achieve 25% moisture were 3 and 7 days for unwetted and wetted alfalfa, respectively. Separating leaching and respiration loss into leaching loss directly caused by rain and respiration loss due to extended exposure for curing is difficult (Collins, 1983).

Collins (1983) reported 3.1- to 4.8-fold increases in losses during drying when wetting occurred. Wetting that occurred after drying (rain on 15% moisture hay) caused losses as high as 55.2%. Fonnesbeck et al. (1982) reported dry matter losses of 4.6 and 9.7% caused by 5 and 20 mm of rain, respectively. Crude protein losses associated with the 5 and 20 mm of rain were 4.3 and 10.2%; these were approximately equal to the dry matter losses. Fonnesbeck et al. (1982) suggested that because fiber components (NDF and ADF) are insoluble, they are immune to leaching by rain; however, the Collins data (1985) indicate some fiber loss because of rain..

Pizzaro and James (1972) reported that the respiration rate of hay wetted to a given moisture content is similar to the respiration rate of the hay at that moisture content before wetting. This suggests that respiration after rain occurrence can be treated like respiration before rain occurrence.

2.1.1.2 Machinery-induced losses

Machinery-induced (mechanical) losses occur each time the crop is manipulated. It is difficult to attribute losses to a given machine because of interactions among treatments. For example, mower loss is difficult to determine because subsequent raking may pick up material the mower has left behind (Straub et al., 1986). Similarly, it is difficult to determine if some material was left behind by the mower or if the material could have been considered a preharvest loss (i.e., leaves that fell before mowing). It is clear that not all machine losses are additive (Rotz and Abrams, 1988).

Despite the difficulty in quantifying mower loss, it is useful to determine its magnitude. Koegel et al. (1985) evaluated 3 mower-conditioners. Of the dry matter loss occurring during hay harvest, approximately 50% occurred during mowing and raking. Mower-conditioner losses averaged 3.9, 5.9 and 7.2% for a reciprocating mower with a fluted roll conditioner, a disk mower with a fluted roll conditioner, and a disk mower with a flail conditioner, respectively. Straub et al. (1986) reported mower conditioner losses of approximately 2.5% for a cutterbar mower with an intermeshing roll conditioner. Rotz et al. (1987) found mowing plus raking loss to be from 0.9 to 6.6%. Losses for reciprocating cutterbar mowers averaged 2.9% without mechanical conditioning and 3.4% with fluted roll conditioning over three cuttings. Mower loss was not affected by chemical conditioning.

Loss expressed as a fraction of yield was higher for cuttings with low yields (Rotz et al., 1987). This was also shown by Savoie et al. (1982) -- absolute losses were nearly the same regardless of yield. For cutterbar mowers, losses were approximately 9 and 20 kg DM/ha without and with a fluted-roll conditioner, respectively. This resulted in relative losses of 0.2 and 0.4% for first cutting and 0.4 and 0.8% for second cutting, during which the yield was 50% lower. Losses due to mowing and conditioning were approximately the same regardless of the time of conditioning (Savoie et al., 1982); however, a second mechanical conditioning treatment increased loss significantly. The combined mowing, conditioning and raking loss was about 3% for disk and cutterbar mowers with either flail or roll conditioners; losses with a flail mower were double those of cutterbar mowers (Rotz and Sprott, 1984). Dale et al. (1978), using data from Hundtoft (1965), modeled mowing losses to be 1.0, 2.1 and 4.6% for cutterbar mowers, cutterbar mowers with conditioning and mowing with heavy crimping, respectively. All mower-conditioner loss was considered to be leaf material. Pitt (1982) modeled mowing losses as 1 and 1.5% without and with conditioning. Rotz et al. (1989a) modeled mower-conditioner loss of leaves (4%) and stems (1%) separately to quantify quality changes attributable to the mower.

Field treatment options following mowing or mowing with conditioning include conditioning, tedding, inverting and raking. The added mechanical conditioning of crimping previously conditioned alfalfa increased losses by 25.9 kg/ha (Savoie et al., 1982). Crimping alfalfa previously conditioned with a flail conditioner increased losses by 8.9 kg/ha.

Tedding alfalfa hay at low moisture contents can result in large leaf losses. When following a cutterbar mower with a roll conditioner, tedding resulted in an average of 54.4 kg/ha loss during second cutting (Savoie et al., 1982). With a yield of 2,350 kg/ha, this constitutes a loss of 2.3%. Tedding of ryegrass hay resulted in about 4% loss per tedding (Bockstaele et al., 1980). Parke et al. (1978) modeled tedding loss with a maximum value of 2.5% for grass; tedding loss was inversely related to moisture content.

Raking can result in a net gain if, during the raking operation, material previously scattered or left behind is gathered (Koegel, et al., 1985). Rotz and Abrams (1988) reported that the greatest loss of forage quality during harvest occurred during raking, with 3.7% of the digestible dry matter and 3.8% of the crude protein lost. Loss for alfalfa hay raked at 35 to 45% moisture at a speed of 5.1 km/h with a parallel bar rake averaged 3.5%; raking loss was inversely proportional to yield raised to the 2.42 power. When a second raking was required, 0.2% additional loss was observed (Rotz and Abrams, 1988). Savoie et al. (1982) reported raking losses of 50 to 80 kg/ha (1 to 4%) for alfalfa hay raked at 60 to 66% moisture. When separated from mowing and conditioning losses, the raking loss was approximately 1% (Koegel et al., 1985).

Dale et al. (1978) modeled raking loss as a function of moisture content, plant species, rake type, raking speed and conditioning using multiplicative factors. All raking loss is considered to consist of leaves that fall from the stems. With a maximum moisture content factor of 1.0, the effect of moisture on raking loss decreases nearly exponentially as moisture content increases. Grasses are assumed to have 50% less loss than legumes. The rake type factor is a function of how gently the crop is treated. Rake speed increases loss linearly up to 10 km/h, where further increases in rake speed do not increase raking loss. Raking loss without prior mechanical conditioning is 95% of that with prior conditioning. Pitt (1982) modeled raking loss as 8% with previous conditioning and 7.6% without conditioning. Rotz et al. (1989a) modeled raking loss of stems as 2% of initial stem mass. Raking loss of leaves ranged from 2 to 21% of leaf dry matter and was inversely related to moisture content (Savoie, 1982). An inverse function of this type was previously used for total (leaf and stem) loss by Hundtoft (1965).

Following mowing and other swath manipulation treatments, the final source of mechanical harvest loss is the harvester. Losses incurred during baling include material missed by the pick-up mechanism and material lost from the baler chamber. The combination of these two losses exceeded the loss incurred during chopping (Straub et al., 1986). Baler pick-up loss averaged 2.1%; chamber losses for a variable chamber round baler averaged 3.1%, with higher losses associated with drier hay (Straub et al., 1986). Baler chamber losses for three types of balers were measured by Koegel et al. (1985). Chamber losses for hay baled at 18% moisture were 2.8, 3.8 and 10.9 for a rectangular, round variable chamber and round fixed chamber baler, respectively. Baler pick-up losses were 2.0 to 2.4% and were the same regardless of baler type because all balers had similar pick-up mechanisms. The pick-up loss during first cutting was less than half that of later cuttings. This is likely due to a nearly constant absolute loss with changing yield as reported by Savoie et al. (1982). Because of differences among cuttings, Koegel et al. (1985) found that neither baler chamber nor total loss can be adequately predicted as a function of baling moisture; however, within cuttings baling moisture did explain a considerable amount of the differences in baler chamber and total losses.

Rotz and Abrams (1988) reported pick-up and chamber losses for a small rectangular baler to be 1.8 and 1.1%, respectively. Even though the quality of the chamber loss material was higher than that of pick-up loss, the total loss of nutrients due to pick-up loss was higher because more material was lost. Pitt (1982) modeled baler loss, including both pick-up and chamber losses, for a rectangular baler with ejector as 4% unless the hay was baled at 30% moisture; then baler loss was 2%. Rotz et al. (1989a) modeled baler loss of leaves (7.5%) and stems (2%) separately. i.e., 7.5% of leaf mass and 2% of stem mass were lost during baling. Dale et al. (1978) modeled baler loss as a function of moisture, plant species and conditioning treatment and assumed all baler loss was leaf material.

Loss during chopping of forages is highly operator dependent. Differences in turning frequency, turning speed and spout alignment could very easily result in losses an order of magnitude larger or smaller than published values. Chopper loss is a function of feed rate, wind speed, moisture content, length of cut and wagon type (roof, air vents, etc.). Straub et al. (1986) reported chopper losses of 2.5% for alfalfa placed in a windrow by the mower-conditioner and 1.4% for alfalfa raked into a windrow from a swath. Based on Whitney (1966), Dale et al. (1978) modeled chopper losses to be 43% higher than baler losses and 25% higher than losses with a baler with a bale ejector. Pitt (1982) modeled chopper losses to be 2%. Rotz et al. (1989a) modeled chopper loss during corn silage harvest as 6%.

It is clear from a study of published loss values that losses from various machines vary widely within experiments and among experiments. The loss data collected during the 1980s has contributed significantly to the knowledge in this area. Although previous models were presented in this discussion, loss models should be based on the latest experimental data because changes in machine design affect machinery-induced losses.

2.1.2 Storage losses

2.1.2.1 Losses during hay storage

Much research has been devoted to the measurement of dry matter losses and quality changes during hay storage (Buckmaster, 1986;

Buckmaster et al., 1988; Rotz et al., 1988; Rotz and Abrams, 1988; Davies and Warboys, 1978; Nehrir et al., 1978; Johnson and McCormick, 1976, Knapp et al., 1975; Weeks et al., 1975; Nelson, 1972, 1968, 1966; Miller et al., 1967; Shepherd et al., 1954). This research has been conducted primarily as comparative experiments to evaluate chemical preservatives. Dry matter loss during indoor storage of hay with less than 20% moisture may range from 5 to 10% (Martin, 1980). Waldo and Jorgensen (1981) suggested a rule of thumb: 1% dry matter loss for each 1% decrease in moisture content during storage.

Martin (1980) suggested that hay which contains more than 15% moisture will heat during storage. The amount of heating that occurs depends on moisture concentration (Buckmaster, 1986; Buckmaster et al., 1988; Nelson, 1966, 1972; Miller et al., 1967; Rotz et al., 1988). With sufficient heating, nitrogen becomes bound to fiber and becomes unavailable for ruminant use. In extreme cases, heat development can result in combustion.

If hay is baled at a low moisture level and stored inside, few nutrient changes occur during storage (Moser, 1980). Weeks et al. (1975) reported little chemical change in loosely stacked hay harvested at 40% moisture. Other research indicates that when hay is baled at moisture levels exceeding 20%, heating and mold development occur and affect nutrient retention (Miller et al., 1967). Quality changes have been significant as baling moisture was increased (Miller et al., 1967; Nehrir et al., 1978; Nelson, 1966, 1968, Buckmaster et al., 1988).

Buckmaster et al. (1988) combined empirical analysis of experimental data and thermodynamic theory to develop a model for predicting dry matter loss and major quality changes during indoor storage of alfalfa hay. In their model, dry matter loss is related to total heat generated from consumption of dry matter. They found that fiber and ash concentrations increase because of the loss of other components. Crude protein loss during storage was less than soluble carbohydrate loss. The increase of acid detergent insoluble (bound) nitrogen was related to the heating of the hay in degree-days above 35°C.

Losses during outside storage of hay vary with weather conditions, bale covering, bale condition (solid or loosely formed) and soil conditions under the bale (Moser, 1980; Martin, 1980). Currence et al. (1976) reported 10.6 and 17.2% dry matter loss for 23.9% moisture alfalfa in round bales stored inside and outside, respectively. The bales were placed on gravel and were stored for approximately 6 months. Belyea et al. (1985) reported dry matter losses in large round bales of alfalfa to be 2.5 and 15% for inside and outside uncovered storage respectively. The rain penetrated 10 to 25 cm into the uncovered bales and as a result, nearly 40% of the original bale dry matter deteriorated. Covered bales stored outside lost only 5.8 to 6.6% of initial dry matter (Belyea et al., 1985).

Anderson et al. (1981) reported alfalfa dry matter losses of 3% for inside storage and 14% for outside storage. The quality of the interior of the bales stored outside was near the quality of the bales stored inside, but because of weathering of the outer 20 cm which made up 42 to 49% of the total bale, bales stored outside had lower digestibility and higher fiber than those stored inside. Burch and Balk (1978) reported losses in bermudagrass hay to be 3.1% and 10% after 5 1/2 months of storage inside and in the field, respectively.

Lechtenberg (1978) reported dry matter loss in grass hay to be 12.8, 9.3 and 8% for hay stored on the ground outside, on crushed rocks outside and inside, respectively, each for 5 months. The unweathered portions of the same bales were 76.8, 85.5 and 92% of the original weight, respectively. In vitro dry matter digestibility (IVDMD) of weathered grass was 16% lower than that of unweathered grass. For an alfalfa/grass mixture, weathering reduced IVDMD by 22% (Lechtenberg et al., 1979).

These literature data suggest that round bale losses for inside or covered storage are on the order of 5%, near that of square bales stored inside. Outside uncovered storage results in larger dry matter loss (10 to 20%) with the loss very dependent on the length of storage and the soil conditions. Typical dry matter loss during outdoor hay storage is about 14%. Data are insufficient to describe accurately any crude protein changes, but it is clear that digestibility decreases and fiber content increases during outside storage.

2.1.2.2 Losses during silage storage

Loss and quality change is more dramatic during ensiling than during hay storage. Dry matter loss during ensiling typically varies from 3 to 25% (McDonald, 1981). The loss can be attributed to respiration, fermentation and effluent production. Loss due to initial aerobic respiration should be less than 1% (Pitt, 1986) but depends on fill rate and compaction within the silo. Losses due to fermentation and effluent are on the order of 1 to 2% and 0 to 7% respectively, and effluent losses are negligible in wilted forages. The remainder of ensiling loss is due to aerobic respiration made possible by oxygen penetration into the forage material throughout the storage period (Pitt, 1986).

Dry matter lost during aerobic respiration is generally accepted to be non-structural carbohydrates; therefore, fiber and protein contents increase and energy content decreases as a result of aerobic respiration. If aerobic respiration results in a sufficient temperature rise, protein may bind to fiber and become unavailable to ruminant animals. Quality changes during fermentation include transformation of protein nitrogen into non-protein nitrogen, production of ammonia, breakdown of hemicellulose and change of soluble carbohydrates into organic acids (Pitt et al., 1985).

Researchers have taken numerous approaches to describe the changes that occur to ensiled forage. Some modelers have used simple expressions to relate dry matter loss to moisture content (McIsaac and Lovering, 1980; Lovering and McIsaac; 1981c). Empirical relationships have also been used to evaluate quality changes during ensiling (Holter, 1983; Lovering and McIsaac, 1981c). Pitt et al. (1985), Leibensperger and Pitt (1987) and Neal and Thornley (1983) have modeled the anaerobic phase of ensiling with detailed models based on a theoretical understanding of the processes. Pitt (1986) developed a model to predict dry matter losses caused by oxygen infiltration into the forage material. Effluent (seepage or runoff) loss has also been modeled (Daynard et al., 1978; Pitt and Parlange, 1987; Weisbach and Peters, 1983; Bastiman and Altman, 1985). Although these models have been useful in certain applications, a comprehensive model of the ensiling process has not been developed.

2.1.3 Feeding and feed allocation

A final process contributing to feed loss is that of feeding. During handling, hauling, unloading and conveying, some feed is lost before it reaches the animal. This loss should be negligible under good management; however, depending on the feeding system and other conditions, the loss of feed during the feeding process may be considerable. Kjelgaard (1979) modeled feeding loss to be 5%. Partenheimer and Knievel (1983) estimated feeding loss to be 4% for silages and 5% for hay. These values should be increased for round bales. Belyea et al. (1985) reported round bale feeding losses of approximately 13% for bales stored inside or covered and near 25% for bales stored outside uncovered. Because feeding does not alter the feed chemically and the loss consists of both leaf and stem components, the quality of fed material should not be affected by feeding loss. An exception might occur if animals selectively eat the ration. (e.g., if they selectively reject stems or cobs.)

An obvious yet often overlooked loss of feed is that of inefficient allocation and/or improper ration balancing. Although the feed is not lost in the sense that it is no longer useful, a loss due to improper feed use is an economic loss. The goal of optimal feed use has prompted application of linear programming (LP) to the area of animal nutrition (Black and Hlubik, 1980; Waller et al., 1980; Klein et al., 1986). Optimum feed use can be determined using LP by optimizing an objective function (e.g., maximize milk production, maximize return over feed cost, or minimize purchased feed cost) subject to various constraints imposed on the diets of the animals. Although the specific rules of ration formulation may vary among scientists, for any one set of ration constraints, there is only one optimal way to feed a given set of feeds. Feed use in any other manner could be considered a loss of feed value.

Applying LP makes determining least cost rations rather easy. A more complicated problem is that of feed allocation. That is, given certain feeds' availability and prices, what is the most economical method of dividing those feeds among the entire dairy herd? Milligan et al. (R.A. Milligan, 1988 personal communication) have worked on a model titled "Max Profit", which maximizes income over feed costs. Though this model goes beyond the boundaries of feed allocation and animal conversion of feedstuffs into milk, an important component of this model describes the animal.

2.2 Animal utilization/assessment of feed nutritional value

The purpose of this section is to review methods previously used to determine feed value. Feed value purely depends on animal utilization of feeds; thus, some discussion is directed toward this issue. This discussion is not a review of animal nutrition; rather it is a summary of current models of animal conversion of feedstuffs into milk, with some information on animal and feed interactions that affect this conversion.

It is common knowledge that forage quality is important. Relative importance, however, is unclear. For example, what difference does an increase of 1% in fiber content make in the value of alfalfa hay? Obviously the answer to such a question has a long list of qualifying statements related to the animal considered and the ration that it is fed. To answer such a question requires experimentation and an accurate model of animal conversion of feedstuffs into milk. The primary considerations for determining forage value are intake, fiber, energy and protein.

Numerous dairy models have been used in the past (Lovering and McIsaac, 1981a; Partenheimer and Knievel, 1983; Rotz et al., 1989a; Parke et al., 1978; Doyle et al., 1983; Savoie, 1982; Parsch, 1982; Waller et al., 1980; Street, 1974). The basis of most models has been a balance of energy and crude protein requirements for described animals within dry matter intake limitations. Energy, protein and intake represent the minimum criteria for ration formulation and have limitations because the intake and protein availability of forages of varying quality are different.

The "Max Profit" model (R.A Milligan, 1988 personal communication) balances rations for several animal groups at one time. Constraints include criteria for each ration as well as limits on feed use based on availability. Unlike most ration balancers, this model determines optimal milk production. Milk production during later stages of lactation depend on milk production during the first few weeks of lactation. Likewise, body weight change is not predetermined, although body weight lost during early lactation must be gained later in lactation.

The work of Conrad (1966) and Mertens (1987) illustrate the effect of diet characteristics on intake. The intake theory is based on intake limitation by either physical fill or physiological energy demand (see Waldo, 1986, for a thorough review of intake literature). The physical fill limitation implies that an animal has a limited capacity to ingest feed. The physiological energy demand limitation implies that an animal will not ingest more energy than it requires. Mertens (1987) presented a simple algebraic model for predicting intake based on the NDF and net energy (NE) content of the diet. Recognizing that not all NDF is equal, the Mertens model stands out from the other countless equations for predicting intake (as functions of milk production, body weight, body weight change and other animal factors) because it clearly separates the effects of animal characteristics on intake from those of feed characteristics.

Although the French fill unit system (Jarrige et al., 1986) uses different terminology than the Mertens model, the concept is nearly the same. An advantage of the French system is that it addresses substitution rates of concentrates for forages; however, a close look at their substitution rate model shows that the functional form can have no biological basis. The lack of data for estimating parameters in the French system renders it less useful for now.

Requirements of energy and protein for dairy animals are presented by NRC (1988). Equations predicting requirements as functions of body weight, body weight change, milk production, days pregnant and animal type are presented. The absorbed protein system (NRC 1985, 1988) has the advantage over a crude protein system (NRC, 1978) in that it addresses protein degradability. An absorbed protein system allows for issues concerning forage conservation methods that affect protein quality to be addressed in the context of animal conversion of feedstuffs into milk.

The fiber content of dairy cattle diets is inversely related to the energy content (Waldo and Jorgensen, 1981). However, a minimum amount of fiber of the proper quality and physical form is necessary in the diet of dairy cattle to obtain maximum intake, to maintain normal ruminal fermentation and milk fat percentage, and possibly to aid in the prevention of postcalving disorders (NRC, 1988). It is suggested that at least one-third of a dairy cow's diet should be long hay, chopped silage or other forage (NRC, 1988). NRC (1988) also suggests minimum concentrations of ADF and NDF. Perhaps the simplest and most comprehensive fiber "rule" is that 75% of the NDF in the diet should come from a forage source (Mertens, 1985b; NRC, 1988).

2.3 Forage system models

Several forage system models have been developed over the past several years as researchers have recognized the strengths of systems analysis. Van Keuren (1974) stated it well when he wrote: " ...system analysis provides the best procedure for integrating all of many variables involved in growing and getting forage to the animal..."

Forage system models have varied widely in their extent of detail, range of applicability and, as a result, usefulness. Two types of system models are available: simulation and linear programming. Simulation must be used to consider the stochastic effects of weather on harvest and growth of forages. Modeling of harvest interactions is also best suited to simulation models. Linear programming models are better suited to those studies concerning optimal allocation of resources.

This section discusses several forage system models. The emphasis is on model strengths, weaknesses and applications. It is interesting to follow the progression of forage system models to see the increases in detail, the number of processes considered and the range of applicability.

Von Bargen (1966) used probability theory to study hay harvest systems. By modeling the probability of rainfall and hay harvest rate, he was able to recommend sizes and combinations of implements necessary to achieve harvest of a given area. The Von Bargen study did not evaluate quality changes occurring during harvest nor the effects of late harvest on whole-farm economics. It related harvest to weather conditions, with a required drying period of two consecutive "open haying days". The probability of this occurrence was modeled only for Nebraska; therefore, the results were not widely applicable.

Millier and Rehkugler (1972) simulated the effect of harvest dates, harvesting rate and weather on the value of forage for dairy cows. With empirical functions for harvested yield as functions of time, they could model the effect of harvest rate and harvest date on harvested yield. Quality was modeled using digestible dry matter converted into total digestible nutrients (TDN). From harvested TDN they determined the number of cow-days of feeding. The model did not include effects of forage protein but was useful nevertheless. The model also did not include losses during harvest and storage. Oddly enough, the work -- done by agricultural engineers -- seemed to jump from the agronomist's viewpoint (harvested yield) to the animal scientist's viewpoint (value to the animal), skipping those processes better related to the engineering field (with the exception of harvest rate, which was considered). Millier and Rehkugler (1972) recognized that their simulation dealt with only a part of the overall milk production system. Their discussion gave results applicable for northeastern U.S. dairy farmers.

Street (1974) briefly discussed a dairy system model and an application of it. The details of the model were not described but the conceptual diagram included many of the animal and feed production factors that affect conversion of feedstuffs into milk. His system simulated harvest and feeding on a weekly basis. With the small time step, the seasonality of milk production, feed demand and feed supply were studied. The model contained considerable detail on the dairy herd and effects on demand for nutrients, but it contained little detail on the effects of weather, harvest procedures and storage on the whole farm system.

The goal of the work by Tseng and Mears (1975) was to outline a framework for connecting component models into a comprehensive model for forage production. Two approaches were discussed: a flow chart descriptive of the entire forage production system, and an LP model for determining the optimal land use plan and forage production scheme. The usefulness of the flow chart was to define the components needed within the model. The LP model maximized the total value of forage produced. Forage quality was maintained by implementing a constraint on the ratio of digestible protein to TDN. Constraints dealing with land and machine use and labor requirements were also implemented. Although it was presented as an optimizing model, its usefulness was limited because it did not consider losses and quality changes during harvest and storage and animal utilization of the produced feeds.

A model dealing with energy and time requirements for forage transport and handling was developed by Kjelgaard and Quade (1975). This model primarily dealt with harvest capacity and efficiency of various harvesting methods. This work was important because it modeled interactions among harvest operations. The model was far from a whole-farm systems model, but it addressed some issues of concern on dairy-forage farms.

Russell et al. (1977) used a simulation model to evaluate effects of harvest system capacity, number of cuts, crop area, harvest starting date and nutrient value on forage yield and quality for 30 harvest seasons. The harvested crop was direct-cut timothy silage. Crop yield and quality were expressed as empirical functions of days of growth (first cutting) or regrowth (subsequent cuttings). Because the crop was harvested as direct-cut silage, constraints on timing of harvest were easily met. Higher harvest system capacities resulted in more cuttings per year, but lower capacities resulted in higher yield per cutting. The crop value was determined by assigning values of $100/tonne protein and $6.93/tonne metabolizable energy. Adding the protein and energy values of the timothy silage gave the total crop value. This approach did not give any value to the fiber in the forage.

Bebernes and Danas (1978) presented a model of hay harvest that combined a standard machinery cost analysis with a hay quality analysis. This simulation model simulated dry down of alfalfa, rewetting from dew, dry matter content and quality (digestible dry matter, TDN, CP) during alfalfa growth, and dry matter losses due to machinery operations and rainfall. The computer model output included drying time requirements, an itemization of dry matter losses, labor requirements and hay nutrition and economic information. Bebernes and Danas (1978) assigned an economic value to the hay based on protein content; thus they were able to determine the economic value of machine- and rain-induced dry matter losses. The combination of machinery cost and hay quality analyses made it possible to compare various harvesting methods on a cost basis and show the effect of farm size on optimal harvest method.

The model of Parke et al. (1978) was the first simulation model to cover all bases between crop growth and animal utilization of the feedstuffs produced. Major components of the model included crop growth, crop harvest, crop storage and animal utilization. The simulation model was limited to one cutting of grass hay with subsequent growth used as pasture (value was assigned to pasture). Effects of weather on dry-down of the crop were modeled, and dry matter losses during harvest due to respiration, machine treatment and rainfall were estimated. Loss during storage was a function of moisture content. The animal model consisted of an LP ration balancer that formulated rations for a herd of lactating cows. The difference in feed cost between 100% purchased feeds vs. properly supplemented farm-produced feeds was used to determine the value of farm-produced feeds. Limitations of the model were: only grass was considered, only one cutting was allowed and data concerning losses were not available. As a first attempt at whole-system modeling, this work was quite useful. For the model to be improved, individual components needed more supporting data; ideally deterministic or mechanistic models of phemomena would be used.

Kjelgaard (1979) evaluated machine activities within the forage system. This study provided the type of information necessary to develop a whole-farm simulation. The emphasis was on energy and labor requirements for various harvest and feeding operations. Using assumptions about dry matter loss at various stages, specific efficiencies (e.g., energy units or hours of labor per unit of forage fed) were calculated for several operations. Although comparisons of harvest systems were made, the quality of the forage produced with various harvest systems was not considered.

Boyce et al. (1980) used the model of Parke et al. (1978) to evaluate the uses of an acid hay preservative, mechanical conditioning and barn drying. To compare systems, they used both the means and variations in hay value. The results showed variations from year to year were so high that studies of this nature carried out solely through experimentation would not likely give significant results because of added experimental error.

Lovering and McIsaac (1981b) presented a forage-dairy model containing five submodels: forage growth, harvest, storage, conversion of feeds to milk and milking of cows and disposal of manure. The forage crop considered was timothy, and all growth functions were developed for eastern Canadian conditions. The amount of dry matter and the CP content were simple functions of harvest date. The harvest model included the three harvest options of direct-cut silage, wilted silage and hay. A drying and rewetting model was a critical part when considering hay systems. Dry matter loss during hay storage was modeled as 10%, with nutrient concentrations unchanged. The model considered ten silo types; dry matter, energy and protein losses were functions of silo type. Feed to milk conversion was modeled by splitting a 365-day lactation cycle into three periods and balancing digestible protein and metabolizable energy requirements for each period. The barn model computed labor and energy requirements associated with milking and manure removal.

The Lovering and McIsaac (1981b) model is non-optimizing, like most large simulation models. The applications of this type of model are to rank management and technology options available to the farmer and to determine sensitivity of economic or biological changes. Limitations of the model were listed by the authors in two areas: decisions not addressable, and poorly represented physical or biological processes. Management issues unaddressable by their model include: choosing the forage crop, allocating land to various crops, incorporating pasture, raising heifers and replacing cows. Poorly represented processes include: feed to milk conversion, dry matter loss and quality changes and effect of barn type on milk production.

Lovering and McIsaac (1981a) used the same model to compare silo types and evaluate trade-offs between barn costs and labor requirements. The analyses were based on a 30-cow dairy in eastern Canada. They made specific recommendations on silo and barn type to maximize net return. McIsaac and Lovering (1982) also used the model to compare timothy harvested as hay, wilted silage or direct-cut silage.

Pitt (1982) developed a forage harvest model based on probability theory. By considering the probabilistic influence of weather on delay in cutting, drying time, leaching losses and respiration losses, the model determined the long-term average and variance of forage yield from various harvesting systems. By computing energy requirements as functions of harvester type, transport distance and storage type, the model was used to develop a criterion for evaluating forage harvest systems in terms of yield vs. energy use. Though it was a very powerful application of probability theory, the model had serious drawbacks in that it did not consider forage quality and feed conversion into milk. Improved models require simulation to represent more accurately losses and quality changes that occur during harvest and storage.

Doyle et al. (1983) developed a mathematical model that combined forage conservation techniques with grazing. The model included four sections: calculation of the herd feed requirements, assessment of the grass growth on grazed lands, determination of cut yields and integration of grazing and conservation. The model did not consider in any detail the harvest of conserved forages, quality change over time or loss due to conservation. This model is unique in considering pasture in combination with harvested forages.

Partenheimer and Knievel (1983) presented a model with the stated purpose "to illuminate some of the interrelationships between forage production practices and other parts of the farm business." The model was set up as a large LP matrix that included such processes as alfalfa production, corn production, changes in feed quality, loss of feeds and conversion of feeds into milk. As is common in most forage system models, the Partenheimer and Knievel model was not uniform in the degree of simplification of various parts of the system. Their model had considerable detail on forage quality and animal nutrient needs, but much less detail on farm growth, machinery complement and product markets. Use of the model was demonstrated by illustrating the effects of urea treatment of corn silage and the price of soybean meal on farm net return. The authors mentioned that limitations of the model were due to data deficiencies and the lack of strong component models.

McGechan (1986) did a major revision of the Parke et al. (1978) model. The structure was not changed, but the component models were improved using data collected during recent years. Improved component models included loss, swath drying and rewetting prediction and the animal conversion of feed to milk.

Table 2.1 summarizes the level of detail for several processes in the economic forage system models discussed. The level of detail is

Table 2.1 Level of detail in the component models of several economic forage system models.

Date	Developer(s)	Detail of Model*					
		Yield	Harvest	Storage	Animal util.	Losses and quality changes	Forage crop
1966	Von Bargen	0	2	0	0	0	alfalfa
1972	Millier and Rehkugler	2	0	0	0	1	alfalfa
1974	Street	0	1	1	2	1	grass
1975	Tseng and Mears	0	3	0	0	0	---
1975	Kjelgaard and Quade	0	3	0	0	0	---
1977	Russell et al.	2	2	1	2	1	timothy
1978	Bebernes and Danas	1	3	0	0	2	alfalfa
1978	Parke et al.	2	2	1	2	1	grass
1979	Kjelgaard	0	3	0	0	0	---
1981	Lovering and McIsaac	2	1	1	2	1	timothy
1982	Pitt	2	3	0	0	0	alfalfa
1982	Parsch and Savoie†	3	3	1	2	1	alfalfa
1983	Doyle et al.	2	0	0	2	0	grass
1983	Partenheimer and Knievel	1	1	1	2	2	alfalfa
1986	McGechan	2	3	2	2	2	grass

* 0: not included in the model; 1: very little detail; 2: moderate detail; 3: very detailed component model

† DAFOSYM.

indicated on a scale from 0 to 3. The models of Lovering and McIsaac (1981b) and the Parke et al. (1978) are the only system models discussed that simulate crop growth, harvest, storage and animal utilization and predict losses and quality changes throughout. The McGechan (1986) revisions to the Park et al. (1978) model increased the detail with which harvest, storage, losses and quality changes are modeled. His improvements have made the model more useful for the analyzing of grass forage systems.

The weak links in most forage system models are the loss relationships and the conversion of feed into milk. Lack of sufficient data has hindered development of accurate models of loss and quality change during forage harvest and storage. The biology of the ruminant is so complex and varying that accurate assessment of feed value is extremely dependent on feed quality and the individual animal. Simulation models can be based on average animals, but this basis must be considered and put into perspective when analyzing results for a complete dairy herd.

2.4 DAFOSYM

DAFOSYM is a dairy forage system model begun in the late 1970s at Michigan State University (Parsch, 1982; Savoie, 1982). DAFOSYM was used for this study because it was the only comprehensive forage system model available that was tailored to the harvest, storage and feeding of alfalfa. As noted in Table 2.1, it modeled the growth and harvest of alfalfa in considerable detail, though the level of detail with which losses, storage and animal utilization were modeled was relatively low.

Several changes had been made to DAFOSYM before this work began.

Rotz (1985) modified the field drying model. DAFOSYM was also modified to accept corn yield data generated by the CERES-MAIZE model of Jones and Kiniry (1986). Other changes were made to the harvest components of the model. e.g., harvest of alfalfa, originally performed in sets of two plots per day, was changed to allow harvest of three plots per day. For DAFOSYM to be used to evaluate value of alfalfa losses, the loss and quality components as well as the animal model needed to be strengthened because these components were relatively weak (objectives 1 and 2, Section 1.2).

DAFOSYM was written as a mainframe computer model that simulated alfalfa growth, corn silage and corn grain yields, harvest, storage, feeding and ration formulation for a dairy herd (Parsch, 1982; Savoie, 1982; Savoie et al., 1985). DAFOSYM was developed as a tool for evaluating alternative technologies and management strategies on a dairy farm. The model has been restructured for use on microcomputers to make it more versatile and usable.

Figure 2.1 illustrates the structure and flow of DAFOSYM. As noted in Table 2.1, it models the growth and harvest of alfalfa in considerable detail. Although several changes had been made to the original model, the components that consider crop storage, losses and quality changes and animal utilization had remained unchanged. Crop growth and harvest depend on the weather, which is site specific and is entered via a data file. The model is structured to simulate as many years (replications, not sequential years) as desired, if weather data are available. Inputs describing the farm and available machinery are also entered via a data file and can be easily changed. DAFOSYM best describes dairy operations in the Great Lakes states.

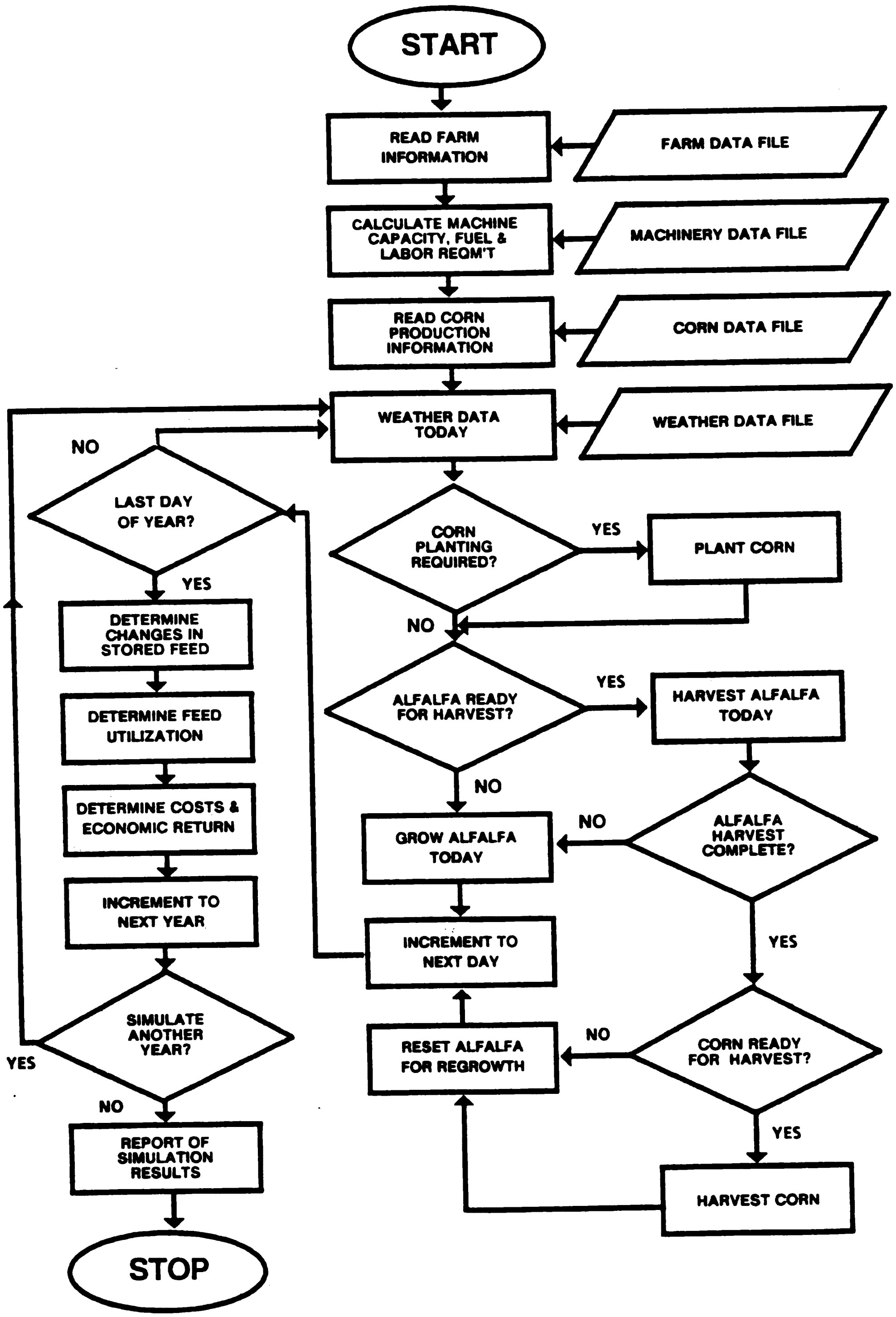

Figure 2.1 Flow chart of DAFOSYM.

Past uses of DAFOSYM include an analysis of the effects of maturity at the time of mowing (Savoie et al., 1985; Rotz et al., 1989a), a comparison of three vs. four alfalfa cuttings (Savoie et al., 1985), a comparison of conservation systems (Savoie et al., 1985; Savoie and Marcoux, 1985), a study of the effect of field curing delays and crop value (Savoie, et al., 1985), a study of the economic returns from chemical conditioning (Rotz, 1985; Rotz et al., 1989a) and an analysis of the effects of harvester size and silo type on farm net return (Rotz et al., 1989b). The most recent analyses (Rotz et al. 1989a, 1989b) incorporated improved component models. Changes to DAFOSYM are currently being documented (Rotz, 1989).

Because the present work includes modifications to the storage and feed conversion components, a review of the original storage and feed conversion submodels is in order. The storage of alfalfa hay or silage was assumed to cause dry matter loss only; i.e., quality characteristics remained unchanged. Research completed since 1982, however, indicates that quality changes do occur during storage. Dry matter loss during storage (in the original model) depended on storage type. These simple quantity adjustment factors did not adequately reflect the real world phenomena and so were replaced with the more detailed models developed in this dissertation.

Two feed to milk conversion models (sometimes referred to as the animal or cow models) were developed with the original DAFOSYM. The Savoie (1982) version was a simple ration balancer based on nutrient requirements (NRC, 1978) and feed quality (TDN and CP). Because nutrient requirements were based on net energy, TDN was converted to net energy for lactation (NE_l).

Farm-produced alfalfa, high moisture ear corn and corn silage were allocated so as to be depleted at the same time. The rations were balanced for six groups of dairy animals (four lactation levels, dry cows and heifers) using the mixed feed of alfalfa, high moisture corn and corn silage. If the mixture could not provide the minimum energy concentration, corn grain was added to the diet until the energy concentration was suitable. Similarly, if the crude protein concentration was low, soybean meal was added to the diet. When the supply of farm-produced feeds was depleted, purchased medium quality hay and corn grain became the alternative feedstuffs.

Although the Savoie (1982) animal model followed NRC (1978) guidelines correctly, it had serious flaws. Maximum dry matter intake was a fixed percentage of body weight, even though intake varies throughout the lactation cycle and is affected by forage quality (NRC, 1988). The original model did not allow milk production to vary with feed quality. Because corn grain and soybean meal could be continually added to the diet, it was possible for the lactating cow rations to contain only corn grain and soybean meal. Clearly this is unrealistic because forage fiber is necessary for proper rumen function (NRC, 1988). The user was required to input the fraction of the lactating cows that corresponded to the four production levels. However, all cows were assumed to be in late lactation, of the same weight and producing milk containing 3.5% fat. No allowance was made for the cyclical nature of requirements through the lactation cycle or for the growth of primiparous cows. The use of soybean meal as the only protein supplement in diets containing large amounts of silages can also be an unfair assessment of reality.

It should be recognized that these flaws may not affect certain forage system analyses, particularly those that evaluate efficiency of harvest systems. However, when results are sensitive to the animal model, as were the results of Savoie and Marcoux (1985), these flaws can have a major impact on the analysis. For example, the Savoie and Marcoux (1985) study was so sensitive to intake prediction for high producing herds that a complete shift of preference from hay to silage resulted when slight changes were made in intake parameters. To obtain a more generic model suitable for addressing a wide range of issues, the factors mentioned above must be considered.

The animal model used by Parsch (1982) was that of Waller et al. (1980). Though the structure of the Parsch animal model was the current "state of the art," it was not incorporated into DAFOSYM because of difficulties in linking forage quality to the ration balancer and subsequently following feed disappearance. The Parsch (1982) animal model assigned prebalanced rations from which feed disappearance was predicted. This approach negated one of the abilities of DAFOSYM -- the prediction of feed quality as it reaches the animal.

3. HARVEST LOSS MODELS

The purpose of this chapter is to present improved models of alfalfa losses that occur during field curing and harvest. The losses can be attributed to plant respiration, rain and mechanical treatment.

3.1 Respiration

Plant cells of freshly cut forages remain alive and continue to respire. During respiration, carbohydrate material in the plant is oxidized into water and carbon dioxide. Dry matter loss from respiration is estimated using the model of Wood and Parker (1971) in combination with assumptions concerning the change in moisture over time. The following equation relates rate of respiration loss (RLR) to moisture content (m) and temperature (T):

$$RLR = 0.000674(m-0.273)e^{0.069T} \qquad [3.1]$$

(Wood and Parker, 1971). Equation [3.1] is applicable for temperatures between 5 and 25°C; the respiration loss can occur only when the crop moisture exceeds 27.3%[1]. To predict total respiration loss, equation [3.1] is integrated over time with appropriate time courses of moisture and temperature.

For each day simulated by DAFOSYM, a minimum and maximum temperature are required inputs from a data file. Rather than model the temperature change throughout the day, it uses average temperatures for

1 All moistures are expressed as wet basis unless otherwise noted.

daytime and nighttime. Average daytime (ATD) and average nighttime (ATN) temperatures are computed as:

$$ATD = (T_{minimum} + 2T_{maximum})/3 \qquad [3.2]$$

$$ATN = (2T_{minimum} + T_{maximum})/3 \qquad [3.3]$$

The moisture of the alfalfa is assumed to follow the pattern shown in Figure 3.1. The moisture contents at daybreak (m_1 and m_3) and dusk (m_2) are computed by the drying and rewetting models of DAFOSYM. Since the alfalfa is drying exponentially, a drying constant (DC) for the daytime hours can be determined:

$$DC = \ln(m_2/m_1)/HDL \qquad [3.4]$$

Using this drying constant, the moisture over time (Figure 3.1) during the daytime hours is:

$$m(t) = m_1 \cdot e^{-DC \cdot t} \qquad [3.5]$$

To get respiration loss during the daytime hours, equation [3.1] is integrated with [3.5] as the relationship of moisture over time:

$$REL_{day} = \int_{t=0}^{t_1} 0.000674[m_1\, e^{-DC\ t} - 0.273]e^{0.069ATD}\, dt \qquad [3.6]$$

The upper limit (t_1) can range from 0 to the number of daylight hours (HDL) until the moisture content of the crop drops to 27.3% within that day (Figure 3.1).

Assuming that overnight rewetting occurs at a constant rate, the moisture rises linearly during the nighttime hours (Figure 3.1):

$$m(t) = m_2 + (m_3-m_2)(t-HDL)/(24-HDL) \qquad [3.7]$$

To calculate respiration loss during the nighttime hours, equation [3.1] is integrated with [3.7] as the relationship of moisture over time:

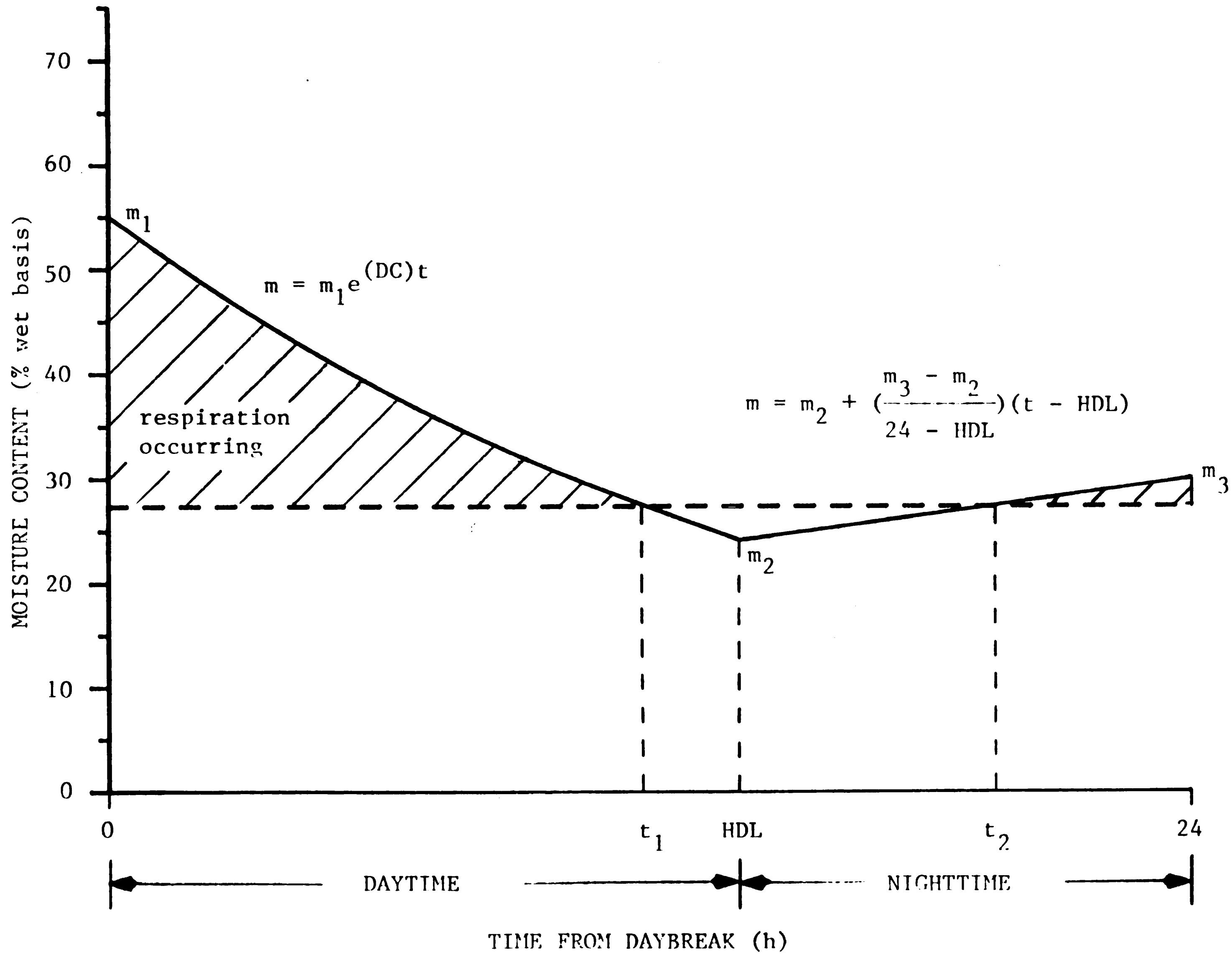

Figure 3.1 Model for moisture variation throughout the day for determination of respiration loss.

$$REL_{night} = \int_{t=t_2}^{24} 0.000674[m_2+(m_3-m_2)(t-HDL)/(24-HDL)-0.273] e^{0.069ATN}\, dt \quad [3.8]$$

The lower limit, t_2 can range from HDL to 24 hours depending, on the time the crop moisture exceeds 27.3% (Figure 3.1).

The total daily respiration loss is the combination of daytime and nighttime respiration loss and is typically 1 to 3% per day. Dry matter lost during respiration is non-protein, non-fiber material (Rotz and Abrams, 1988); therefore, the crude protein (CP) and neutral detergent fiber (NDF) concentrations increase because of respiration loss:

$$CP_f = CP_i/[1-(REL_{day}+REL_{night})] \quad [3.9]$$

$$NDF_f = NDF_i/[1-(REL_{day}+REL_{night})] \quad [3.10]$$

The effects of respiration are the same for both leaf and stem material.

3.2 Rain

The rain loss model is as presented by Rotz et al. (1989a). Total dry matter loss consists of leaf shatter and leaching losses. Leaf shatter loss (RNLL) is proportional to the amount of rainfall (RAIN) with a maximum loss of 15% of total plant dry matter:

$$RNLL = 0.0037RAIN \le 0.15 \quad [3.11]$$

Leaf shatter causes a reduction in overall quality because leaves are of higher quality than stems. Some dry matter is also lost from both leaves and stems because of the dissolving of plant constituents. The leaching loss (RNL) consists of dry matter washed from the plant and is an exponential function of the amount of rainfall:

$$RNL = (1-NDF)(1-e^{-0.011RAIN}) \quad [3.12]$$

Leached material consists of totally digestible, non-NDF components.

Crude protein loss is 20% greater than the loss of other dry matter:

$$NDF_f = NDF_i/(1-RNL) \qquad [3.13]$$

$$CP_f = CP_i[1-1.2RNL]/(1-RNL) \qquad [3.14]$$

Leaching loss is assumed to affect leaves and stems similarly.

Because the data used to develop relationships [3.11] through [3.14] were not adjusted for respiration loss, loss predicted using these relationships includes the respiration loss that occurs following rain. To avoid double accounting of respiration loss, the respiration rate is subsequently set to zero once rain has occurred.

Predicted quality changes based on these relationships correspond well with the data of Collins (1982, 1983, 1985), Fonnesbeck et al. (1982) and Rotz and Abrams (1988).

3.3 Machinery

Machinery operations do not change the chemical composition of the crop; quality is affected only by mechanical losses when the leaf to stem ratio changes. Because leaves and stems have different quality characteristics, machinery-induced losses are subdivided into leaf losses and stem losses.

Let the total loss for a mechanical treatment be identified as TL. If l is the leaf fraction of the lost material and s is the stem fraction, the fractions of leaf and stem mass lost during the treatment are:

$$LL = TL \cdot l/L \qquad [3.15]$$

$$SL = TL \cdot s/S \qquad [3.16]$$

where L and S are the fractions of the crop that are leaves and stems before the treatment, respectively. The leaf and stem fractions are set initially by the alfalfa growth model and are updated after each mechanical treatment. To reduce the number of required variables, equation [3.16] is rewritten as:

$$SL = TL(1-l)/(1-L) \qquad [3.17]$$

since

$$l + s = 1 \qquad [3.18]$$

and

$$L + S = 1 \qquad [3.19]$$

Rotz et al. (1989a) reviewed mower and mower-conditioner loss data and concluded that material lost during mowing and conditioning is approximately 75% leaves (l=0.75) and 25% stems (s=0.25). Total cutterbar mower loss is about 1% (TL = 0.01). The data of Koegel et al. (1985) show that a disk mower causes approximately 2% more total loss than a cutterbar mower; this results in a total cutting loss of 3%.

It is desirable to separate the effects of the conditioning treatment from those of the cutting treatment. The model of Rotz et al. (1989a) indicated that fluted-roll conditioning adds an additional 1% total loss. Flail conditioning is a more severe treatment than roll conditioning. Koegel et al. (1985) reported that flail conditioning loss is approximately 1% higher than roll conditioning loss; thus flail conditioning causes 2% loss.

Combined mowing and conditioning losses range from 1% (cutterbar mower) to 5% (disk mower with flail conditioner), depending on the cutting/conditioning combination. These mowing and conditioning loss relationships, summarized in Table 3.1, agree favorably with the models of Pitt (1982) and Dale et al. (1978).

Table 3.1 Models of machinery-induced losses*.

Machine treatment	Total loss (fraction of DM)	Fraction of loss material that is leaves
Mower	0.01 to 0.03	0.75
Conditioner	0.01 to 0.02	0.75
Rake	$0.096Y^{-2.42}m^{-2}$	$1-2.87m^{2}$
Tedder	$(0.096m^{-2}-0.277)Y^{-2.42}$	1.00
Baler or chopper pickup	2.0	0.40
Rectangular baler chamber	$0.057e^{-5.4m}$	0.80
Bale ejector	0.025L	1.00
Round (fixed chamber) baler chamber	$0.228e^{-5.4m}$	0.80
Round (variable chamber) baler chamber	$0.080e^{-5.4m}$	0.80
Stack wagon chamber	$0.313e^{-5.4m}$	0.80
Chopper spout	$4.3e^{-9m}$	0.75

* m = moisture content, decimal wet basis
Y = yield, T DM/ha
L = fraction of plant that is leaves

Rotz and Abrams (1988) published the following relationship for raking loss (RL) as a function of crop yield (Y):

$$RL = 0.6026Y^{-2.42} \qquad [3.20]$$

Equation [3.20] pertains to alfalfa raked at 35 to 45% moisture at a raking speed of 5.1 km/h. Raking loss has been modeled in the past as a function of moisture content (Dale et al., 1978; Savoie, 1982). These previous moisture functions indicate that raking loss is approximately inversely related to the square of the moisture content. To adjust the Rotz and Abrams (1988) relationship for moisture content effects, the inverse relationship (m^{-2}) was incorporated into equation [3.20]. The leading coefficient (0.6026) was changed so that the predicted loss at a moisture content of 40% was unchanged; i.e., raking loss evaluated for $m=0.40$ is given by equation [3.20]. The improved raking model is (Figure 3.2):

$$RL = 0.096Y^{-2.42}m^{-2} \qquad [3.21]$$

Note that if raking is the third mechanical operation, TL = RL.

It is commonly accepted that raking affects leaves more than stems. The raking loss model of Dale et al. (1978) assumes raking loss material is 100% leaves, but the data of Savoie (1982) showed that nearly half of the raking loss material is stems. The original DAFOSYM fixed the stem loss due to raking as 2% of stem mass, with the leaf loss varying with moisture content at raking. For the improved raking model, stem loss is a function of yield, while leaf loss is a function of yield and moisture content.

Rotz and Abrams (1988) reported raking loss material to have a crude protein content of approximately 20.1%. If the leaves and stems have crude protein contents of 28 and 11% (Buxton et al., 1985), respectively, the raking loss is on the average, 46% stems and 54% leaves. This is in agreement with experimental data published by Savoie (1982) which indicated that the material lost during raking contained 54% leaves on the average. For a moisture content of 40%, this implies that the stem loss due to raking (SLR) as a fraction of dry matter is:

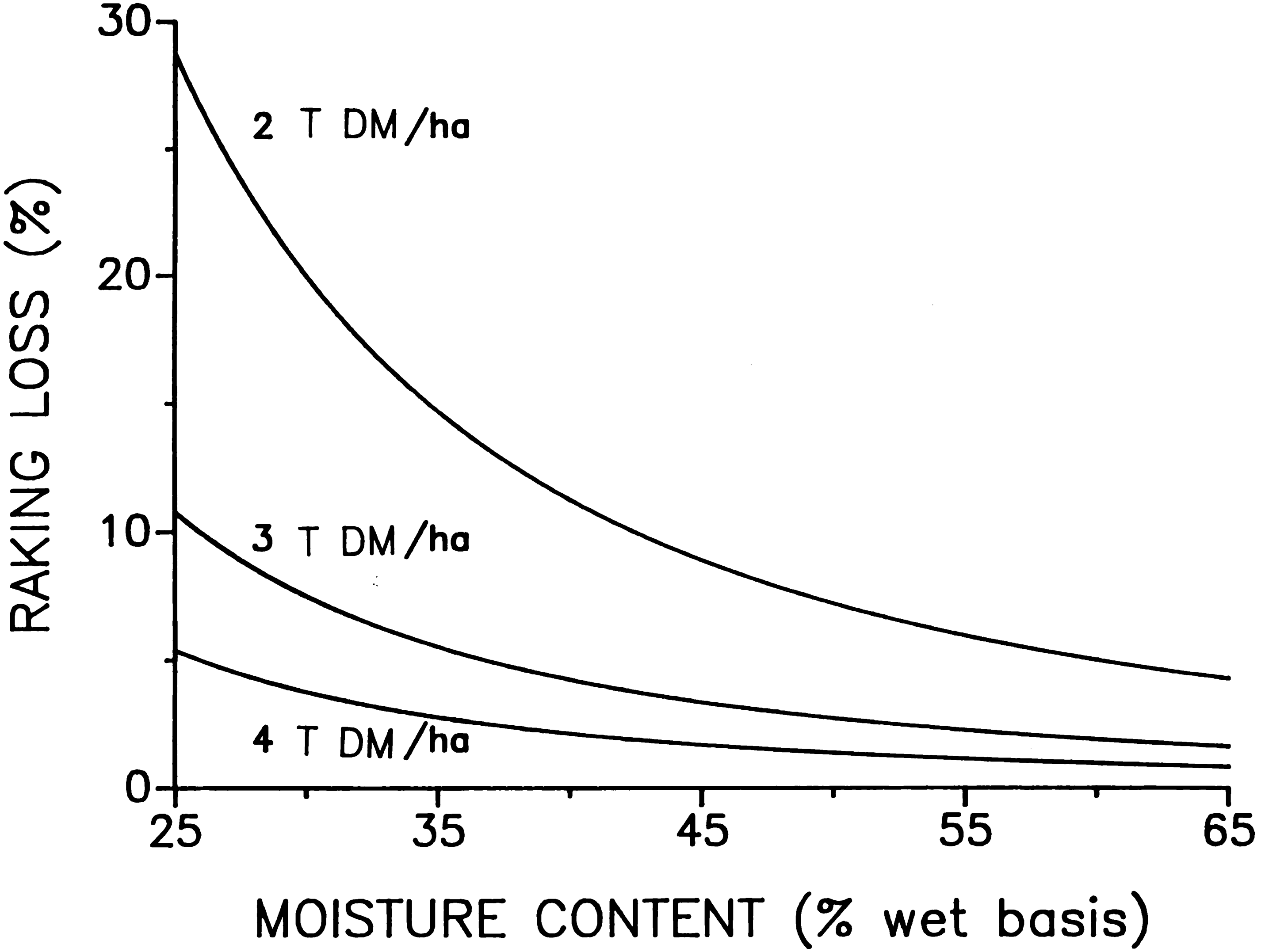

Figure 3.2 Raking loss as affected by yield and moisture content.

$$SLR = 0.277Y^{-2.42} \quad [3.22]$$

Stem loss is limited to 50% of current stem mass. Stem loss is subtracted from total raking loss to determine leaf loss due to raking (LLR) as a fraction of dry matter:

$$LLR = (0.096m^{-2}-0.277)Y^{-2.42} \quad [3.23]$$

For consistency, the leaf and stem losses during raking are expressed as a fraction of the leaf and stem mass, respectively:

$$LL_{raking} = (0.096m^{-2}-0.277)Y^{-2.42}/L \quad [3.24]$$

$$SL_{raking} = 0.277Y^{-2.42}/S \quad [3.25]$$

The fraction of loss material that is leaves is a function of moisture content only:

$$l_{raking} = (0.096m^{-2} - 0.277)/(0.096m^{-2})$$
$$= 1 - 2.87m^{2} \quad [3.26]$$

A tedder spreads alfalfa into a swath for faster drying. Measured dry matter losses due to tedding were between 1 and 2% (Savoie et al., 1981). Tedding is generally applied at high moisture contents. Tedding losses at very low moisture contents have not been published. Parke et al. (1978) modeled tedding loss for grasses as a decreasing function of moisture content. Tedding loss is assumed to be 100% leaves (l=1.0) and, for lack of better information, tedding leaf loss is assumed to be equal to raking leaf loss (equation [3.24]).

Losses during baling are separated into pick-up and chamber losses. Models for predicting each of these losses are based on published data as well as on unpublished experimental data collected at Michigan State University.

Baler pick-up and chamber losses were measured over four alfalfa cuttings where the moisture content at baling, yield and feed rate into the baler were varied (Table 3.2). Pick-up loss samples were collected by manually picking up all the fresh material left by the baler pick-up mechanism in a 1/2 m^2 area. Chamber loss was accumulated over a measured length of windrow on tarpaulins attached under the baler chamber. All losses were converted to a percentage of yield based on a yield estimate taken from a 3 meter length of swath.

The experimental data (Table 3.2) do not give a significant relationship between pick-up loss and moisture content at baling, yield and/or feed rate. The mean of 1.6% pick-up loss is slightly lower than published values of 1.8% (Rotz and Abrams, 1988), 1.8 to 2.8% (Straub et al., 1986) and 2.0 to 2.4% (Koegel et al., 1985). Friesen (1977) reported typical pick-up losses of 0.5 to 1%, with the loss reaching 5% under poor conditions. Based on all data, a pick-up loss of 2.0% of the available crop was selected (Figure 3.3).

Rotz and Abrams (1988) reported the crude protein content of the pick-up loss to be 18.4%. If the leaves and stems were 28 and 11% crude protein, respectively, as is typical, the pick-up loss was approximately 40% leaves (l=0.40) and 60% stems (s=0.60).

Baler chamber loss (BCL) depends on the baling moisture content because dry leaves are more easily shattered than moist leaves. The data of Table 3.2 give the following relationship:

$$BCL = 0.038e^{-5.4m} \qquad [3.27]$$

$$(r^2 = 0.42)$$

For the average moisture of 19%, the predicted chamber loss is 1.4%. Published values of chamber loss for rectangular-type balers are 1.1% at 20% moisture (Rotz and Abrams, 1988), 4.8% at 29% moisture and 7.3% at 21% moisture (Straub et al., 1986), 2.8% at 18% moisture (Koegel, et

Table 3.2 Baler pick-up and chamber loss (small rectangular bales).

Cutting	Moisture at baling (% w.b.)	Yield (T DM/ha)	Feed rate (kg DM/min)	Pickup loss (%)	Chamber loss (%)
1	25.0	4.83	67.8	1.9	1.0
1	26.0	4.00	114.2	4.7	1.3
1	23.0	5.18	73.5	3.2	1.5
1	19.0	4.88	135.7	3.5	0.8
2	17.4	4.49	60.3	2.5	2.6
2	14.8	5.16	133.4	1.6	1.7
2	13.8	5.02	67.3	1.6	2.7
2	11.0	5.53	146.6	1.3	2.3
2	6.4	4.82	64.7	3.3	3.6
2	7.1	4.36	112.5	1.7	3.5
3	17.1	4.01	44.6	0.4	1.1
3	16.5	3.41	71.4	0.9	0.9
3	12.6	2.99	33.4	1.0	1.6
3	13.6	4.81	99.7	0.6	1.2
3	21.6	3.40	38.7	0.8	0.6
3	20.8	2.63	54.5	1.1	0.5
4	30.4	4.65	51.0	0.7	1.0
4	26.1	5.77	118.0	0.5	0.8
4	23.3	4.85	53.8	0.5	1.3
4	23.8	3.92	80.8	0.3	1.3
4	21.1	3.05	42.7	1.4	1.9
4	19.3	3.23	87.5	1.3	1.8
MEANS	18.6	4.32	79.6	1.6	1.6

al., 1985) and 2 to 3% (Friesen, 1977). Equation [3.27] gives a relationship between moisture content and chamber loss, but other published data indicate that chamber losses are higher than equation [3.27] estimates. Increasing the loss as predicted by [3.27] by 50% provides better agreement with published values. Total chamber loss for rectangular-type balers is thus modeled by (Figure 3.3):

$$BCL = 0.057e^{-5.4m} \qquad [3.28]$$

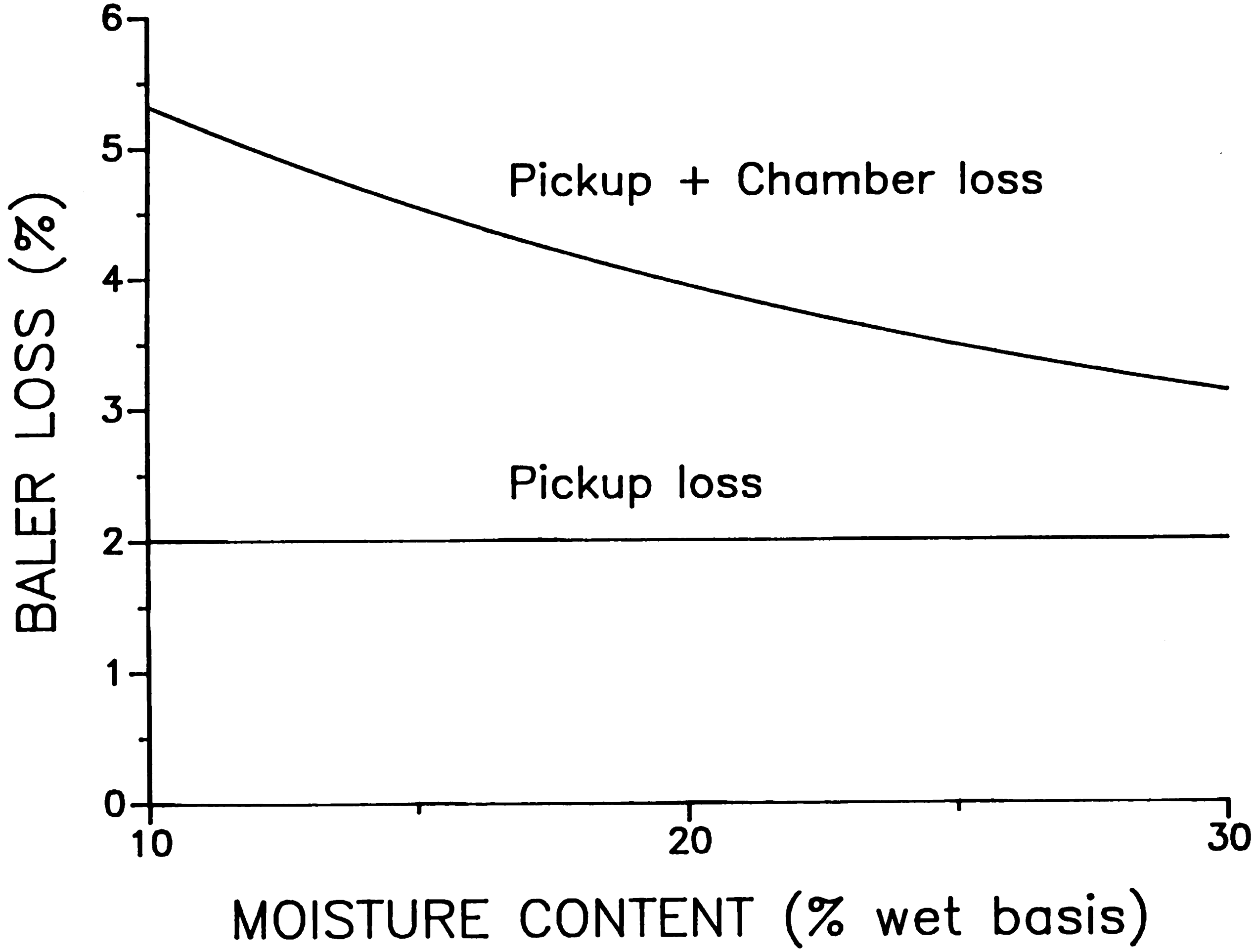

Figure 3.3 Baler loss as affected by moisture content.

Rotz and Abrams (1988) reported the crude protein content of chamber loss to be 24.2%. The procedure used to separate pick-up loss into stem and leaf fractions shows that chamber loss is approximately 80% leaves (l=0.80) and 20% stems (s=0.20).

Total loss during the baling operations consists of 2% attributable to the pick-up mechanism and a variable amount (equation [3.28]) attributable to chamber loss (Figure 3.3). The total loss ranges from approximately 6% at 12% moisture to 3% at 30% moisture. These figures differ slightly with the models of Kjelgaard (1979) (3% loss) and Pitt (1982) (4% loss, 2% loss at 30% moisture).

A rectangular baler with a bale ejector has higher leaf loss than one without a bale ejector; thus, leaf loss is increased 2.5% if a bale ejector is used (Savoie, 1982).

Less loss data is available for round balers than for rectangular balers. The data of Koegel et al. (1985) show pick-up loss is the same for round balers as for rectangular balers and chamber loss is higher for round balers. Based on the data of Koegel et al. (1985), chamber loss for round balers with variable chambers (belts) is estimated to be 1.4 times that of rectangular balers. For fixed chamber round balers, chamber loss is four times greater.

As mentioned in Chapter 2, chopping losses are highly operator dependent. However, a model is required that predicts typical chopper losses. Savoie (1982) modeled chopper losses as 5% for wilted silage and 2% for direct-cut silage (Kjelgaard, 1979). Straub et al. (1986) measured chopper losses to be from 1.4 to 2.5%. Chopper loss is attributed to the pick-up mechanism and the spout. Although chopper pick-up mechanisms usually have more teeth than baler pick-up mechanisms, chopper field speed is typically higher. It seems reasonable that pick-up losses for balers and choppers are similar. In light of the Straub et al. (1986) data and the Kjelgaard (1979) value, the spout loss from a chopper probably ranges from 0.5 to 5% of the crop. It is clear that drier alfalfa is more susceptible to chopper loss than wet alfalfa. Chopper spout loss (CSL) is assumed to be an exponentially decreasing function of moisture content (Figure 3.4):

$$CSL = 4.3e^{-9m} \qquad [3.29]$$

Equation [3.39] predicts loss values that cover the range reported by Straub et al. (1986). Chopper spout loss is assumed to contain 75% leaves (l=0.75) and 25% stems (s=0.25) (Savoie, 1982).

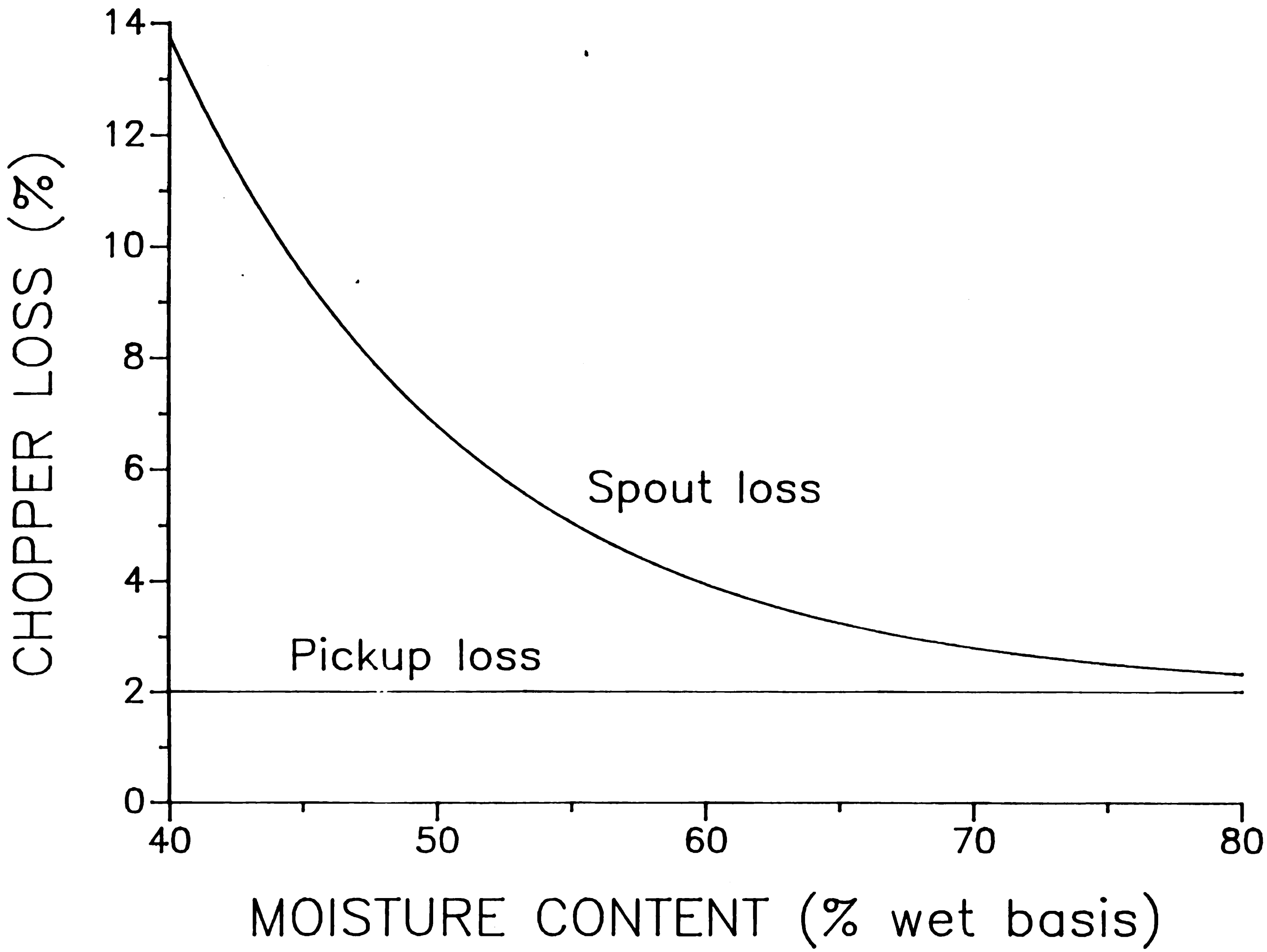

Figure 3.4 Chopper loss as affected by moisture content.

4. STORAGE AND FEEDING MODELS

Forages are stored either as hay or as silage. The processes that occur during these two storage methods differ greatly and so are modeled differently. This chapter discusses incorporation of a hay storage model into DAFOSYM and develops and evaluates a comprehensive model of silo storage. Quantity loss during feeding is also modeled. (FORTRAN code for the storage model is included as Appendix A.)

4.1 Inside hay storage

The model of indoor hay storage incorporated in subroutine HAY was developed by the author (Buckmaster, 1986; Buckmaster et al., 1988). Dry matter loss and quality changes are predicted for pure, untreated alfalfa hay. Several assumptions about bale density and stack size were made to make the model more computer efficient. Based on thermodynamic theory, the model for dry matter loss in alfalfa hay is:

$$L = \frac{86.4Q + 2433[m_i - m_f(1-m_i)/(1-m_f)]}{[1-m_i]\,[14206-2433m_f/(1-m_f)]} \qquad [4.1]$$

To use equation [4.1], initial and final moisture contents and the amount of heat generated during storage must be known. Within DAFOSYM, the moisture content of the hay entering storage is determined by the harvest model. Hay is stored for enough time to allow complete drying; therefore, a final moisture content of 0.12 is used. The total respiration heat generated during storage is:

$$Q = 3289(m_i)^{2.18}(\rho_i)^{0.50} + 3779(m_i)^{1.23}(\rho_i)^{0.94} \qquad [4.2]$$

Estimates of the initial density of rectangularly baled hay as a function of initial moisture content are based on the data of Buckmaster (1986):

$$\rho_i = 0.100 + 0.44m_i \quad [4.3]$$

Dry matter loss is estimated using equation [4.1] with the simulated initial moisture content (from harvest), a final moisture content of 0.12 and the total respiration heat generation estimated using equations [4.2] and [4.3].

Quality characteristics of concern within DAFOSYM are fiber and protein. Buckmaster et al. (1988) presented an assessment of acid detergent fiber changes during storage. The data of Rotz and Abrams (1988) suggest a similar relationship for neutral detergent fiber. The change in NDF during storage is predicted by:

$$NDF_f = NDF_i/(1-L) \quad [4.4]$$

Three protein characteristics are important in the animal model of DAFOSYM: crude protein content, acid detergent insoluble protein content, and protein degradability. Changes in crude and acid detergent insoluble protein (ADIP) contents during storage are modeled as in Buckmaster et al. (1988):

$$CP_f = CP_i(1-0.4L)/(1-L) \quad [4.5]$$

$$ADIP_f = (ADIP_i + 0.0000373HDD)/(1-L) \quad [4.6]$$

where $ADIP_i$ is equal to 0.8% of dry matter (i.e., $ADIP_i$ = 0.008). Simulation of heating in degree-days (HDD) for numerous stacks through prediction of temperature over time is extremely time consuming. Rather than performing these calculations repetitiously, time/temperature relationships were simulated for stacks of 1,000 bales for initial moisture contents ranging from 12 to 25%. Corresponding densities were computed using equation [4.3]. Simulated data for heating in degree-days were empirically modeled as a function of the initial moisture content of the hay:

$$\begin{aligned} HDD &= 48460(m_i-0.12)^{1.836} & \text{if } m_i > 0.12 \\ &= 0 & \text{if } m_i \leq 0.12 \\ & \qquad (r^2 = 1.000) & \end{aligned} \qquad [4.7]$$

Acid detergent insoluble protein content is predicted using equations [4.6] and [4.7]. Caution should be used when applying these relationships. Equation [4.6] is based on data ranging from 0 to 354 HDD. Extrapolation beyond 400 HDD (m_i of approximately 20% according to equation [4.7]) can be unrealistic and should be avoided. This caution does not pose a problem in DAFOSYM, however, because moisture content at baling should not exceed 20% without the use of a chemical preservative.

For use in the animal model, the acid detergent insoluble protein has to be expressed as a fraction of crude protein. That is:

$$ADIPCP_f = ADIP_f/CP_f \qquad [4.8]$$

Degradability of alfalfa hay is assumed to be 70% and is discussed further in Chapter 5.

4.2 Outside hay storage

Based on the published data reviewed in Chapter 2, dry matter loss during outside storage of round hay bales is approximately 5% (L=0.05) if the bales are covered and 14% (L=0.14) if uncovered. Published data indicate that fiber concentration increases during outside storage. Assuming that (as in indoor storage) fiber is not lost, the fiber content as a fraction of dry matter increases with the loss of non-fiber material:

$$NDF_f = NDF_i/(1-L) \qquad [4.4]$$

In published data, protein changes during outside hay storage did not show any significant trends (Anderson et al., 1981; Currence et al., 1976). It is reasonable to expect some protein loss due to leaching by rain. This, in addition to the slight protein loss that occurs during indoor storage, implies that the loss of crude protein as a fraction of crude protein would be approximately the same as total dry matter loss as a fraction of dry matter. Thus, the crude protein content during outside storage remains unchanged:

$$CP_f = CP_i \qquad [4.9]$$

Because ADIP is related to heat development (Buckmaster et al., 1988), heat development in round bales stored outside must be modeled. An attempt to model heating in round bales stored outside is futile with available data because factors such as wind conditions, rainfall occurrence, ambient temperature and bale condition are variable. Considering the size of round bales, it is reasonable to assume that heat generated within the bale is dissipated before the bale temperatures reach 35^{o}C for a significant length of time as long as bale moisture is relatively low (25% moisture or less). For this reason, the ADIP content of hay stored outside is considered to remain constant:

$$ADIP_f = ADIP_i \qquad [4.10]$$

4.3 Silo storage

DAFOSYM offers several silage structure options and allows up to four alfalfa and two corn silage structures. The silos can be bunker, top-unloaded tower or bottom-unloaded tower silos. Two of the four alfalfa silos can be designated for low quality forage; the other two, for high quality forage. Associated with each silo are its dimensions, capacity and initial cost and the permeability of the wall or cover.

It is assumed that structures containing similar quality forage are emptied over a 12-month period and that only one structure of each quality is open at a time. Because it is common for alfalfa silage silos to be refilled within one year, the silo capacity is increased for later cuttings if some alfalfa silage was harvested during an earlier cutting. It is assumed that there are 30 days between cuttings; therefore, a silo filled with alfalfa silage during first cutting can hold an additional 1/12 of its capacity for each of the following cuttings. Because of the nature of filling and unloading a bunker silo, refilling of this type of structure is not permitted.

The literature contains several models dealing with silage storage (Pitt, 1986; Pitt et al., 1985; Neal and Thornley, 1983; Holter, 1983; Lovering and McIsaac, 1981c; Leibensperger and Pitt, 1987), but an integrated model that simulates the entire ensiling process --including filling, fermentation and feedout -- is not available. The following sections contain the development and evaluation of such a model.

4.3.1 Model development

4.3.1.1 Overall model structure

The ensiling process can be divided into four phases. The first phase is before sealing (preseal). A silo is filled by plots (in DAFOSYM one plot is the material harvested in three hours). The first phase considers changes caused by aerobic respiration that occurs from the time a plot is placed into the silo until it is covered with another plot or, in the case of the last plot in the silo, until the silo is covered with plastic. The second phase is fermentation which includes all dry matter and quality changes that occur under anaerobic conditions. During the third phase, infiltration, oxygen penetrates the silo wall (tower silos) or the cover (bunker silos) into the stored material to allow aerobic respiration. During the last phase, feedout, dry matter loss is due to aerobic respiration both on the silage surface inside the silo and in the silage in the feed bunk. The intended use of the model is for wilted silages with dry matter contents above 30%. Therefore, effluent production is not considered.

The concept on which the silo model is based is that of oxygen diffusion into the forage material. For a tower silo, assuming angular symmetry, the diffusion is two dimensional: axially downward and radially inward. The two-dimensional problem is approximated by three one-dimensional phases, each describing different time periods. During the first phase, preseal, the top surface of the forage material is uncovered; thus, radial diffusion of oxygen is negligible over a short period of time. The fourth phase, feedout, considers oxygen diffusion similarly because the opened surface is again exposed to air. The third phase, infiltration, considers the long-term effects of radial oxygen diffusion. Because of relative dimensions and the fact that the feedout phase deals with the opened surface, the silo is considered to be a tube with insulated ends for the modeling of the infiltration phase.

Even though oxygen is diffusing into the forage material, the rate of diffusion is slow enough that forage undergoes anaerobic fermentation. Fermentation is modeled as phase two even though phase three, infiltration, occurs simultaneously. Similar arguments hold for the breakdown of the phases in a bunker silo.

The four phases are linked together to simulate the entire ensiling process. The linkage is different for tower and bunker silos. Because plots are removed in different order, there are also slight differences between top- and bottom-unloaded tower silos.

In a top-unloaded tower silo, the plots are numbered in the order in which they were harvested and in the reverse order in which they are removed from the silo (Figure 4.1a). Each of the four phases is simulated sequentially for each plot in a tower silo. The density during phase 1 is the uncompacted density. It is assumed that the silo is filled prior to fermentation; therefore, the density during fermentation is higher and depends upon the position of the plot within the silo. Forage density is estimated as by Pitt (1983). The depth to the top of a given plot is computed using the density of each plot above the given plot and the cross-sectional area of the silo. The temperature of the ensiled crop as it enters the fermentation phase includes the temperature rise from phase 1.

Once fermentation has been simulated for a plot, the third phase, infiltration, is simulated. The length of time each plot is in the silo is the time required to remove all of the material above (or below in a bottom-unloaded silo) the current plot plus half of the current plot. This time is determined from the feed rate, which is computed in such a way that the silo is emptied over a given length of time.

Feedout, phase 4, is simulated following infiltration. The density of the exposed silage surface is the compacted density; uncompacted density is always used for in-bunk respiration. Total dry matter loss from all phases cannot exceed the total respirable substrate available in the feed.

Refilling of a tower silo complicates the model. In the top-

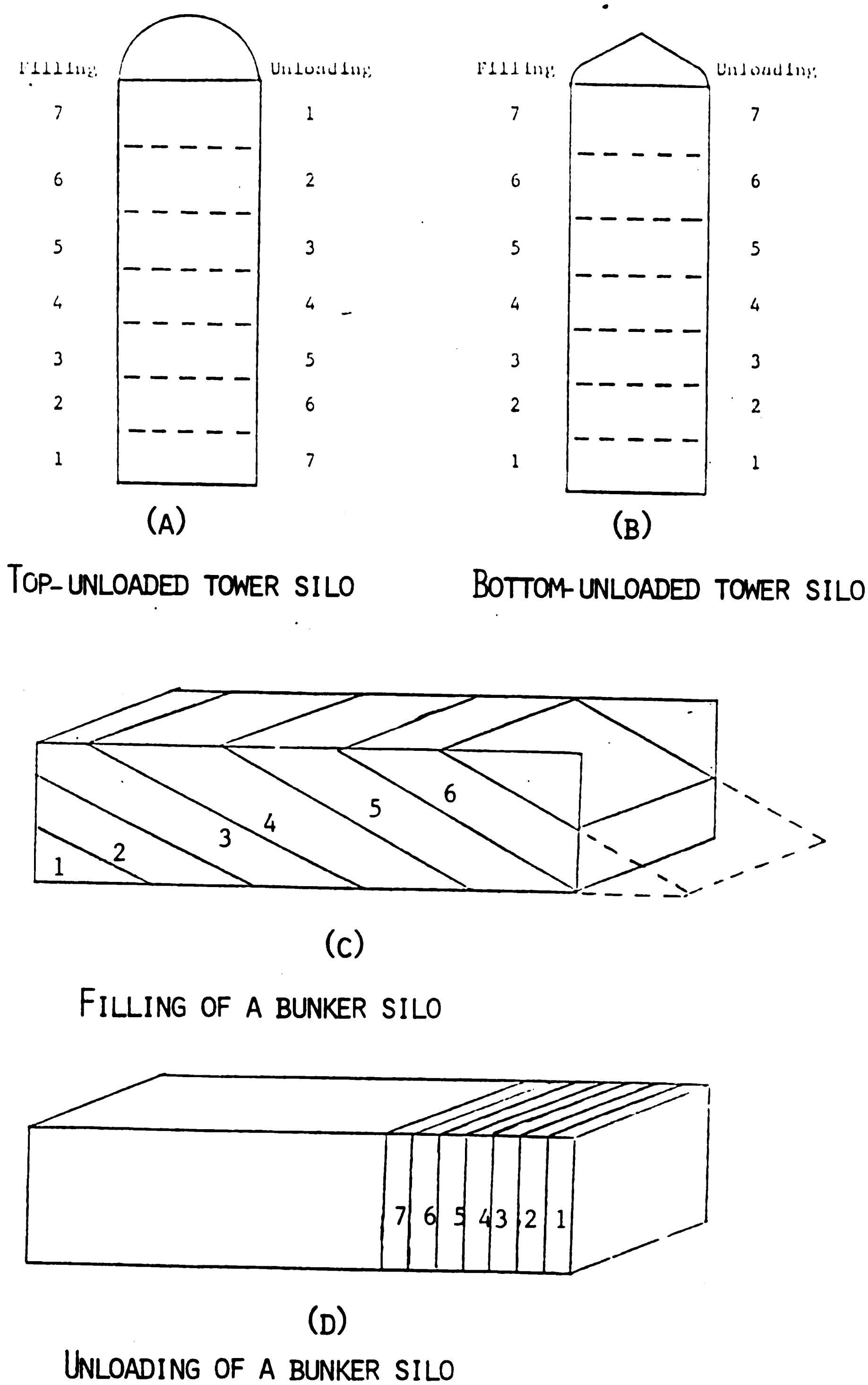

Figure 4.1 Order of filling and unloading of plots in silos.

unloaded tower silo, refilling is modeled by increasing the length of time the original plots in the bottom of the silo are in the silo. Plots placed into the silo during refilling or plots replaced by the refill are treated identically in the model. It is assumed that refilling does not change the density of the original plots in the bottom of the silo.

The bottom-unloaded tower silo is modeled like the top-unloaded silo. A difference is the length of time each plot remains in the silo. Because plots are removed from the silo in the same order that they were harvested (Figure 4.1b), the length of time a plot is in the silo is the time required to remove the plots below the given plot plus half of that plot.

The effect of refilling a bottom-unloaded silo is an increase in the density of the original plots that remain in the silo. For plots removed prior to refilling, density remains the same as in a silo without refilling. For the original plots that remain in the silo during refilling, the time in the silo is split into two segments: one before refilling and one after refilling. Infiltration losses are simulated for the first time period using the original density of the plots. The density after refilling depends on plot position within the silo.

Figure 4.1c illustrates plot placement in a bunker silo. A bunker silo is not emptied one plot at a time; rather, vertical sections that contain material from several plots are removed (Figure 4.1d).

Phase 1 in the bunker silo is simulated for each plot as it is placed into the silo. Estimation of surface area is based on a slope of one-half during filling. After preseal has been simulated, fermentation is simulated for each plot using the compacted density.

Because infiltration is vertically downward into a bunker silo and the silo is emptied in vertical sections, the plots become indistinguishable once the silo is filled. Following preseal and fermentation, which are simulated for each plot, the moisture content and quality at any point in the bunker is considered to be the average moisture content and quality of all material in the silo. Thus, before infiltration, the vertical sections each contain material of identical quantity and quality. The time that each vertical section remains in the silo is the amount of time required to remove the vertical sections in front of the current section.

With this overview of how the four phases are linked together, the mathematical models for each phase will be developed.

4.3.1.2 Phase 1: Preseal

Changes that occur before the sealing of a plot are the result of plant respiration, and they include dry matter loss, a change in dry matter content and a temperature rise. Proteolysis is assumed to be negligible until fermentation begins. During the preseal phase, oxygen infiltration is assumed to be vertically downward into the forage material. Oxygen infiltration through the silo wall is assumed to be negligible compared with the infiltration into the open surface. The preseal portion of the silo model is a modification of the work of Pitt (1986). Pitt (1986) modeled respiration rate (μ) in forage material as:

$$\mu = \frac{\mu_a \, (K_m + \psi_a) \, f_C \, \psi}{\psi_a \, (K_m + \psi)} \qquad [4.11]$$

The relationship for estimating the respiration rate in air (μ_a) as a function of crop type, pH, temperature and dry matter content is given by Pitt (1986).

For the geometry shown in Figure 4.2, the differential equation and boundary conditions describing the steady state diffusion of oxygen is:

$$\frac{d^2\psi}{dx^2} - \frac{\rho\ \mu_a\ (K_m + \psi_a)\ f_C\ \psi}{D\ \phi\ \tau\ \psi_a\ (K_m + \psi)} = 0 \qquad [4.12a]$$

subject to: $\psi(x{=}0) = \psi_a$ [4.12b]

$$\frac{d\psi(h)}{dx} = 0 \qquad [4.12c]$$

(Pitt, 1986). At a constant temperature, silage pH, silage dry matter content and density, equation [4.12a] can be simplified to:

$$\frac{d^2\psi}{dx^2} - \frac{\gamma\ \psi}{(K_m + \psi)} = 0 \qquad [4.13]$$

where $\gamma = \rho\mu_a(K_m+\psi_a)f_C/(D\phi\tau\psi_a)$ is a constant. Equation [4.13] is a non-linear equation that can be solved numerically to estimate the oxygen concentration profile. Using superscripts to denote iterations, equation [4.13] can be rewritten as:

$$\frac{d^2\psi^{(k+1)}}{dx^2} - \frac{\gamma\ \psi^{(k+1)}}{(K_m + \psi)^{(k+1)}} = 0 \qquad [4.14]$$

Using a Taylor series expansion on the second term gives:

$$\gamma\frac{\psi^{(k+1)}}{(K_m+\psi)^{(k+1)}} = \gamma\frac{\psi^{(k)}}{(K_m+\psi)^{(k)}} + \gamma\frac{d(\psi/(K_m+\psi))^{(k)}}{d\psi}(\psi^{(k+1)}-\psi^{(k)}) \qquad [4.15]$$

which can be simplified to:

$$\gamma\frac{\psi^{(k+1)}}{(K_m+\psi)^{(k+1)}} = \gamma\frac{\psi^{(k)}}{(K_m+\psi)^{(k)}} + \gamma\frac{K_m}{(K_m+\psi^{(k)})^2}(\psi^{(k+1)}-\psi^{(k)}) \qquad [4.16]$$

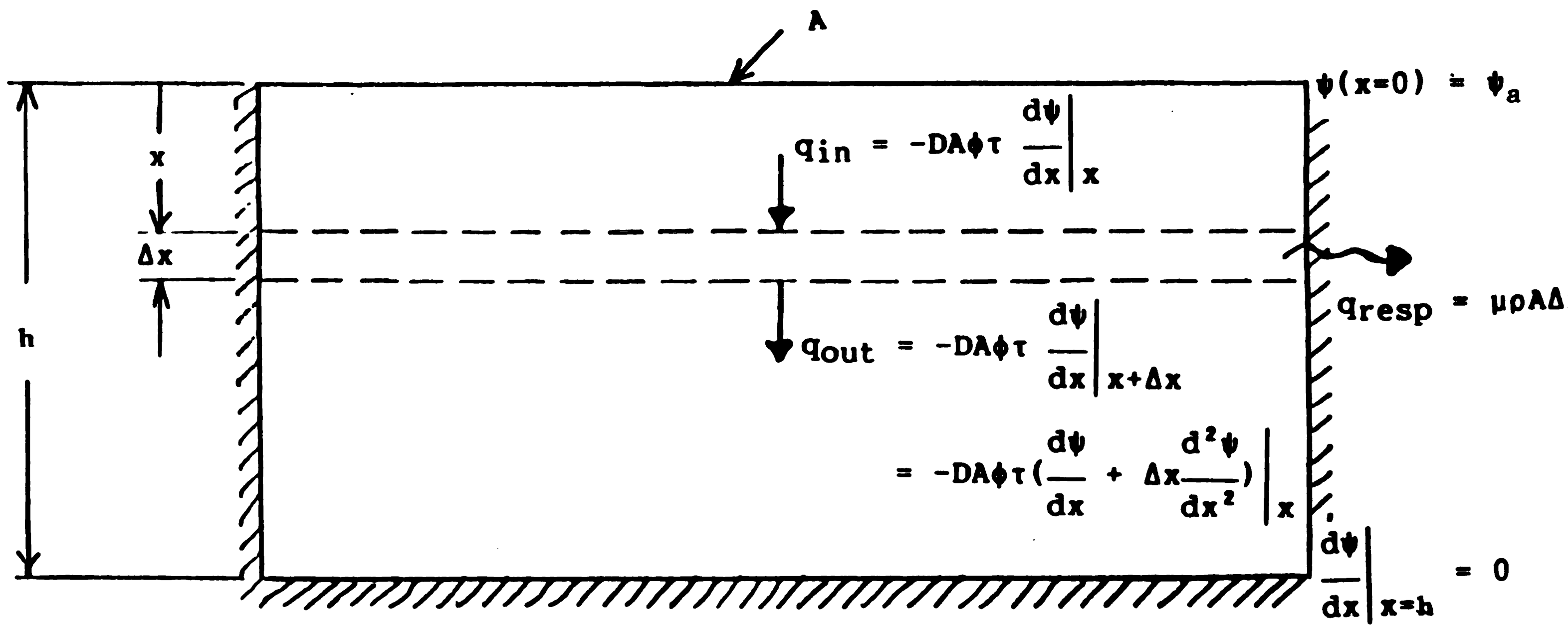

Figure 4.2 Geometry of 1-dimensional steady state oxygen diffusion into forage material (Pitt, 1986).

Substitution of equation [4.16] into [4.14] with rearrangement gives:

$$\frac{d^2\psi^{(k+1)}}{dx^2} - \gamma \frac{K_m}{(K_m+\psi^{(k)})^2} \psi^{(k+1)} = \frac{\gamma\ (\psi^{(k)})^2}{(K_m+\psi^{(k)})^2} \qquad [4.17]$$

Equation [4.17] can be used with finite differences to obtain a set of simultaneous equations to be solved at each iteration. It is noteworthy that few iterations are necessary for adequate convergence and that the set of simultaneous equations is in tridiagonal form for quick solving.

Once the oxygen concentration profile is known, a respiration rate profile is computed using equation [4.11]. From this, the average respiration rate over the depth of the plot ($\bar{\mu}$) can be calculated.

Within DAFOSYM, an approximate oxygen concentration profile is used rather than the finite difference approach. Starting with the non-linear diffusion equation [4.13], a linear approximation is incorporated (Pitt, 1986):

$$\frac{d^2\psi}{dx^2} - \psi/\alpha^2 = 0 \qquad [4.18]$$

where α^2 approximates $(K_m + \psi)/\gamma$. Because ψ varies only from 0 to 0.21 (oxygen concentration in air), this approximation can be made with little change in predicted dry matter loss. The zero intercept on the approximation is necessary for the oxygen concentration profile to approach zero at infinite depth. The solution of equation [4.18] subject to the boundary conditions of [4.12b] and [4.12c] is:

$$\psi(x) = \frac{\psi_a\ e^{-h/\alpha}}{e^{h/\alpha} + e^{-h/\alpha}}\, e^{x/\alpha} + \frac{\psi_a\ e^{h/\alpha}}{e^{h/\alpha} + e^{-h/\alpha}}\, e^{-x/\alpha} \qquad [4.19]$$

For ensiled forages, α ranges from 5 to 25 cm; therefore, h/α is large and equation [4.19] can be further approximated by:

$$\psi(x) = \psi_a\ e^{-x/\alpha} \qquad [4.20]$$

To estimate the dry matter loss, the average respiration rate over the depth of the plot is needed. Substituting the oxygen concentration relationship [4.20] into equation [4.11] and integrating over the depth of the plot gives:

$$\bar{\mu} = 1/h \int_0^h \frac{\mu_a\ f_C\ (K_m+\psi_a)}{\psi_a} \frac{\psi_a\ e^{-x/\alpha}}{(K_m + \psi_a\ e^{-x/\alpha})} dx \qquad [4.21]$$

$$= \frac{-\mu_a\ f_C\ (K_m+\psi_a)\ \alpha}{\psi_a\ d} [\ln(K_m + \psi_a e^{-h/\alpha}) - \ln(K_m + \psi_a)] \qquad [4.22]$$

A value of $\alpha = 1/(9\gamma)^{0.5}$ was chosen so the error in dry matter loss prediction was small. Because the oxygen concentration in silage is low, it is important that the approximation of $\alpha^2 \simeq (K_m + \psi)/\gamma$ fits more closely at ψ near 0.0 rather than at ψ near 0.21. With the approximation of $\alpha = 1/(9\gamma)^{0.5}$, agreement between preseal dry matter loss (expressed as a fraction) as predicted by the finite difference approach and the approximation as presented was to the fourth decimal place for several typical plots of silage.

For modeling the oxygen concentration profile, h refers to the depth of a plot in a tower silo. Because the plots in a bunker silo are much shallower, h refers to the total depth in the bunker to date; i.e., preseal loss in a bunker silo is not confined to the top plot alone.

Dry matter loss during the preseal phase can be related to the average respiration rate and the duration of the preseal phase (t_1). Using the respiration reaction:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2 + \text{HEAT (2870 kJ/mole)} \qquad [4.23]$$

and assuming the density of oxygen is $0.00133 g/cm^3$ (ideal gas at $20°C$):

$$L_1 = 0.0299\ \bar{\mu}\ t_1\ /\ DM \qquad [4.24]$$

where: $0.0299 = (0.00133g\ O_2/cm^3\ O_2)$
$(180g\ silage\ lost/192g\ O_2\ used)(24h/day)$

Within DAFOSYM, dry matter loss during the preseal phase is estimated using equation [4.24] with the average respiration rate approximated by equation [4.22]. The change in dry matter content during the preseal phase is estimated by equation [4.23]: for each 180 g of dry matter lost, 108 g of water is produced.

Temperature rise before sealing is computed with the assumption that the heat generated raises the temperature of the ensiled material. A lumped analysis is used; thus the plot is assumed to have uniform temperature. Using the specific heat estimate of Pitt (1983), the temperature rise (ΔT) is:

$$\Delta T = \frac{2870\ L_1}{0.18(1.89+4.19(1/DM-1))}$$

$$= 6932L_1\ /\ (1.82/DM\ -\ 1) \qquad [4.25]$$

The preseal model uses a time step of one day, thus the temperature rise due to respiration on the first day affects the respiration rate on the second day, etc.

All dry matter lost is respirable substrate (i.e., sugars and starch). Therefore, as dry matter is lost during the preseal phase, neutral detergent fiber and crude protein concentrations increase:

$$NDF_1 = NDF_i\ /\ (1-L_1) \qquad [4.26]$$

$$CP_1 = CP_i\ /\ (1-L_1) \qquad [4.27]$$

4.3.1.3 Phase 2: Fermentation

Models of changes in alfalfa silage and corn silage due to fermentation and respiration of air trapped during ensiling were developed using the model of Pitt et al. (1985) as modified by Leibensperger and Pitt (1987). Numerous runs of their simulation model were used to develop a data base of important quality changes for different values of initial temperature, air to herbage ratio and dry matter content. Two methods of modeling these data were considered. The first was to treat the generated data as a table for interpolation. The second, reported here, was to fit empirical functions to the generated data. The model of Pitt et al. gives time courses of quality, yet only final quality characteristics were of interest for the comprehensive model. Simplifying the detailed model to empirical equations greatly decreased the execution time of the comprehensive model, with the difference in each predicted quality change being 3% or less.

Some quality changes are very non-linear and at times not monotonic with respect to the input variables; therefore, the generated data were divided into subsets such that, within the subsets, the effect of each variable could be modeled with a mathematically simple function. Transformations were performed to assure continuity among the functions. Least squares regression was used to fit functions to the data. For both alfalfa and corn silage, the temperature rise in degrees Celsius during fermentation is nearly equal to the air to herbage ratio.

The alfalfa fermentation functions are applicable for initial temperatures (T) from 5 to 45°C, dry matter contents (DM) from 20 to 60% and air to herbage ratios from 0.5 to 3.4. Values for other initial characteristics are listed in Table 4.1. Fermentation functions for alfalfa silage were:

$$L_2 = 0.0156 - 0.0364(DM-0.20) \qquad [4.28]$$

Table 4.1. Initial crop characteristics used to develop fermentation relationships.

Characteristic	Alfalfa	Corn
pH	5.9	5.7
Buffering capacity (mEq/g DM)	0.597	0.244
Water soluble carbohydrate (% DM)	8.0	30.5
Crude protein (% DM)	17.0	8.5
Insoluble protein (% CP)	67.0	84.0
Hemicellulose	9.5	34.0
Lactic acid bacteria population (#/g DM)	f(T)*	$1(10)^6$

*Lactic acid bacteria population = $895(10)^{0.0699T}$
T = Temperature ($^\circ$C)

$$\begin{aligned} NPN = {} & 0.4187 + 0.0114(T-5) - 0.169(DM-0.20) + \\ & 0.0128(T-5)(DM-0.20) - 0.0515(T-5)(DM-0.20)^2 \\ & \leq 0.765 \end{aligned} \qquad [4.29]$$

$$\begin{aligned} PH &= 4.43 && .20<DM<.33, \quad 5<T<18 \\ &= 4.43 - 0.164(T-5)(DM-0.33) && .20<DM<.33, \quad 18<T<45 \\ &= 4.43 + 5.06(DM-0.33) && .33<DM<.46, \quad 5<T<45 \\ &= 5.09 - 0.538(T-5)(DM-0.46) && .46<DM<.60, \quad 5<T<18 \\ &= 5.09 + 2.06(DM-0.46) && .46<DM<.60, \quad 18<T<45 \end{aligned} \qquad [4.30]$$

The Pitt et al. model simulates water-soluble carbohydrate production due to acid and enzyme hydrolysis of hemicellulose. To evaluate neutral detergent fiber (NDF) content change based on hydrolysis alone causes error because the solubility of the NDF in alfalfa silage changes during ensiling. The model for total hemicellulose change (HC) during fermentation is:

$$HC = 0.0261 + 0.0000546(T-5) \qquad [4.31]$$

The corn fermentation functions are applicable for initial temperatures from 0 to 40°C, dry matter contents from 15 to 60%, and air to herbage ratios from 1.0 to 2.0. Values for other initial characteristics are listed in Table 4.1. Fermentation functions for corn silage are:

$$L_2 = 0.00864 - 0.0193(DM-.15) \quad [4.32]$$

$$NPN = 0.20 + 0.00753T + 0.297(DM-0.15) - 0.879(DM-0.15)^2 \quad [4.33]$$

$$PH = 3.82 + 4.03(DM-0.15) \quad [4.34]$$

$$HC = 0.0367 + 0.000333T \quad [4.35]$$

Before infiltration is simulated for a given plot, the amount of dry matter in the plot is decreased and the neutral detergent fiber and crude protein concentrations are adjusted to reflect the changes during fermentation:

$$NDF_2 = (NDF_1-HC) \;/\; (1-L_2) \quad [4.36]$$

$$CP_2 = CP_1 \;/\; (1-L_2) \quad [4.37]$$

4.3.1.4 Phase 3: Infiltration

The new model for loss due to oxygen infiltration is based on one-dimensional steady-state oxygen diffusion: radially inward in the case of a tower silo, downward into a bunker silo and downward into the top plot of a tower silo. The model is illustrated in Figure 4.3 with the concept of a moving front. Outside or above the front, all respirable substrate has been depleted; inside or below the front, loss due to oxygen infiltration has not occurred. Dry matter loss due to oxygen infiltration is limited by oxygen and respirable substrate availability.

It is assumed that oxygen is used in the respiration reaction (equation [4.23]) as it reaches the moving front; thus, the rate of respiration equals the rate at which oxygen reaches the front. With the rate of respiration driven by the rate of oxygen infiltration, the rate

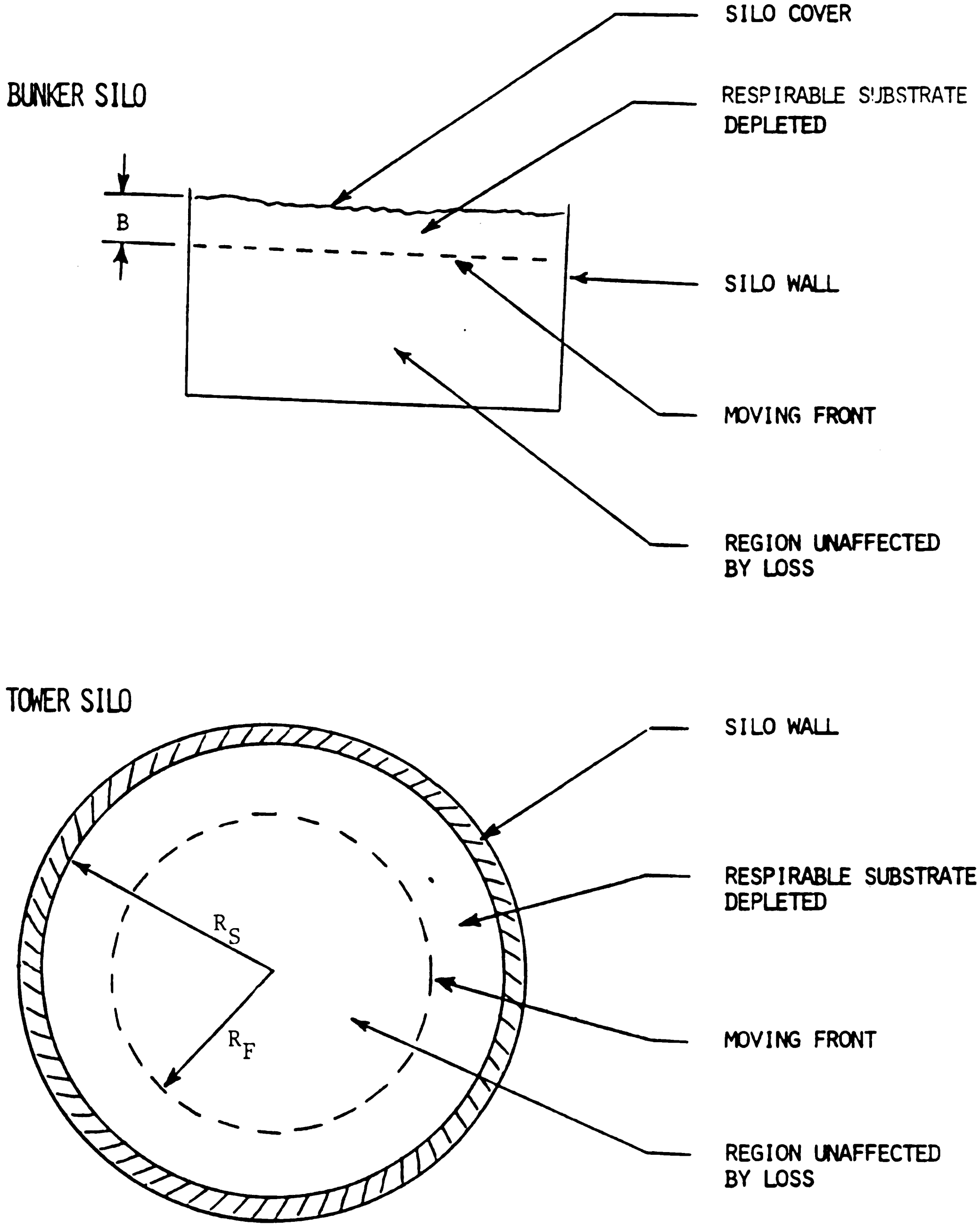

Figure 4.3 Moving-front concept for modeling loss due to oxygen infiltration into silos.

of dry matter loss (and thus the amount lost) is determined by the rate of oxygen infiltration.

The oxygen must penetrate the silo and forage material to reach the front; therefore, the effective permeability has contributions from both the silo wall (tower) or cover (bunker) and any forage to the outside of (tower) or above (bunker) the moving front. Aerobic respiration resulting from oxygen infiltration occurs slowly; any heat generated is assumed to be readily dissipated.

The rate of oxygen infiltration to the front is:

$$q = 10000\ U_{eff} \cdot A \cdot (\psi_a - \psi_f)$$

$$= 2100 \cdot U_{eff} \cdot A \qquad [4.38]$$

since $\psi_a = 0.21$ and $\psi_f = 0.0$. The rate of dry matter loss (l_{inf}) is related to the oxygen infiltration rate using the density of oxygen and stoichiometry of the respiration reaction [4.23]:

$$l_{inf} = q\ (0.00133\ g\ O_2/cm^3\ O_2)(180\ g\ \text{silage lost}/192\ g\ O_2\ \text{used})$$

$$= 0.001247\ q \qquad [4.39]$$

The location of the front affects the infiltration rate and thus affects the rate of dry matter loss. The movement of the front is modeled using a 10-day time step (Figure 4.4). For each 10 days, the amount of dry matter loss is estimated by:

$$LI_j = 0.24\ l_{inf} \qquad [4.40]$$

where: $0.24 = (10\ d)(24\ h/d)(1\ kg/1000\ g)$.

Combining equations [4.38], [4.39] and [4.40] and simplifying gives:

$$LI_j = 0.628\ U_{eff} \cdot A \qquad [4.41]$$

Because a bunker silo is unloaded in vertical sections, the bunker is divided into vertical sections with each section containing the amount of material removed during 10 days. The duration of phase 3 (t_3)

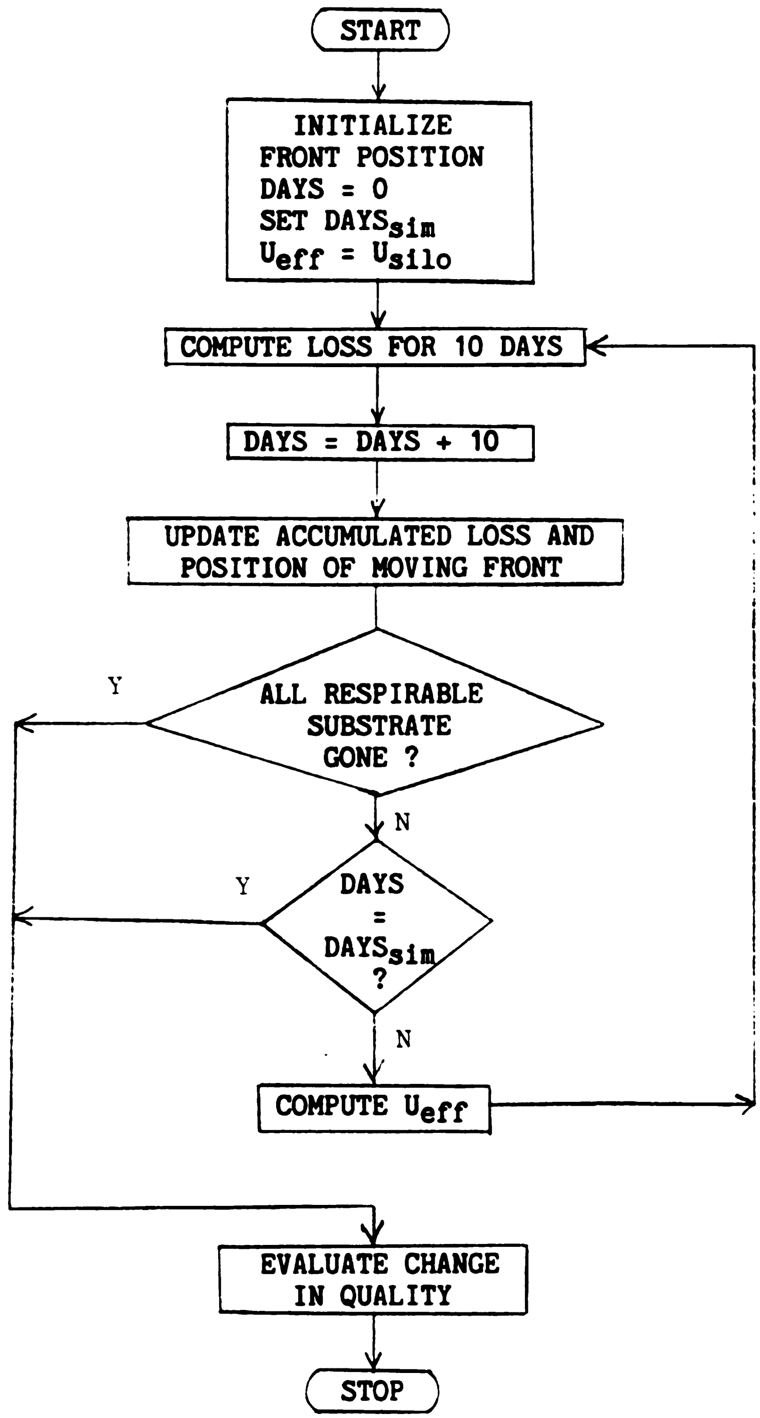

Figure 4.4 Algorithm used for modeling the moving-front concept of loss due to oxygen infiltration.

is different for each vertical section and is determined by the feedout rate (FR).

For a bunker silo, the effective permeability is a function of the cover permeability (U_{cover}), silage porosity (ϕ), the position of the front (B) and diffusion parameters (D and τ).

$$U_{eff} = (1/U_{forage} + 1/U_{cover})^{-1} \qquad [4.42]$$

where: $U_{forage} = D\phi\tau/B$

The depth of the moving front at any given time is computed by:

$$B = 100\ L_{td} \cdot H\ /\ RS \qquad [4.43]$$

where the respirable substrate (RS) and fraction of dry matter lost to date (L_{td}) are given by:

$$RS = 1 - NDF - CP - ASH \qquad [4.44]$$

$$L_{td} = AL/M \qquad [4.45]$$

The area of the moving front (A) in a bunker silo is the horizontal area of the vertical section:

$$A = 10\ FR\ /\ (\rho \cdot DM \cdot H) \qquad [4.46]$$

Similar relationships were used to model infiltration into a tower silo. The function for U_{forage} changed because of differences in geometry:

$$U_{eff} = (1/U_{forage} + 1/U_{wall})^{-1} \qquad [4.47]$$

where: $U_{forage} = D\phi\tau/(100\ R_f\ \ln(R_s/R_f))$

The position of the moving front at any given time is given by:

$$R_f = (R_s^2\ (1-L_{td}/RS))^{0.5} \qquad [4.48]$$

where the dry matter lost to date (L_{td}) is computed in a similar manner as above but using the initial amount of dry matter in the plot. In the case of a tower silo, the area of the moving front is:

$$A = 2\ \pi\ R_f \cdot d \qquad [4.49]$$

Because all dry matter lost is respirable substrate, the neutral detergent fiber and crude protein contents of the forage increase:

$$NDF_3 = NDF_2 / (1-L_3) \quad [4.50]$$

$$CP_3 = CP_2 / (1-L_3) \quad [4.51]$$

where: $L_3 = L_{td}$ when accumulated loss (AL) is summed from time 0 to t_3.

4.3.1.5 Phase 4: Feedout

Dry matter loss during feedout is divided into two portions: that occurring inside the silo, and that occurring in the feed bunk. Feeding loss from handling or animal rejection is considered separately from feedout loss, which models only dry matter loss due to respiration.

The feedout phase in the silo is similar to preseal in that the surface is exposed to air and oxygen can diffuse into the forage. For feedout in a top-unloaded tower silo, diffusion is one-dimensional downward into the forage; in a bottom-unloaded tower silo, diffusion is one-dimensional upward into the forage; in a bunker silo, diffusion is one-dimensional from the opened end inward. Feedout loss is modeled using the same procedure used for modeling preseal loss, but the density and other factors affecting the respiration rate are different during feedout. Once the respiration rate profile during feedout is determined, the in-silo feedout loss is computed by incorporating the duration of phase 4:

$$L_{4a} = .0299\ \bar{\mu}\ t_{4a} / DM \quad [4.52]$$

where: $t_{4a} = L'/DF$.

During bunk exposure, the density of the crop is assumed to be its uncompacted density. The in-bunk loss is estimated by converting respiration rate in air to dry matter loss using a form of equation

[4.24]:

$$L_{4b} = 0.0299\ \mu_a\ t_{4b} \ /\ DM \qquad [4.53]$$

Total dry matter loss during feedout is the combination of in-silo and in-bunk losses:

$$L_4 = L_{4a} + L_{4b} \qquad [4.54]$$

Again, because all dry matter lost is respirable substrate, the neutral detergent fiber and crude protein contents increase:

$$NDF_4 = NDF_3 \ /\ (1-L_4) \qquad [4.55]$$

$$CP_4 = CP_3 \ /\ (1-L_4) \qquad [4.56]$$

4.3.2 Model validation

True validation (proof of model accuracy) of a silo storage model is difficult primarily because of errors in measurement of real data. Data on losses during ensiling contain considerable error due to errors in dry matter content and weight measurements. Ideally, losses during each of the four phases should be measured and compared to simulated losses during the corresponding phases; however, it is difficult if not impossible to obtain such data in a real silo.

To check the validity of the model, predicted dry matter losses and final non-protein nitrogen concentrations were compared to published results from Bolsen et al. (1980, 1981), Bolsen and Ilg (1981, 1982), Jackson and Lessard (1977), Kung et al. (1987) and Woodford (1987). Data collected from alfalfa and corn silages in bunker as well as tower silos were included. In the literature, not all of the necessary input data were published. In many cases, initial quality was not given. Typical NDF, CP and ash contents were assumed when necessary to determine the amount of respirable substrate in the forage. Frequently, the temperatures at filling and feedout times were not reported. Feedout temperature was assumed to be 15°C; the temperature at the time of filling, if unavailable, was assumed to be 20°C for alfalfa and 8°C for corn silage.

Published information on fill rate, storage time and feedout rate was used for model input. In several cases, the silo size was given, but the amount placed into storage was not. In those cases, the model computed capacity, but capacity estimates could not be validated with experimental data.

Table 4.2 contains comparisons of predicted and published dry matter loss values. The model validity was tested by linear regression of actual vs. predicted dry matter loss. Comparisons of the resulting slope and intercept to 1.0 and 0.0, respectively, indicated a valid model ($p = 0.07$). When the intercept of the actual vs. predicted data was forced to be 0.0, the actual dry matter loss averaged 1.1% higher than the predicted. Although the model predicts reasonable values for dry matter loss and can be identified as an unbiased estimator, the variance between the predicted and actual values was high ($r^2 = 0.06$). Much of the variance can be attributed to the difficulty in gathering accurate data from silo experiments.

Errors in the estimate of silo wall (tower silos) or cover (bunker silos) permeability are likely to be a cause of discrepancy between predicted and actual losses. To investigate sensitivity to silo permeability, the permeability necessary for agreement between predicted and actual dry matter loss was determined (Table 4.2). In most cases, the permeability value is reasonably close to the estimated value. In the four cases where such an analysis yields unreasonable silo

Table 4.2. Dry matter losses predicted by the silo model compared to losses reported for actual silos.

Description crop[a]	silo[†]	Source of published data	$U_{estimated}$ cm/h	Dry Matter Loss (%) actual	predicted	$U^{§}$ cm/h
A	SB	Woodford, 1987	3.0	9.8	12.6	1.8
A	SB	Woodford, 1987	2.0	7.5	3.7	---
A	SB	Woodford, 1987	2.0	6.0	6.3	1.9
A	SB	Woodford, 1987	4.0	8.5	8.2	4.5
A	ST	Kung et al., 1987	1.8	4.6	11.5	0.5
A	ST	Kung et al., 1987	2.0	12.7	12.4	2.1
A	ST	Bolsen and Ilg, 1982	3.0	10.5	9.0	4.0
A	ST	Bolsen et al., 1980	3.0	6.9	7.9	2.4
A	ST	Bolsen et al., 1981	3.0	12.8	8.8	7.1
C	ST	Bolsen and Ilg, 1981	3.0	6.7	8.4	2.2
C	LT	Jackson and Lessard, 1977	4.0	9.2	4.0	---
C	LT	Jackson and Lessard, 1977	4.0	8.8	5.5	---
C	LT	Jackson and Lessard, 1977	4.0	13.6	8.9	---
			mean	9.0	8.2	

[*] A = alfalfa, C = corn
[†] SB = small bunker, ST = small tower, LT = large tower
[§] U = permeability of silo wall or cover at which predicted loss equals published loss (missing data implies errors in addition to permeability estimate causes discrepancies)

permeabilities, the differences between predicted and actual losses could have easily been caused by errors in determining other simulation parameters such as initial quality, feedout temperature or feedout rate or measurement errors in the actual data. The sensitivity analysis section that follows illustrates the effects of these factors on dry matter loss.

Non-protein nitrogen (NPN) concentration in alfalfa silages is predicted using equation [4.29]. Published results of NPN concentration were compared to simulated values (Table 4.3). Comparisons of predicted and published NPN concentrations again indicate that the model predicts reasonable values. Over the small range of values available, the use of the slope/intercept hypothesis for comparison was not warranted.

4.3.3 Sensitivity analysis

The silo model was used to determine the sensitivity of predicted dry matter loss to several factors: silo permeability, silo size, silo type, feedout rate, initial quality, crop type and moisture content of the forage. Because the dry matter lost is respirable substrate, a study of dry matter loss gives a good indication of changes in NDF and CP as well.

In the sensitivity analysis, unless otherwise noted, all silos are of the same capacity and emptied over a 360-day time span, feedout temperature is 15°C, the crop is alfalfa silage, and permeabilities are 2, 4 and 4 cm/h for the wall of a bottom-unloaded tower silo, the wall of a top-unloaded tower silo and the cover of a bunker silo, respectively. Crop moisture contents are 50, 60 and 65% (wet basis) for bottom-unloaded, top-unloaded and bunker silos, respectively, unless specified otherwise.

Figure 4.5 illustrates the effect of tower silo wall and bunker cover permeability on dry matter losses for three types of silos, each with a capacity of 150 tonnes dry matter. The tower silos are 6.10 m in diameter by 21.3 m high; the comparably sized bunker is 9.14 x 3.05 x 28.9 m. Permeability of stave silo walls ranges from 3 to 10 cm/h (Pitt, 1986). Because of probable pinholes in bunker silo covers, the permeability of silo covers is most likely in the same range (Pitt,

Table 4.3. Predicted and published concentrations of non-protein nitrogen in alfalfa silages.

Dry matter content		NPN concentration actual*	predicted
34.0		53.0	62.0
31.6		63.5	65.0
35.2		59.5	55.0
27.3		62.1	56.0
34.8		51.7	66.0
	mean	58.0	60.8

* Source: Woodford (1987)

1986). Bottom-unloaded "sealed" silos would have lower oxygen permeabilities. Decreased silo condition (increased permeability) can have a large impact on silo losses. An increase in silo wall permeability from 2 to 4 cm/h caused 2.0 and 3.2% more loss in the top and bottom-unloaded silos, respectively.

Figure 4.5 indicates that at a common silo wall permeability, a bottom-unloaded silo has higher loss. The susceptibility of forage to dry matter loss is very dependent on density -- less dense silage experiences more loss. In a bottom-unloaded tower silo, the most susceptible (least dense) forage material remains in the silo the longest time. The opposite is true for a top-unloaded tower silo. Comparisons of silo type must accurately reflect silo permeability because of this sensitivity. For typical permeabilities (2, 4 and 4 cm/h for bottom-unloaded, top-unloaded and bunker silos, respectively), dry matter losses are nearly the same regardless of silo type for this size silo.

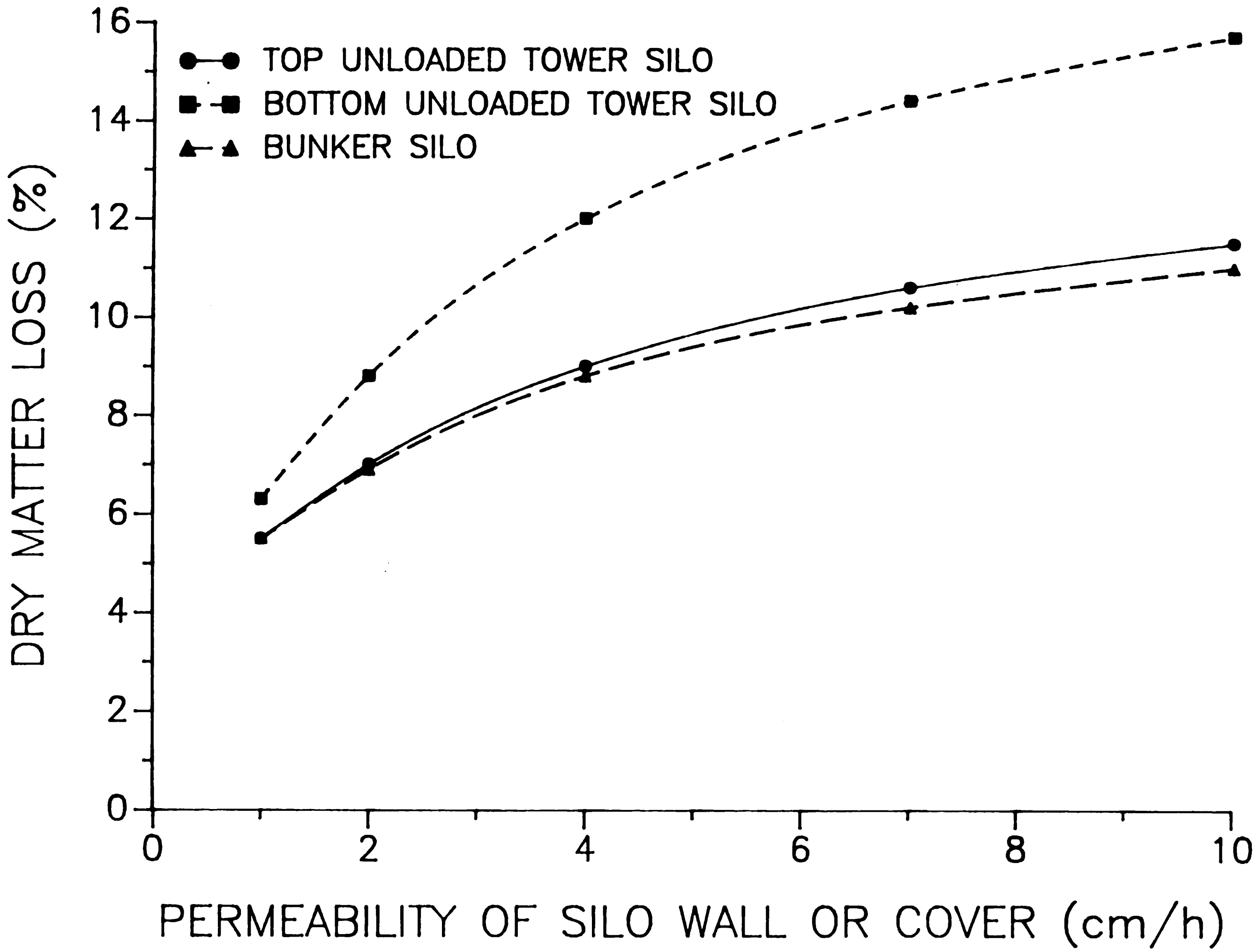

Figure 4.5 Effect of silo permeability on predicted dry matter loss in silos filled with alfalfa silage (150 T DM capacity) emptied over 360 days.

Figure 4.6 illustrates the effect of silo capacity on dry matter loss. All silos were emptied over 360 days; therefore, the feedout rate was different for each capacity. Loss as a fraction of initial dry matter is decreased with larger tower silos because of the higher density in the lower portion of the silo which allows less oxygen penetration. In bunker silos, which have a more constant dry matter density, the dry matter loss levels off at about 7%. This occurs because of a maximum feasible bunker depth. Increasing the capacity of large bunkers adds surface area in proportion to the increase in capacity as depth is held constant.

Because most dry matter loss occurs during the infiltration phase, the length of time that forage remains in the silo has a large impact on dry matter loss; therefore, feedout rate affects dry matter loss. Figure 4.7 illustrates the relationship for a 6.1 x 21.3 m top-unloaded tower silo. As storage time increased, total dry matter loss during ensiling increased almost linearly. Approximately 0.6% dry matter was lost per month. For the medium-sized tower silo, reducing the days to empty the silo from 360 to 120 days resulted in 4.5% less dry matter loss. The effect was similar for a bottom-unloaded tower silo and a bunker silo of comparable capacity.

Figure 4.7 also illustrates the effect of feedout temperature on total dry matter loss. Feedout temperature affects only losses that occur during the fourth phase, but the effects are important. It was assumed that feedout temperature was constant over the entire feedout period. An increase in feedout temperature of 25°C can cause 1.0 to 3.5% more dry matter loss. Temperature at feedout had more effect on losses in less dense material (near the top of a tower silo or in a

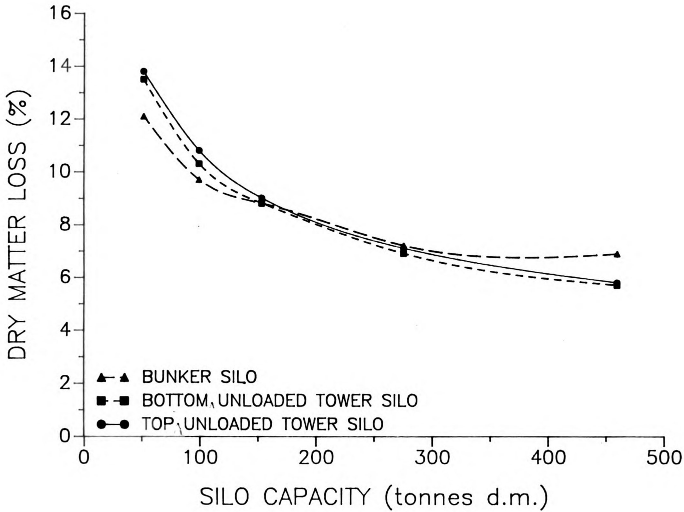

Figure 4.6 Effect of silo size on predicted dry matter loss.

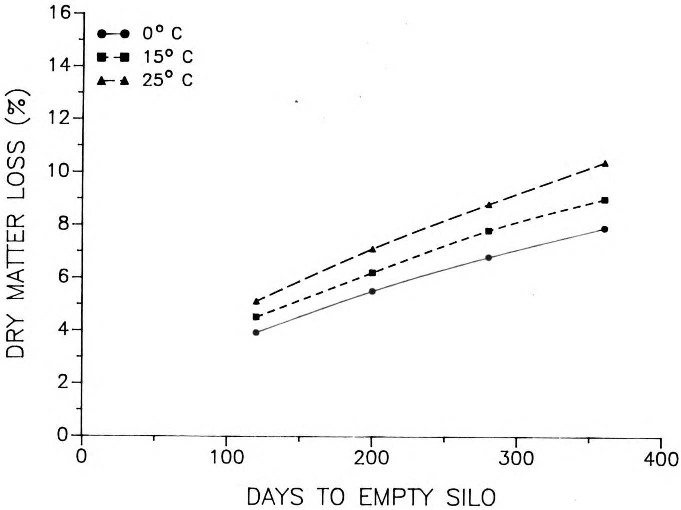

Figure 4.7 Effect of feedout rate and temperature during feedout on dry matter loss in a 6.1 x 21.3 m top-unloaded tower silo.

bunker silo).

Based on equation [4.42] one might expect losses during ensiling to depend on initial forage quality. Comparing simulated losses for alfalfa with 32% NDF and 25% CP to alfalfa with 50% NDF and 17% CP showed that total dry matter loss was 0.5% higher for the higher quality material. This change was small primarily because NDF increases are typically accompanied by CP decreases; thus the respirable substrate remains relatively constant. For the same reason, dry matter loss in corn silage (55% NDF, 9% CP) is nearly the same as that in alfalfa silage.

Over the moisture content range of 50 to 65%, total dry matter loss depends only slightly on moisture content. At 50% moisture in a top-unloaded 6.1 m x 21.3 m tower silo, dry matter loss was 9.4%. At 65% moisture, dry matter loss was 8.4%. Note that this model does not consider effluent production which will result in increased loss at higher moisture contents.

Figures 4.8 and 4.9 illustrate the sensitivity of non-protein nitrogen (NPN) content to temperature and dry matter content. Over the dry matter content range for reasonable management (30 to 50%), NPN concentration is more dramatically affected by temperature than by dry matter content. This illustrates the need to keep silage temperatures as low as possible.

4.4 Feeding loss

Feeding loss as modeled in DAFOSYM consists of animal refusal and feed lost during transport between the storage location and the feed bunk. Feeding loss was assumed to affect quantity only; quality remains

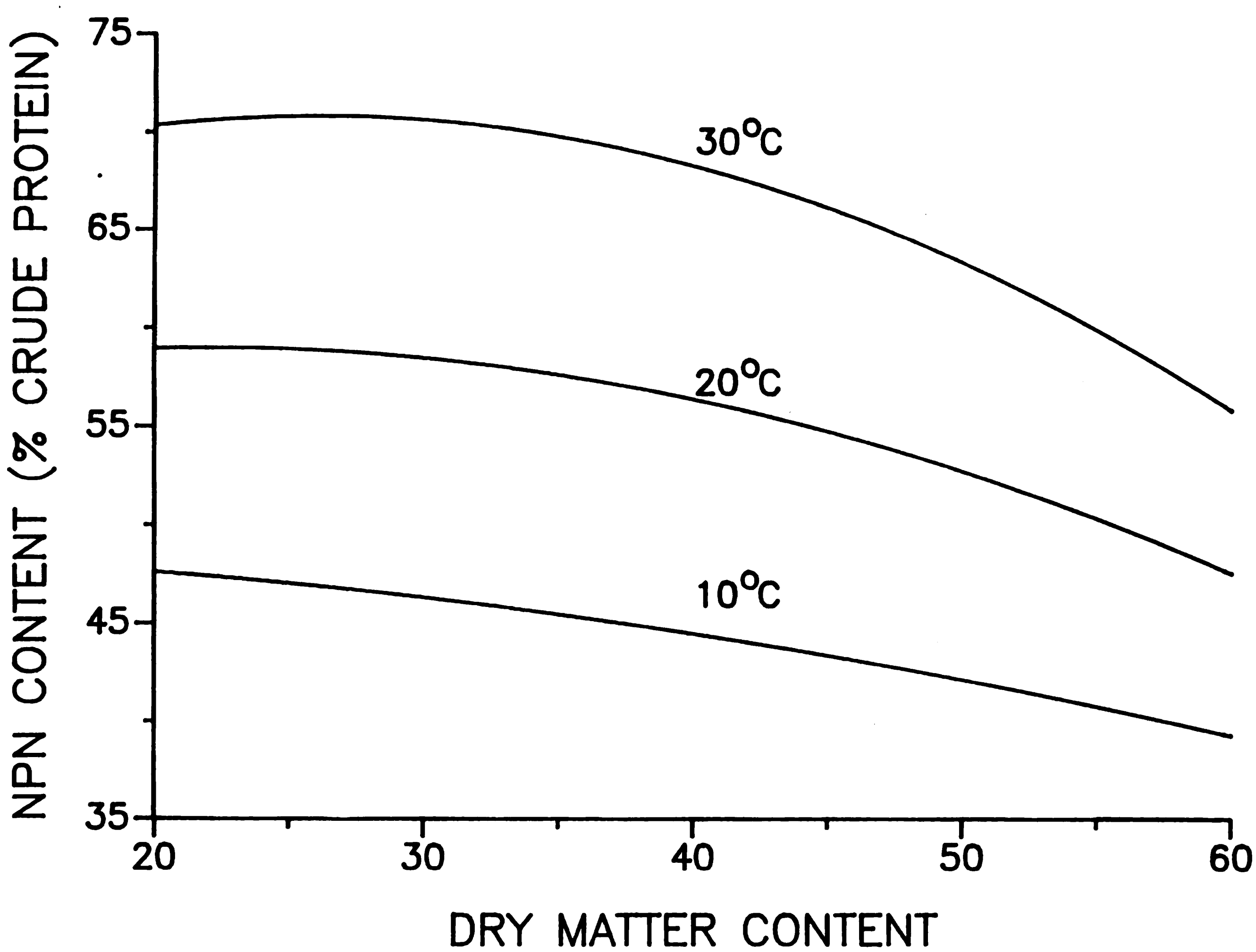

Figure 4.8 Effect of dry matter content and temperature on predicted non-protein nitrogen content in alfalfa silage.

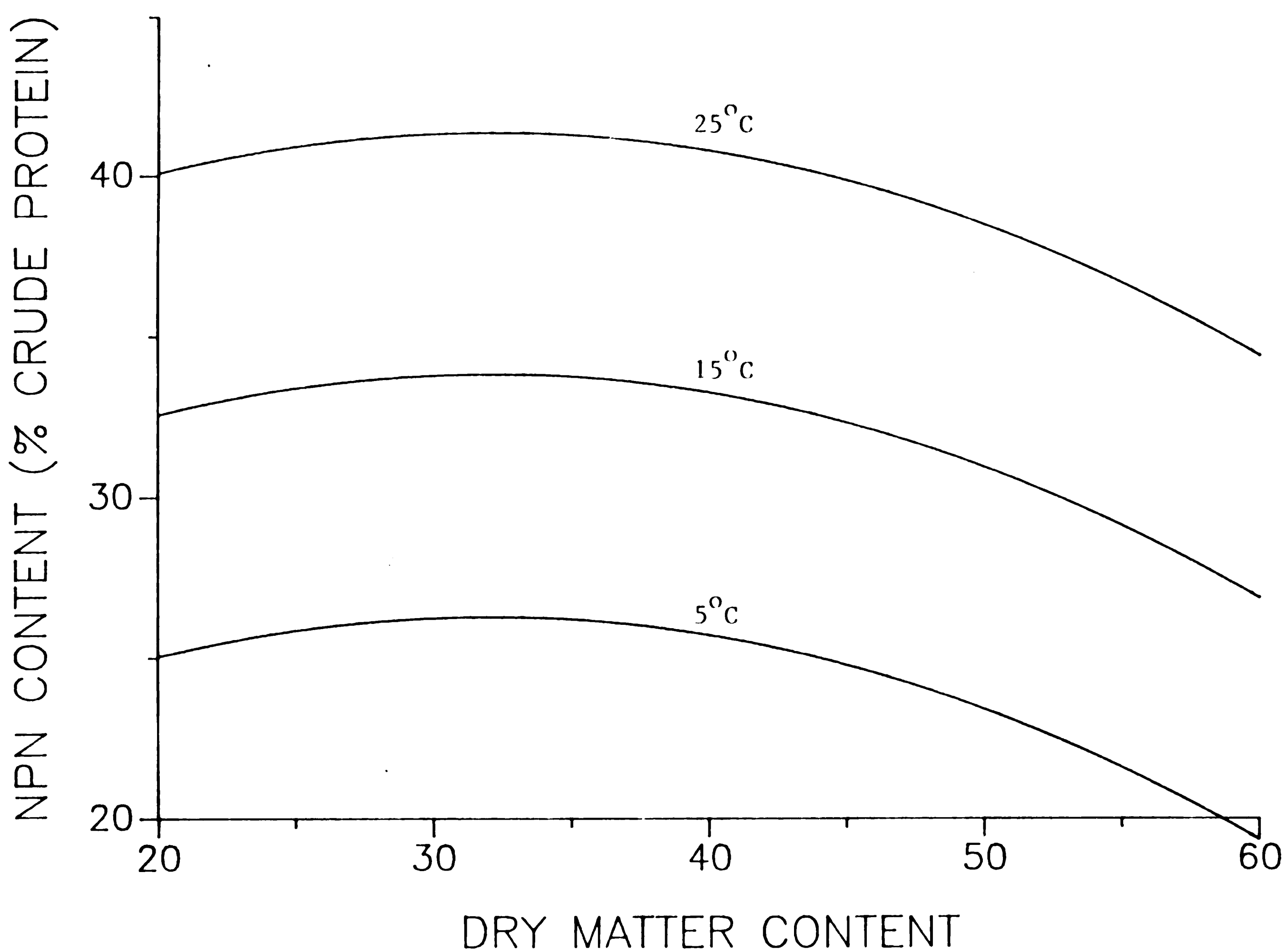

Figure 4.9 Effect of dry matter content and temperature on predicted non-protein nitrogen content in corn silage.

unchanged. Feeding loss for all feeds except round hay bales was assumed to be 5%. Loss during feeding of round bales was assumed to be 14% if they had been stored inside and 25% if they had been stored outside.

5. ANIMAL UTILIZATION MODEL

When considering forage value on the dairy farm, the importance of the animal cannot be overemphasized. Production of milk is the capstone of all processes that converts labor, resources and capital into a salable product. The conversion of feed into milk reveals the effects of alternative technologies and management strategies on feed value.

The objectives of the animal model are to predict feed intake and milk output for a given supply of feed. In effect, the model provides an estimate of forage value based on dairy cow performance and so provides feedback on how crop growth, harvest and storage affect animal performance. The model developed here is not intended to be a ration balancer for on-farm use. Rather, it estimates the potential milk production from given feed and the required supplemental feed for producing a given amount of milk.

The three major sections of this chapter describe models for lactating cows, growing heifers and the combined dairy herd. The single-animal models are used to determine rations that yield given milk production levels or daily gains. The whole-herd model uses the single-animal models and includes the division of the herd as well as feed allocation to the various herd groups.

It is the purpose of this chapter to define clearly the new animal models in DAFOSYM. Care is taken to give considerable detail on structure with some insight into why the structure was chosen; however, an understanding of the biology behind the relationships will require a review of the referenced work.

Several subroutines make up the animal model. Table 5.1 lists these subroutines and their functions and tells from which subroutine they are called.

5.1 Lactating cow model

The objective of the lactating cow model is to formulate rations that meet the nutrient requirements of a given lactating or dry cow. It was assumed that forage quality will have negligible impact on mineral supplementation, so the model deals with only intake, fiber, energy and protein. Rations are formulated using linear programming. Constraints imposed on the formulated diet are developed in the following sections.

5.1.1 Dry matter intake

It is commonly accepted that intake is controlled by two mechanisms: physiological energy demand and physical fill (Conrad, 1966). The control of intake by physiological energy demand implies that a cow will ingest no more energy than she requires. When balancing a ration, energy intake is forced to equal the energy requirement so the ration meets the requirement without providing excess energy. The intake constraint of concern, then, is physical fill; i.e., the ingestive capacity of the animal cannot be exceeded. Using the work of Mertens (1987):

$$I \cdot F \leq C \qquad [5.1]$$

Of the chemical analyses available, NDF should be most highly correlated to the space-occupying or fill effect of the diet. Soluble constituents in feeds dissolve and contribute very little to the fill effect of diets. Fiber displaces volume in the rumen and NDF is the

Table 5.1 Animal model subroutines and their function in the prediction of animal performance.

Subroutine	Called by	Function
COWFD	REPORT	Main animal model program. Transfers feed information, sets up feeding order, transfers feed utilization information back to REPORT.
FEEDUM	COWFD	Calls ration formulators, assures feed stocks are fed correctly.
FEED	FEEDUM	Allocates feeds according to decision rules.
SINGLE	FEEDUM	Ration formulator for lactating cows and heifers. Sets up constraint equations and calls for LP solution.
ROWSET	SINGLE	Sets up the auxiliary matrix for LP solution.
LPSOLV	SINGLE	Solves the ration LP problem.

only fiber routinely used that isolates all fibrous components: cellulose, hemicellulose and lignin. Neutral detergent fiber has been shown to be highly correlated with the volume or bulk density of feeds (Mertens, 1980; 1985a). Because not all NDF is equal in its fill effect, an adjusted NDF (ANDF) is used for fill units and [5.1] is rewritten as:

$$DMI \cdot ANDF_{diet} \leq IC \qquad [5.2]$$

Ingestive capacity (IC) is directly related to the frame size of the animal:

$$IC = C_{ic} \cdot BASEWT \qquad [5.3]$$

(Mertens, 1987). The ingestive capacity coefficient (C_{ic}) is a function of stage of lactation and maturity of the animal. Mertens (1987) reported that daily NDF intake was 1.2 ± 0.1% of body weight per day (i.e., IC = 0.012 ± 0.01). This typical value was adjusted over the lactation cycle. Daily ingestive capacity for cows in early lactation was calculated from an experiment in which an alfalfa/corn/soybean meal ration containing 30% NDF was fed to cows for the first 14 weeks of lactation (Dado and Mertens, unpublished). Other IC's were calculated from the data of Mertens (1985b). The frame size indicator (BASEWT) is the body weight during the second stage of lactation and is discussed further in Section 5.5.

The physical fill constraint gives a maximum amount of fiber that the cow can ingest per day. To incorporate this intake constraint in a linear programming approach, the following notation is used:

$$\Sigma\, x_i \cdot ANDF_i \;\leq\; C_{ic} \cdot BASEWT \qquad [5.4]$$

5.1.2 Fiber

Both the amount and the physical characteristics of fiber have important effects on rumen function and milk synthesis. Long fiber is needed to promote the rumination activity and rumen function necessary to maintain the rumen environments that result in the production of the necessary amounts and types of fermentation products for milk synthesis. Rations are constrained so that, of the fiber in the total ration, 75% comes from long or coarsely chopped forage (NRC, 1988). This is implemented with the concept of roughage value (RV). The RV is equal to the ANDF value of forages; it is 0.0 for concentrates and protein supplements. The constraint is, then, that the roughage value in the diet must exceed 75% of the ANDF in the diet; i.e.,

$$\Sigma\ x_i \cdot RV_i \geq 0.75\ \Sigma\ x_i \cdot ANDF_i \qquad [5.5]$$

Rearranged for easy implementation into an LP format, [5.5] becomes:

$$\Sigma\ x_i(RV_i - 0.75ANDF_i) \geq 0 \qquad [5.6]$$

If the diet cannot meet energy and protein requirements and satisfy the RV and intake constraints, the LP problem statement will have no feasible solution. When this occurs, milk production is reduced 2% and a new ration is attempted.

5.1.3 Energy

The net energy for lactation requirement is estimated using the National Research Council (1988) relationships. The total net energy requirement (NE_1^T) includes needs for maintenance, pregnancy, weight change and lactation:

$$NE_1^T = NE_{1,m} + NE_{1,p} + NE_{1,g} + NE_{1,l} \qquad [5.7]$$

where:

$$NE_{1,m} = 0.08BW^{0.75} \qquad [5.8]$$

$$NE_{1,p} = \begin{cases} 0.024BW^{0.75} & \text{if days pregnant} \geq 210 \\ 0 & \text{if days pregnant} < 210 \end{cases} \qquad [5.9]$$

$$NE_{1,g} = \begin{cases} 5.12\Delta BW & \text{if } \Delta BW \geq 0.0 \\ 4.92\Delta BW & \text{if } \Delta BW < 0.0 \end{cases} \qquad [5.10]$$

$$NE_{1,l} = (0.3512 + 0.0962PFAT)MPD \qquad [5.11]$$

The net energy content of feeds depends on the level at which the cow is producing milk (i.e., multiple of maintenance). Using a 4 percent reduction in feed NE_1 content for each multiple of maintenance (MMNT) (NRC, 1988), the energy content of feed i is adjusted from the energy content for three times maintenance if intake is other than three times maintenance:

$$NE_{1,i,adjusted} = NE_{1,i}\ (1-0.04(MMNT-1))/0.92 \qquad [5.12]$$

where:

$$MMNT = NE_l^r \; / \; NE_{l,m} \qquad [5.13]$$

Alternatively, since the 4% per multiple of maintenance reduction is used for all feeds, the requirement can be increased by the inverse of the factor in equation [5.12] and the energy content of the feeds held constant at the three times maintenance level; i.e., adjust NE_l^r by:

$$NE_{l,adjusted}^r = 0.92NE_l^r/(1-0.04(MMNT-1)) \qquad [5.14]$$

Although this approach is somewhat misleading, it simplifies implementation because the energy content of the feedstuffs does not change as rations are balanced for different animals.

The energy constraint to the LP ration balancer is then:

$$\Sigma \, x_i \cdot NE_{l,i} \; = \; NE_{l,adjusted}^r \qquad [5.15]$$

and the energy contents of each feed, $NE_{l,i}$ is three times maintenance. The equality assures that the ration will not provide excess energy.

5.1.4 Protein

Protein requirements are calculated as in NRC (1988), using the absorbed protein system (NRC, 1985). The absorbed protein requirement (AP^r) includes needs for maintenance, weight change, pregnancy, lactation and fecal output:

$$AP^r = MNTP/0.67 + DPA + YPN/0.5 + LPN/0.7 + FPN \qquad [5.16]$$

where:

$$MNTP = 0.0002BW^{0.6} + 0.00275BW^{0.5} \qquad [5.17]$$

$$DPA = 0.256\Delta BW \qquad \text{(lower limit of -0.1875)} \qquad [5.18]$$

$$\begin{aligned} YPN &= 0.001136BW^{0.7} && \text{if days pregnant} \geq 210 \\ &= 0 && \text{if days pregnant} \leq 210 \qquad [5.19] \end{aligned}$$

$$LPN = (0.019 + 0.004PFAT)MPD \qquad [5.20]$$

$$FPN = 0.090IDM \qquad [5.21]$$

The lower limit on difference protein absorbed (DPA) incorporates an upper boundary on mobilized protein. The indigestible dry matter (IDM) is estimated from the intake and digestibility of an approximate diet:

$$IDM = PDMI(1-ATDN) \qquad (5.22)$$

In the approximate diet, intake is predicted from the energy requirement and recommended energy concentrations for the diet (NRC, 1988):

$$PDMI \approx NE_1^r/NE_{1,diet} \qquad [5.23]$$

where:

$$NE_{1,diet} = 1.25 \qquad \text{for dry cows}$$

$$= 1.42 + 0.01(MPD-MPD_{min})(RELMBS)(0.74)/(0.3512+0.0962(PFAT))$$

(lower limit of 1.42, upper limit of 1.72) for lactating cows [5.24]

$$MPD_{min} = 10(RELMBS)(0.74)/(0.3512+0.0962(PFAT)) \qquad [5.25]$$

$$RELMBS = ((BW)/600)^{0.75} \qquad [5.26]$$

To estimate the digestiblity from the energy concentration, a production level of three times maintenance is assumed:

$$ATDN = 0.92(NE_{1,diet} + 0.12) / 2.45 \qquad [5.27]$$

The requirement for absorbed protein is used in ration formulation. The procedure discussed here differs slightly from that of NRC (1988) to provide a more clear description of what occurs in the digestive tract of a ruminant.

Protein absorbed through the intestine walls is available from two sources: microbial protein (MCP) formed in the rumen, and available rumen escape protein (AESCP = CP(1-DEGR-ADIP)). The efficiency of converting MCP into absorbed protein is 64% (NRC, 1988). This 64% comes from 80% efficiency in converting ammonia to bacterial true protein in combination with a bacterial true protein digestibility of 80%. NRC (1988) suggests that escape protein is 80% digestible. Previous dairy (NRC, 1978) and current beef (NRC, 1984) requirements are based on total absorbability of 75 to 80% and 90%, respectively. With an escape protein digestibility of 80%, this cannot be true (i.e., a weighted average of 64% and 80% cannot be in the range of 80 to 90%); thus, escape protein must have a digestiblity of approximately 95%. The use of 80% digestibility is warranted when unavailable (or fiber-bound) undegraded protein is not explicitly subtracted from total undegraded protein as in NRC (1988). The following is based on the 64 and 95% conversion rates for MCP and AESCP, respectively, because unavailable protein is subtracted from total undegraded protein.

Following NRC (1988), the absorbed protein requirement is split into two fractions: degradable and undegradable, or escape. Degraded protein is converted into microbial protein in the rumen and is later absorbed through the walls of the small intestine. Undegraded protein (sometimes referred to as bypass protein) passes through the rumen unchanged before being absorbed from the small intestine.

The bacterial crude protein yield (BCP_{diet}) is determined by the amount of substrate in the diet for microbial growth. For a lactating cow, the substrate is expressed in terms of the net energy in the diet:

$$BCP_{diet} = 6.25(0.01)NE \qquad [5.28]$$

(D.R. Mertens, 1988 personal communication). Though this relationship is not applicable with diets containing fatty sources of energy, within DAFOSYM it poses no problem. This substrate must be matched with an appropriate amount of ammonia in the rumen for proper microbial activity to occur. If the conversion efficiency of rumen ammonia into bacterial protein is 90% (NRC, 1988), the rumen available protein (RAP^r) (ammonia) requirement is:

$$RAP^r = BCP_{diet}/0.9 \qquad [5.29]$$

The ammonia comes from degraded intake protein as well as recycled ammonia. If 15% of intake protein is recycled (NRC, 1988), the rumen available protein is:

$$RAP_{diet} = NH3_{diet} + 0.15CP_{diet} \qquad [5.30]$$

where:

$$NH3_{diet} = \Sigma\ x_i \cdot DEGR_i \cdot CP_i \qquad [5.31]$$

$$CP_{diet} = \Sigma\ x_i \cdot CP_i \qquad [5.32]$$

If excess degraded protein is allowed in the diet, the rumen available protein requirement can be expressed as the following ration constraint:

$$\Sigma\ x_i \cdot CP_i(DEGR_i+0.15) \geq BCP_{diet}/0.9 \qquad [5.33]$$

Given a total absorbed protein requirement, that that is not provided by microbial protein must be provided as available escape protein. Using the 64% and 95% efficiencies discussed above:

$$0.64BCP_{diet} + 0.95AESCP_{diet} \geq AP^r \qquad [5.34]$$

Equation [5.34] can be rewritten so the available escape protein requirement is an explicit ration constraint:

$$\Sigma\ 0.95x_i \cdot AESCP_i \geq AP^r - 0.64BCP_{diet} \qquad [5.35]$$

The protein constraints on the diet are then [5.33] and [5.35]. These constraints will allow excess protein in the diet but will assure protein requirements are satisfied.

5.1.5 Linear program implementation

The ration constraints outlined above are in the form of inequalities. These constraints are solved using linear programming (LP) as algorithm which solves simultaneous inequalities. The feed options in the LP solution are forage, high moisture ear corn, dry corn grain, soybean meal and distiller's grains. The objective function for the LP is rigged to maximize forage use. To accomplish the goal of maximum forage use, a "ration cost" is minimized:

$$\text{Minimize:} \quad \Sigma\, x_i \cdot PRICE_i$$

where the relative prices (PRICE) of forages, corn grain, soybean meal and distiller's grain are 0, 1.0, 2.2 and 1.6, respectively. The forage mix is determined from feed allocation rules discussed in Section 5.5.2.1. High moisture ear corn (HMEC) cannot be readily sold, so it is desirable to deplete HMEC supplies before feeding corn grain, if possible. For the purpose of balancing rations, the relative price of HMEC is set to zero if HMEC is available. If it is unavailable, the relative price is set higher than that of corn grain so it will not become part of the diet.

The ration constraints for lactating and dry cows are repeated here for clarity:

$$\Sigma\, x_i \cdot ANDF_i \leq C_{ic} \cdot BASEWT \qquad [5.4]$$

$$\Sigma\, x_i(RV_i - 0.75ANDF_i) \geq 0 \qquad [5.6]$$

$$\Sigma\, x_i \cdot NE_{l,i} = NE^r_{l,adjusted} \qquad [5.15]$$

$$\Sigma\, x_i \cdot CP_i(DEGR_i + 0.15) \geq BCP_{diet}/0.9 \qquad [5.33]$$

$$\Sigma\, 0.95x_i \cdot AESCP_i \geq AP^r - 0.64BCP_{diet} \qquad [5.35]$$

It is possible that for given feeds and a given animal, these five constraints present an unsolvable problem. Reducing the milk production level until the feeds can satisfy all animal requirements (Section 5.5.2.1) resolves this problem.

5.2 Growing heifer model

The objective of the growing heifer model is to formulate rations that meet the nutrient requirements of a described heifer. Again the assumption is that forage quality will have negligible impact on mineral supplementation, so the model is concerned with only intake, fiber, energy and protein. The structure is exactly the same as that of the lactating cow model. Intake and fiber constraints are the same except that the ingestive capacity of a growing heifer is a function of her current body weight (BW):

$$IC = C_{ic} \cdot BW \qquad [5.36]$$

The differences in energy and protein requirements are outlined in the following sections.

5.2.1 Energy

The common energy system for growing animals includes requirements for net energy for both gain and maintenance. Because intake is being predicted rather than predetermined, it was necessary to simplify these relationships to one equivalent energy requirement. Because net energy for maintenance (NE_m) and gain (NE_g) energy concentrations in feeds are computed from metabolizable energy (ME) (NRC 1984), the equivalent system was based on ME.

The metabolizable energy concentration in the diet is specified as a function of relative weight (RELLW) (NRC, 1988):

$$ME_{diet} = 2.67 - 1.072(RELLW-.125)$$
$$2.00 \leq ME_{diet} \leq 2.67 \qquad [5.37]$$

where:

$$RELLW = BW/800 \quad [5.38]$$

for large-breed females.

The maintenance and gain energy concentrations in the diet are functions of the metabolizable energy concentration of the diet:

$$NE_{g,diet} = 1.42(ME_{diet}) - 0.174(ME_{diet})^2 + 0.0122(ME_{diet})^3 - 1.65 \quad [5.39]$$

$$NE_{m,diet} = 1.37(ME_{diet}) - 0.138(ME_{diet})^2 + 0.0105(ME_{diet})^3 - 1.12 \quad [5.40]$$

Based on these concentrations, the amount of intake necessary to meet requirements is computed:

$$PDMI \approx DMI_m + DMI_g \quad [5.41]$$

where:

$$DMI_m = NE_m^r / NE_{m,diet} \quad [5.42]$$

$$DMI_g = NE_g^r / NE_{g,diet} \quad [5.43]$$

(NRC, 1988). The maintenance and gain energy requirements are:

$$NE_m^r = 0.086BW^{0.75} \quad [5.44]$$

$$NE_g^r = 0.035BW^{0.75}\Delta BW^{1.119} + \Delta BW \quad [5.45]$$

for large-breed female dairy animals. A metabolizable energy requirement (ME^r) is computed from the ME concentration and the approximate intake:

$$ME^r = ME_{diet} \cdot PDMI \quad [5.46]$$

In an LP format, the energy constraint for the diet of a growing heifer is:

$$\Sigma\, x_i \cdot ME_i = ME^r \quad [5.47]$$

Equation [5.15] for lactating cows is replaced by equation [5.47] when formulating rations for growing heifers.

5.2.2 Protein

The absorbed protein system (NRC, 1985; 1988) is also used for growing heifers. The requirements are the same as those of lactating cows except for protein requirements due to weight change and fecal output. For the growing heifers, difference protein absorbed (DPA) is zero. In its place is retained protein (RPN). The absorbed protein requirement for growing heifers is:

$$AP^r = MNTP/0.67 + RPN/0.65 + YPN/0.5 + FPN \qquad [5.48]$$

where:

$$RPN = \Delta BW(0.211 - 0.0262NE_g^r/\Delta BW) \qquad [5.49]$$

and MNTP, FPN and YPN are computed as outlined for lactating cows. For growing heifers, the adjusted total digestible nutrient content in the diet (ATDN) (necessary for prediction of FPN) is estimated from digestible energy (DE):

$$ATDN = 0.92DE_{diet}/4.409 \qquad [5.50]$$

where:

$$DE_{diet} = (ME_{diet}+0.45)/1.01 \qquad [5.51]$$

The structure of the dietary protein constraints is exactly the same as that for the lactating cow: i.e., two protein inequalities -- one for degraded protein (5.33), one for available escape protein (5.35). A difference is that the bacterial protein yield is expressed as a function of baseline TDN rather than net energy of lactation. For growing heifers (D.R. Mertens, 1988 personal communication):

$$BCP_{diet} = 6.25(0.0230)BTDN_{diet} \qquad [5.52]$$

where:

$$BTDN_{diet} = \Sigma\ x_i \cdot BTDN_i \qquad [5.53]$$

Baseline TDN is related to metabolizable energy (NRC, 1988):

$$BTDN_i = (ME_i + 0.45) / [(1.01)(4.409)] \qquad [5.54]$$

5.3 Feed characteristics

Ration constraints are composed of a right-hand side, which specifies a limit or requirement of the animal, and a left-hand side summation, which specifies nutrients provided by the feeds. Feed characteristics traced through growth, harvest and storage of all forages include neutral detergent fiber (NDF) and crude protein (CP). DAFOSYM also models non-protein nitrogen (NPN) content of silages and the acid detergent insoluble protein (ADIP) content of hay. The ration constraints involve these as well as other characteristics that can be assumed constant for a given forage or can be determined from NDF and CP.

Table 5.2 includes quality characteristics for typical ruminant feedstuffs. The first five lines of the table summarize characteristics of purchased feeds and farm-produced non-forage feeds. These characteristics are assumed to be constant (i.e., do not vary from year to year).

Adjusted NDF content of forages is equal to the NDF content. The roughage value for alfalfa hay and alfalfa silage is also equal to the NDF content. The roughage value of corn silage is credited to the stover and husks in the silage; thus, the roughage value is the total NDF content less the NDF contribution from the grain in the corn silage:

$$RV_{corn\ silage} = NDF_{corn\ silage} - GR\ NDF_{grain} \qquad [5.55]$$

The grain to total dry matter ratio (GR) is computed in the corn growth model. The NDF concentration of corn grain is 0.12 (Table 5.2).

Table 5.2 Characteristics* of various ruminant feeds.

Feed	NDF	ANDF	RV	NE_l	ME	CP	DEGR†	ADIP
Corn grain	0.12	0.12	0.0	2.03	3.47	0.10	0.48	0.02
High-moisture ear corn§	0.29	0.167	0.0	1.84	2.85	0.093	0.45	0.09
Distiller's grain	0.44	0.14	0.0	1.99	3.47	0.295	0.46	0.087
Soybean meal	0.14	0.14	0.0	1.86	3.29	0.518	0.65	0.006
Medium quality alfalfa hay	0.47	0.47	0.47	1.31	2.14	0.18	0.70	0.05
Low quality alfalfa hay	0.52	0.52	0.52	1.20	1.98	0.15	0.70	0.06
High quality alfalfa hay	0.40	0.40	0.40	1.46	2.48	0.21	0.70	0.04
Medium quality alfalfa silage	0.46	0.46	0.46	1.33	2.34	0.19	0.77	0.05
Low quality alfalfa silage	0.49	0.49	0.49	1.26	2.08	0.16	0.77	0.05
Corn silage	0.48	0.48	0.42	1.50	2.48	0.084	0.69	0.059

* NDF neutral detergent fiber, fraction of dry matter
ANDF adjusted neutral detergent fiber, fraction of dry matter
RV roughage value, fraction of dry matter
NE_l net energy for lactation, Mcal/kg
ME metabolizable energy, Mcal/kg
CP crude protein, fraction of dry matter
DEGR protein degradability, fraction
ADIP acid detergent insoluble protein, fraction of crude protein
† D.R. Mertens (1988 personal communication); NRC (1988)
§ HMEC contains approximately 15 percent cobs

Protein degradability of alfalfa hay is assumed to be constant at 0.70. Degradability of silages is computed from the non-protein nitrogen (NPN) content as predicted by the silo model. It is assumed that all NPN is degraded and that 50% of the true protein is soluble and degraded. Thus, the insoluble true protein is the undegraded portion.

$$DEGR_{silages} = NPN + 0.5(1-NPN)$$

$$= 0.5 + 0.5NPN \qquad [5.56]$$

Forage net energy for lactation values are predicted from NDF content (D.R. Mertens, 1988 personal communication):

$$NE_{l,alfalfa} = 2.323 - 2.16NDF_{alfalfa} \quad [5.57]$$

$$NE_{l,corn\ silage} = 2.692 - 2.491NDF_{corn\ silage} \quad [5.58]$$

Based on published data (NRC, 1988), ME of forages (alfalfa and corn silage) is 65% greater than the NE_l; thus, for forages:

$$ME_i = 1.65NE_{l,i} \quad [5.59]$$

5.4 Verification

Verification (does the model perform as intended) of the animal model was carried out by formulating rations for describable animals, and comparing the nutrient contents of those rations to those suggested by NRC (1988). The intent was to replicate (or agree with) Table 6.5, "Recommended nutrient content of diets for dairy cattle," in NRC (1988). It should be recognized that the NRC table contains only typical values. As NRC warns and this validation study points out, nutrient concentrations in the diet should vary with the feeds in the diet and should not be considered as fixed standards. Rather, with intake limitations recognized, emphasis should be placed on meeting requirements per day.

5.4.1 Lactating cow model

For verification of the lactating cow model, rations were formulated with several forage options. Each diet was balanced using the described forage, corn grain, soybean meal and distiller's grain. Descriptions of the animals matched those of Table 6.5 (NRC, 1988); i.e., weight of 600 kg, weight change of +0.33 kg/day, milk production from 0 to 50 kg/day and milk fat of 4.0%. In addition to these characteristics, the animal model requires the number of days pregnant and the daily ingestive capacity of ANDF as a fraction of body weight.

These were assumed to be 0 and 0.011, respectively.

Table 5.2 lists the characteristics of each feed, and Table 5.3 lists each diet as formulated by the model. The values for dry matter intake predicted by the new model agreed very well with the values in Table 6.1 of NRC (1988). Nutrient concentrations in the formulated diets are listed in Tables 5.4, 5.5 and 5.6 along with the NRC recommendations.

With medium quality alfalfa hay (MQH) or corn silage (CS) as the forage source, the maximum sustainable milk production was approximately 30 kg/day (Table 5.3). This would correspond roughly to 7,100 kg per lactation. At higher milk production levels, it was not possible to meet the nutrient requirements while satisfying the fiber intake limitation. Note that use of high quality alfalfa resulted in higher potential milk production. The intake increased as milk production increased because the bulky forages were replaced by concentrates to meet nutrient requirements. By method of solution, each diet as formulated maximizes intake, given the nutrient requirements to be satisfied.

For all milk production levels (0 to 40 kg/day), the formulated diets had energy concentrations that agreed very well with those suggested by NRC (1988) (Table 5.4). Differences in energy concentration can be explained solely by intake differences because the total daily energy requirement was satisfied. For the dry cow (0 kg milk/day), the energy concentrations were higher than the NRC recommendations for all diets except the low quality hay (LQH) diet. For the dry cow, the most suitable forage is LQH with little or no corn silage.

Table 5.3. Formulated rations for 600 kg cows producing varying amounts of 4% fat milk while gaining 0.33 kg/day.

Forage source*	Amounts in diet (kg/day) HAY	AS	CS	CG	SBM	DST	Daily DMI
0 kg milk/day							
MQH	10.2	0.0	0.0	0.0	0.0	0.0	10.2
MQH+CS	4.4	0.0	4.4	0.0	0.6	0.0	9.3
MQMF	3.0	3.0	3.0	0.0	0.5	0.0	9.5
HQH	9.2	0.0	0.0	0.0	0.0	0.0	9.2
LQH	10.9	0.0	0.0	0.0	0.2	0.0	11.1
MQAS	0.0	9.6	0.0	0.0	0.4	0.0	9.9
CS	0.0	0.0	7.3	0.0	1.3	0.0	8.6
10 kg milk/day							
MQH	13.7	0.0	0.0	0.0	0.0	0.0	13.7
MQH+CS	6.0	0.0	6.0	0.0	0.6	0.0	12.6
MQMF	4.1	4.1	4.1	0.5	0.0	0.0	12.8
HQH	12.3	0.0	0.0	0.0	0.0	0.0	12.3
LQH	12.3	0.0	0.0	1.4	0.0	0.1	13.9
MQAS	0.0	13.1	0.0	0.0	0.3	0.0	13.4
CS	0.0	0.0	10.0	0.0	1.6	0.0	11.6
20 kg milk/day							
MQH	12.9	0.0	0.0	4.1	0.0	0.3	17.3
MQH+CS	6.4	0.0	6.4	1.8	0.0	2.0	16.7
MQMF	4.3	4.3	4.3	2.2	0.0	1.8	16.9
HQH	16.2	0.0	0.0	1.1	0.0	0.0	17.2
LQH	11.2	0.0	0.0	4.9	0.0	1.2	17.3
MQAS	0.0	13.2	0.0	2.6	0.0	1.4	17.3
CS	0.0	0.0	12.8	0.4	1.7	1.3	16.2
30 kg milk/day							
MQH	11.6	0.0	0.0	8.7	0.0	0.6	21.0
MQH+CS	5.8	0.0	5.8	7.3	1.6	0.0	20.5
MQMF	3.9	3.9	3.9	7.2	0.5	1.2	20.6
HQH	14.6	0.0	0.0	6.3	0.0	0.0	20.9
LQH	10.1	0.0	0.0	9.7	1.2	0.0	21.1
MQAS	0.0	11.9	0.0	7.4	0.0	1.7	21.0
40 kg milk/day							
HQH	12.9	0.0	0.0	12.8	0.0	0.2	24.9

* Feed characteristics are in Table 5.2.

MQH 100% medium quality alfalfa hay
MQH+CS 50% medium quality alfalfa hay, 50% corn silage
MQMF 33% medium quality alfalfa hay, 33% medium quality alfalfa silage, 33% corn silage
HQH 100% high quality alfalfa hay
LQH 100% low quality alfalfa hay
MQAS 100% medium quality alfalfa silage

Table 5.4. Net Energy of lactation (Mcal/kg) of formulated rations for 600 kg cows producing varying amounts of 4% fat milk while gaining 0.33 kg/day*.

Forage source	Milk production (kg/day) 0	10	20	30	40
NRC†	1.25	1.42	1.52	1.62	1.72
MQH	1.31	1.31	1.49	1.63	*
MQH+CS	1.44	1.43	1.54	1.66	*
MQMF	1.41	1.40	1.53	1.66	*
HQH	1.46	1.46	1.49	1.63	1.73
LQH	1.21	1.29	1.49	1.62	*
MQAS	1.35	1.34	1.49	1.63	*
CS	1.55	1.55	1.59	*	*

* Missing data implies that forage quality was too low to satisfy all ration criteria.
† Nutrient concentration recommended in NRC (1988).

Comparing the NDF content in all diets to those suggested by NRC show that, in general, the model allows more NDF in the diet than necessary (Table 5.5). The higher NDF concentration is in agreement with recommendations made by animal scientists at Michigan State University (J.W. Thomas, 1987 personal communication). Perhaps diets with poorer quality forages would better agree with the NRC guidelines. With the forages used in these verification diets, the amounts of concentrate in the diet were relatively low.

The crude protein contents of the diets, although generally higher, were in satisfactory agreement with NRC suggestions (Table 5.6). Diets containing excess degraded protein are noted in Table 5.6. In these diets, either the forages used were simply of higher quality than necessary or the use of soybean meal was more economical than the use of

Table 5.5. Neutral detergent fiber content (fraction) of formulated rations for 600 kg cows producing varying amounts of 4% fat milk while gaining 0.33 kg/day*.

Forage source	Milk production (kg/day) 0	10	20	30	40
NRC†	.35	.28	.28	.28	.25
MQH	.47	.47	.38	.32	*
MQH+CS	.45	.46	.40	.32	*
MQMF	.45	.46	.39	.32	*
HQH	.40	.40	.38	.32	.27
LQH	.51	.48	.38	.31	*
MQAS	.45	.45	.38	.32	*
CS	.43	.43	.41	*	*

* Missing data implies that forage quality was too low to satisfy all ration criteria.
† Nutrient concentration recommended in NRC (1988).

Table 5.6. Crude protein content (fraction) of formulated rations for 600 kg cows producing varying amounts of 4% fat milk while gaining 0.33 kg/day*.

Forage source	Milk production (kg/day) 0	10	20	30	40
NRC†	.12	.12	.15	.16	.17
MQH	$\underline{.18}$	$\underline{.18}$	$\underline{.16}$	.15	*
MQH+CS	$\underline{.16}$	$\underline{.15}$	.15	.15	*
MQMF	$\underline{.17}$	$\underline{.16}$	$\underline{.16}$	.15	*
HQH	$\underline{.21}$	$\underline{.21}$	$\underline{.20}$	$\underline{.18}$	.16
LQH	$\underline{.16}$	$\underline{.15}$	.15	.15	*
MQAS	$\underline{.20}$	$\underline{.20}$	$\underline{.19}$	$\underline{.17}$	*
CS	$\underline{.15}$	.14	.15	*	*

* Missing data implies that forage quality was too low to satisfy all ration criteria.
Underlined entries indicate diets containing excess degraded protein.
† Nutrient concentration recommended in NRC (1988).

distiller's grain. This resulted in diets providing more crude protein than necessary.

To assure effects of body weight change on requirements were computed correctly, sample calculations were performed for a 600 kg cow producing 30 kg milk containing 4% fat. The cow was assumed to be less than 210 days pregnant. Table 5.7 contains the results. These calculations showed that the impact of body weight change on requirements was correct.

5.4.2 Growing heifer model

To verify the growing heifer model, rations were formulated with several forage options, as previously described. Descriptions of the animals matched those of Table 6.5 in NRC (1988); i.e., weights of 150, 250 and 400 kg and weight change of +0.70 kg/day. In addition to these characteristics, the animal model requires the number of days pregnant and the daily ingestive capacity of ANDF as a fraction of body weight. These were assumed to be 0 and 0.011 respectively for each heifer group.

Each ration as formulated by the model is listed in Table 5.8. Average dry matter intakes of 4.0, 6.0 and 8.8 kg/day for the three groups agreed closely with the corresponding values of 3.8, 5.6 and 8.9 kg/d computed using the NRC relationships. Table 5.9 gives the crude protein and metabolizable energy concentrations in the diet for each ration. The differences in energy concentration are relatively small and can be explained by the differences in intake. The crude protein concentrations are higher than NRC (1988) recommendations. In all but two diets (CS-based diets for older heifers), excess degraded protein was provided in the diet because the forage source was of higher quality

Table 5.7 Impact of body weight change of a 600 kg cow producing 30 kg of 4% fat milk on net energy and absorbed protein requirements.

Body weight change (kg/day)	Net energy requirement (Mcal/day)	Absorbed protein requirement (kg/day)
-1.5	23.8	1.85
-1.0	26.3	1.90
-0.5	28.7	2.00
0.0	31.2	2.18
0.5	33.8	2.36
1.0	36.3	2.53
1.5	38.9	2.71

Table 5.8. Formulated rations for heifers gaining 0.70 kg/day.

Forage source*	HAY	AS	CS	CG	SBM	DST	Daily DMI
	Amounts in diet (kg/day)						
3-6 months (150 kg)							
LQH	2.9	0.0	0.0	0.6	0.0	0.6	4.1
LQH+CS	1.5	0.0	1.5	0.0	0.1	0.0	4.0
LQMF	1.0	1.0	1.0	0.0	0.0	0.9	4.0
MQH	3.3	0.0	0.0	0.4	0.0	0.4	4.1
MQH+CS	1.5	0.0	1.7	0.0	0.3	0.4	4.0
MQMF	1.1	1.1	1.1	0.0	0.2	0.5	4.1
CS	0.0	0.0	2.9	0.0	0.8	0.0	3.8
6-12 months (250 kg)							
LQH	5.0	0.0	0.0	1.2	0.0	0.0	6.2
LQH+CS	2.7	0.0	2.7	0.6	0.0	0.0	6.0
LQMF	1.8	1.8	1.8	0.7	0.0	0.0	6.0
MQH	5.7	0.0	0.0	0.5	0.0	0.0	6.2
MQH+CS	2.9	0.0	2.9	0.2	0.0	0.0	5.9
MQMF	1.9	1.9	1.9	0.2	0.0	0.0	6.0
CS	0.0	0.0	5.3	0.0	0.3	0.0	5.6
> 12 months (400 kg)							
LQH	8.2	0.0	0.0	1.2	0.0	0.0	9.4
LQH+CS	4.4	0.0	4.4	0.2	0.0	0.0	9.0
LQMF	2.9	2.9	2.9	0.3	0.0	0.0	9.1
MQH	9.4	0.0	0.0	0.0	0.0	0.0	9.4
MQH+CS	4.4	0.0	4.4	0.0	0.0	0.0	8.7
MQMF	3.0	3.0	3.0	0.0	0.0	0.0	8.9
CS	0.0	0.0	7.5	0.0	0.6	0.0	8.0

* Feed characteristics are in Table 5.2

MQH 100% medium quality alfalfa hay

MQH+CS 50% medium quality alfalfa hay, 50% corn silage

MQMF 33% medium quality alfalfa hay, 33% medium quality alfalfa silage, 33% corn silage

HQH 100% high quality alfalfa hay

LQH 100% low quality alfalfa hay

MQAS 100% medium quality alfalfa silage

Table 5.9 Crude protein (fraction) and metabolizable energy (Mcal/kg) concentrations of formulated rations for heifers gaining 0.70 kg/day.

Forage source	CRUDE PROTEIN* Age (months)†			METABOLIZABLE ENERGY Age (months)		
	3-6	6-12	>12	3-6	6-12	>12
NRC§	.16	.14	.12	2.60	2.47	2.27
LQH	.16	.14	.14	2.38	2.24	2.16
LQH+CS	.16	.12	.12	2.47	2.34	2.26
LQMF	.17	.13	.13	2.44	2.31	2.22
MQH	.18	.18	.17	2.39	2.25	2.16
MQH+CS	.18	.13	.13	2.47	2.35	2.32
MQMF	.19	.15	.15	2.44	2.32	2.28
CS	.18	.11	.12	2.61	2.51	2.52

* All diets except CS diets for older heifers contained excess degraded protein.
† Average weights of 150, 250 and 400 kg for 3-6, 6-12 and >12 month old heifers, respectively.
§ Nutrient concentration recommended in NRC (1988).

than necessary or the use of soybean meal was more economical than the use of distiller's grain.

To assure that the effects of body weight change on requirements were computed correctly, sample calculations were performed for a 400 kg heifer assumed to be less than 210 days pregnant. Table 5.10 contains the results which show that the impact of body weight change on requirements was correct.

5.5 Whole-herd model

The whole-herd model uses a time step of one year. The objective was to describe a complete dairy herd, balance rations for all animals in the herd and, in doing so, predict feed disappearance and milk

Table 5.10 Impact of body weight change of a 400 kg heifer on metabolizable energy and absorbed protein requirements.

Body weight change (kg/day)	Metabolizable energy requirement (Mcal/day)	Absorbed protein requirement (kg/day)
0.0	12.5	0.278
0.5	17.8	0.456
1.0	23.9	0.635
1.5	30.3	0.815

production. The whole-herd model uses the single-animal models described above, incorporates a distribution of animals in the herd and allocates available feeds to them. The model does not simulate day-to-day feeding, although it can be used to give insight into optimal feed allocation.

5.5.1 Herd composition

A standard distribution of animals was assumed for the herd. From these standard data, milk production of the herd, the number of first-lactation cows, the sizes of the animals and the number of heifers can be adjusted. The cows are separated into groups according to the time spent in each of three stages of lactation and the dry period. A typical 390-day lactation cycle (13-month calving interval) is divided into four sections (Figure 5.1). The groups correspond to the first 60, the next 90 and the next 180 days of lactation with 60 days allotted for the dry period. A typical cow spends 15.4% of the time in the first stage of lactation, etc. The average number of days pregnant for cows in the four stages are 0, 0, 130 and 250, respectively. The young and

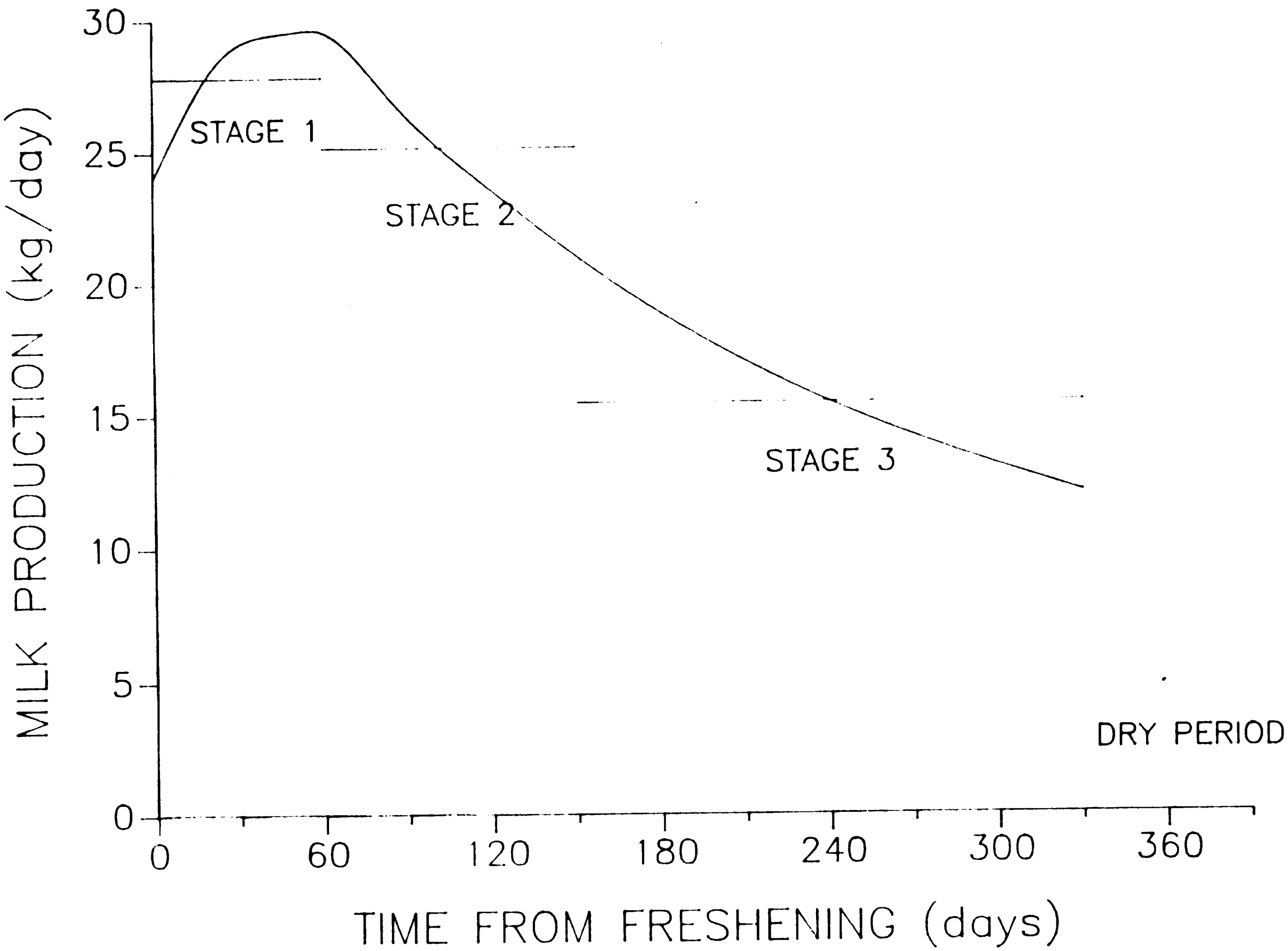

Figure 5.1 Division of the lactation curve of a typical cow producing 6,700 kg of milk in a 390-day lactation cycle.

old heifers average 0 and 180 days pregnant, respectively.

The standard herd is described in Table 5.11. The data in the table are adjusted to change herd characteristics as follows. The table is based on a mature cow that produces 6,270 kg of milk per year (6,700 kg per 390-day lactation). To adjust the herd average milk production, the milk production per day for each group is found by:

$$MPD = (BASEMP/6270)(\text{table value for milk production}) \quad [5.60]$$

If forage quality limits milk production during the first stage of lactation, milk production in the later stages is decreased proportionately. The body weights and changes in body weights are based on a mature cow's having an average weight of 622 kg during the second stage of lactation. If the animals are of a different size, body weight and body weight change for each animal are adjusted from the table values by:

$$BW = (BASEWT/622)(\text{table value for BW}) \quad [5.61]$$

$$\Delta BW = (BASEWT/622)(\text{table value for } \Delta BW) \quad [5.62]$$

The fraction of cows experiencing their first lactation is accounted for by computing a weighted average milk production, milk fat, body weight, body weight change and intake factor (C_{1C}) for all cows in each of the four stages of lactation:

$$Y_j = FFC \cdot Y_{j,\text{first lactation}} + (1\text{-}FFC)Y_{j,\text{mature}} \quad [5.63]$$

where Y refers to the animal characteristics in Table 5.11 and Y_j is the value used for ration formulation when considering group j. For a typical herd with 26% primiparous cows, the resulting characteristics are in Table 5.12.

Rations should not be balanced for the average animal in a given group because this would limit the production level of the higher

Table 5.11 Parameter values used to describe animals in the dairy herd.

Animal group	Number in group*	Milk production (kg/d)	Milk fat (%)	Body weight (kg)	Body weight change (kg/d)	C_{ic} (kg ANDF/ kg BW)
Young heifers	XYHEIF	0.0	---	200	0.82	0.0105
Old heifers	XOHEIF	0.0	---	400	0.48	0.0110
Stage 1 mature cows	.154(XLCT)(1-FFC)	29.0	3.8	639	-0.72	0.0107
Stage 2 mature cows	.231(XLCT)(1-FFC)	26.2	3.4	622	0.10	0.0120
Stage 3 mature cows	.461(XLCT)(1-FFC)	16.1	3.6	664	0.41	0.0130
Mature dry cows	.154(XLCT)(1-FFC)	0.0	---	722	0.65	0.0120
Stage 1 first lactation cows	.154(XLCT)(FFC)	23.6	3.8	524	-0.44	0.0094
Stage 2 first lactation cows	.231(XLCT)(FFC)	21.3	3.4	524	0.30	0.0106
Stage 3 first lactation cows	.461(XLCT)(FFC)	13.0	3.6	588	0.55	0.0114
First lactation dry cows	.154(XLCT)(FFC)	0.0	---	658	0.66	0.0110

* XYHEIF (number of young heifers), XOHEIF (number of old heifers), XLCT (number of lactating cows) and FFC (fraction of cows experiencing first lactation) are user-defined inputs.

Table 5.12 Description of a herd with 26% primiparous cows.

Animal group	Number in group*	Milk† production (kg/d)	Milk fat (%)	Body weight (kg)	Body weight change (kg/d)	C_{ic} (kg ANDF/ kg BW)
Young heifers	XYHEIF	0.0	---	200	0.82	0.0105
Old heifers	XOHEIF	0.0	---	400	0.48	0.0110
Stage 1	.154(XLCT)	27.6	3.8	609	-0.65	0.0104
Stage 2	.231(XLCT)	24.9	3.4	596	0.15	0.0116
Stage 3	.461(XLCT)	15.3	3.6	644	0.45	0.0126
Dry cows	.154(XLCT)	0.0	---	705	0.65	0.0117

* XYHEIF (number of young heifers), XOHEIF (number of old heifers) and XLCT (number of lactating cows) are user-defined inputs.
† Based on a 390-day lactation cycle with a herd average milk production level of 6,225 kg per lactation.

producing animals. Likewise, it is not advisable to formulate rations for the highest producer because lower producers would receive too rich a diet and this would waste feed. A balance between these options is to incorporate lead factors. A lead factor is a multiplicative constant by which the average production level in a group is adjusted upward to account for variability within the group. Based on the data of Stallings and McGilliard (1984), the lead factors used for the whole herd model were 1.12, 1.07 and 1.07 for the first, second and third stages of lactation, respectively. Ration requirements are computed using MPD multiplied by the respective lead factor. This results in a diet in which nutrient concentrations are higher than needed for the average cow, though feed disappearance is computed for the average animal.

5.5.2 Feed allocation

Feed allocation is of utmost importance in correctly evaluating forage systems. Least cost rations usually do not provide least cost or maximum profit production because of less than optimal decisions concerning feed allocation.

The feeds potentially produced on the DAFOSYM farm may include any combination of the following: high quality alfalfa silage, low quality alfalfa silage, high quality alfalfa hay, low quality alfalfa hay, corn silage, high moisture ear corn and corn grain. Possible purchased feeds include corn grain, medium quality alfalfa hay, soybean meal and distiller's grain. It is the objective of the feed allocation scheme to distribute these feeds properly so that purchased feed costs are low and, at the same time, all animal requirements are met.

Two feed allocation methods are discussed in this chapter. The first, decision rule feed allocation, is typical of the better dairy farmers. In this approach, the best forages are allocated to those animals with the highest nutrient requirements according to decision rules. The second, linear programming, combines feed allocation and ration formulation into a relatively large linear programming problem. DAFOSYM uses the decision rule allocation. The LP approach outlined here is intended as an ancillary model. In either approach, feeds are allocated at the end of the year. The model assumes that feed stocks and the quality of the feeds in storage are known.

5.5.2.1 Decision rule

Feed allocation was designed to make the best use of available feeds. The best way to use low quality alfalfa is to feed it to non-lactating cows, the animals with the lowest requirements. The highest producing lactating cows should be fed the highest quality alfalfa.

If there is no feasible solution to the LP ration constraints, the forages are not of sufficient quality to support the target milk production. When there is no feasible solution, the model reduces milk production (MPD) by 2% and attempts a new ration. This is repeated until a feasible ration is formulated.

Silages (alfalfa and corn) are not readily sold. The allocation scheme is set up to use ensiled forages at a faster rate than those that are not ensiled; however, there is no guarantee that stocks of ensiled forages will be completely depleted during the year.

The term "feeding order" is used here to imply a priority order for determining which feeds should be fed to which animals. The simulation of dairy herd feeding assumes that, once rations are determined for each group, the groups will be fed the corresponding rations for the entire year.

The feeding order was set for best feed use. Feeding animals with low nutrient requirements (dry cows and heifers) first allows for low quality alfalfa to be utilized where needed. Feeding the highest producing lactating cows next allows for the best alfalfa to be utilized where needed. Feeding of the lower producing cows last is beneficial because low quality alfalfa is used for animals with lower requirements when stocks of high quality alfalfa are depleted. Similarly, feeding younger heifers after feeding dry cows and older heifers will assure that, if a shortage of low quality alfalfa exists, the animals with higher requirements will receive the better feeds.

One might suggest feeding lactating cows with high quality hay, then feeding dry cows and heifers with low quality hay. With this feeding order, a shortage of sufficient high quality hay poses the following question: should the lower producing lactating cows be fed low quality hay or purchased medium quality hay? Purchasing hay with stocks still on the farm may not seem sensible; yet, if low quality hay stocks are also low, some lactating cows may get low quality hay while heifers or dry cows get medium quality hay. The priority order set in the previous paragraph eliminates this decision. Feeding priority starts at the high and low ends of the requirement spectrum; if purchased hay of medium quality is needed, it is provided to those animals with moderate needs.

The relative pricing of HMEC and CG within the LP ration formulator assures that HMEC will be used before CG, if possible, but the forage must be preassigned for the single-animal model. The preferred forage for stage 1 lactating cows is high quality alfalfa. For other lactating cows, the preferred forage is a mix of corn silage and high quality alfalfa. For dry cows and growing heifers, the preferred forage is corn silage plus low quality alfalfa. Alternative forages are used only when preferred forage stocks are depleted. If corn silage is not available, alfalfa is the only forage. If high quality alfalfa hay is in the preferred forage and is unavailable, low quality alfalfa hay is used and vice versa (similarly for alfalfa silages). If all farm-produced alfalfa has been fed, purchased medium quality alfalfa hay is used.

The forage mix is determined using an approximate forage requirement for the entire herd. The objective of the forage assignment is to completely use ensiled feeds before using alfalfa hay, if possible. Because forage use is maximized, intake for all animals is maximized. Using the roughage value constraint, we can obtain an estimate of the annual forage requirement for each group:

$$ARV_j = 0.75C_{ic} \cdot BW \cdot 365(\text{number in group } j) \qquad [5.64]$$

In practice, the ARV of dry cows should be decreased by approximately 30% because their intake is not typically at maximum. Summing the ARV over all groups (j=1 to 6) gives an estimate of the annual forage requirement:

$$ARVH = \Sigma\ ARV_j \qquad [5.65]$$

Because it is preferred to use all the corn silage on the farm, the fraction of alfalfa in the forage is computed so that all corn silage will be used:

$$FAIF = 1 - CSRV/ARVH \qquad [5.66]$$

The corn silage roughage value (CSRV) available is the amount of corn silage stored on the farm times its roughage value. Based on that part of the annual roughage value requirement estimate that is not supplied by corn silage, the fraction of hay in the alfalfa portion of the forage is computed so that alfalfa silage is used up, if possible.

$$FHAYIA = 1 - ASRV/(ARVH-CSRV) \qquad [5.67]$$

Computing the amount of a given feed in the ration involves using these fractions along with the ration as determined by the single-animal model. For example, the amounts of corn silage, alfalfa silage and alfalfa hay in the ration would be:

$$CS = FFID(1-FAIF)DMI \quad [5.68]$$

$$ALFSIL = FFID \cdot FAIF(1-FHAYIA)DMI \quad [5.69]$$

$$HAY = FFID \cdot FAIF \cdot FHAYIA \cdot DMI \quad [5.70]$$

Once a ration has been formulated, the next step is to determine how many animals in the current group can be fed the given ration for 365 days with current feed stocks. If all animals in the group can be fed the given ration, no problem exists; if not, as many as can be fed are fed, and the balance are fed with alternate feeds. If milk production within the group is different because different rations were used, a weighted average milk production level is computed for the group. Remaining feed quantities are updated each time a group of animals is fed.

5.5.2.2 Linear programming

The linear programming approach to feed allocation and simultaneous ration formulation is illustrated in Figure 5.2. This tabular format of LP setup can be used to minimize feed costs, meet ration criteria for all animal groups and, at the same time, meet constraints on the use of farm-produced feeds. The LP format has 37 rows and 66 columns. (Implementation using Fortran code involved 43 rows -- 6 being inactive -- to allow for easier experimentation with the model.) All non-labeled entries in Figure 5.2. are zeros.

The LP format has seven major regions of importance, each with a corresponding right-hand side. The six regions along the diagonal assure that the nutrient requirements and intake limitations of all animals are adequately satisfied. The seventh region across the bottom

		Feeds fed to animal group 1	Feeds fed to animal group 2	Feeds fed to animal group 3	Feeds fed to animal group 4	Feeds fed to animal group 5	Feeds fed to animal group 6	Right-Hand Side
		1 2 . . . n	1 2 . . . n	1 2 . . . n	1 2 . . . n	1 2 . . . n	1 2 . . . n	
minimize:		C_1 C_2 ----> C_n	C_1 C_2 ----> C_n	C_1 C_2 ----> C_n	C_1 C_2 ----> C_n	C_1 C_2 ----> C_n	C_1 C_2 ----> C_n	
subject to								
GROUP 1		F_1 F_2 ----> F_n						$\le IC_j$
		R_1 R_2 ----> R_n						$\ge O_r$
		N_1 N_2 ----> N_n						$= NE_{1,r,j}$
		D_1 D_2 ----> D_n						$\ge RAP_j$
		E_1 E_2 ----> E_n						$\ge EP_j$
GROUP 2			F_1 F_2 ----> F_n					$\le IC_j$
			R_1 R_2 ----> R_n					$\ge O_r$
			N_1 N_2 ----> N_n					$= NE_{1,r,j}$
			D_1 D_2 ----> D_n					$\ge RAP_j$
			E_1 E_2 ----> E_n					$\ge EP_j$
GROUP 3				F_1 F_2 ----> F_n				$\le IC_j$
				R_1 R_2 ----> R_n				$\ge O_r$
				N_1 N_2 ----> N_n				$= NE_{1,r,j}$
				D_1 D_2 ----> D_n				$\ge RAP_j$
				E_1 E_2 ----> E_n				$\ge EP_j$
GROUP 4					F_1 F_2 ----> F_n			$\le IC_j$
					R_1 R_2 ----> R_n			$\ge O_r$
					N_1 N_2 ----> N_n			$= NE_{1,r,j}$
					D_1 D_2 ----> D_n			$\ge RAP_j$
					E_1 E_2 ----> E_n			$\ge EP_j$
GROUP 5						F_1 F_2 ----> F_n		$\le IC_j$
						R_1 R_2 ----> R_n		$\ge O_r$
						M_1 M_2 ----> M_n		$= ME_{jr}$
						D_1 D_2 ----> D_n		$\ge RAP_j$
						E_1 E_2 ----> E_n		$\ge EP_j$
GROUP 6							F_1 F_2 ----> F_n	$\le IC_j$
							R_1 R_2 ----> R_n	$\ge O_r$
							M_1 M_2 ----> M_n	$= ME_{jr}$
							D_1 D_2 ----> D_n	$\ge RAP_j$
							E_1 E_2 ----> E_n	$\ge EP_j$
STOCKS	1	g_1	g_2	g_3	g_4	g_5	g_6	$\le AMT_k$
	2	g_1	g_2	g_3	g_4	g_5	g_6	$\le AMT_k$
	:							$\le AMT_k$
	:							$\le AMT_k$
	s	g_1	g_2	g_3	g_4	g_5	g_6	$\le AMT_k$

AMT_k : amount of feed k available, kg per year
C_i : cost of feed i, \$/kg dm
D_i : ammonia pool contribution from feed i
: $CP_i(DEGR_i + 0.15)$
$E_{i,r}$: available escape protein content of feed i, fraction
EP_j : escape protein requirement for group j, kg/d
: $AP_j - 0.578RAP_j$
F_i : adjusted NDF content of feed i, fraction
g_j : 365(number of animals in group j)
IC_j : ingestive capacity of group j
M_{ir} : ME content of feed i, Mcal/kg
ME_d : metabolizable energy requirement for group j, Mcal/d
$NE_{1,j}$: net energy requirement for group j, Mcal/d
N_i : NE_1 content of feed i, Mcal/kg
R_i : $(RV_i - 0.75ANDF_i)$
RAP_j : rumen available protein requirement for group j, kg/d
RV_i : roughage value of feed i
s : number of feeds with limited supply

Figure 5.2 Linear programming format for simultaneous feed allocation and ration formulation.

of the matrix assures that constraints on the supply of farm-produced feeds are not violated.

The feed prices used in the objective function are the selling price for farm-produced feeds and the purchase price of other feeds, as these represent the true opportunity prices of the feeds. Formulation of rations using this LP structure will result in true, least-cost rations from the whole farm perspective. The purpose of the LP structure is to evaluate the "loss" due to less than optimal use of feeds. All output from the LP allocator should be recognized as an upper bound on efficiency of allocation because logistics of feeding may impose constraints that is does not take into consideration.

It is important to note that the only difference between the decision rule and LP approaches is in feed allocation. Ration constraints for the approaches are identical, as are descriptions of the herd and available feeds.

6. ALFALFA VALUE

The cow model developed in the previous chapter is useful for determining the milk production potential from a given supply of forages and the required supplemental[1] feeds to produce that amount of milk. This chapter outlines a procedure and includes some results of an attempt to use the animal model of Chapter 5 to evaluate, in economic terms, incremental changes in alfalfa quality. The value of alfalfa is determined by considering the effects of forage quality on milk production and supplemental feed costs throughout the lactation cycle. Relative feed value is determined by dividing the value of the alfalfa by the value of a reference alfalfa.

6.1 Simulation approach

The process of determining alfalfa value included several steps and assumptions about the animal and feeds. The first step was, for various levels of alfalfa quality, to balance rations for an animal in each of the three lactation stages. Based on these rations, annual milk production (AMP), annual supplemental feed cost (ASFC), annual corn silage use (ACS) and annual alfalfa use (AA) were computed. The third step was to arbitrarily assign a value to a reference alfalfa quality. Based on this reference, the value of alfalfa at other quality levels

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[1] Supplemental feeds in the context of this chapter include corn grain, soybean meal and distiller's grain.

was ascribed by assuming a constant amount of unallocated income per cow.

6.1.1 Determination of alfalfa value

Unallocated income (UAI) was computed as milk income less feed costs and the extra cost of labor, veterinarian bills or other factors that increase as milk production increases.

$$UAI = P_{milk}\ AMP - ASFC - P_{corn\ silage}\ ACS - V\ AA - L\ P_{milk}\ AMP \qquad [6.1]$$

Expenses due to increased milk production were assumed to be 12% of the milk price (L=0.12, J.R. Black, 1988 personal communication); therefore, when an increase in milk production was associated with a change in the ration, only 88% of the increased revenue could be credited to the ration change because 12% was required to cover other costs. Corn silage price (value) was assumed to be \$0.05/kg DM and milk price was assumed to be \$0.25/kg. Therefore, equation [6.1] can be rewritten as:

$$\begin{aligned} UAI &= 0.25AMP - ASFC - 0.05ACS - V\ AA - 0.12(0.25)AMP \\ &= 0.22AMP - ASFC - 0.05ACS - V\ AA \qquad [6.2] \end{aligned}$$

Alfalfa value was determined by maintaining a constant value of unallocated income:

$$UAI = UAI_{ref} \qquad [6.3]$$

The reference alfalfa containing 45% NDF and 18% CP was assigned a value of \$0.05/kg DM. Substitution of equation [6.2] into [6.3] with rearrangement gives:

$$V = \frac{0.22(AMP-AMP_{ref})-(ASFC-ASFC_{ref})-0.05(ACS-ACS_{ref})+V_{ref}\ AA_{ref}}{AA} \qquad [6.4]$$

Values for AA_{ref}, AMP_{ref} and $ASFC_{ref}$ are determined from the diets formulated with the reference alfalfa (Appendix C).

6.1.2 Animal Characteristics

Forage value was determined only for lactating cows. Therefore, only the three stages of milk production were considered. Body weight, weight gain, milk fat and intake characteristics of the animal are presented in Table 5.12. (Although the base cow weighs 596 kg, the cow is hereafter referred to as a 600 kg cow). Potential milk production per day for the animal was varied to reflect two milk production levels (7,940 kg/cow-y and milk production limited by forage quality only). Using the production levels in Table 5.12 as a base, milk per day (MPD) corresponding to the three stages associated with the annual production level of 7,940 kg was:

$$MPD_{stage\ 1} = 27.6\ (7940/6225) \qquad [6.5]$$

$$MPD_{stage\ 2} = 24.9\ (7940/6225) \qquad [6.6]$$

$$MPD_{stage\ 3} = 15.3\ (7940/6225) \qquad [6.7]$$

For evaluating rations in the case where milk production was limited by forage quality, target milk production was set to an unreasonably high value. All rations for the animal in the first stage of lactation were then unsolvable. Milk per day was therefore decreased by 0.1 kg/day until all requirements could be satisfied. The milk production in later stages was set in proportion to milk production during the first stage. For this reason, this analysis is perhaps more sensitive to forage quality than is reality.

6.1.3 Feed characteristics

Rations were formulated in which the forage was 1/3 alfalfa hay, 1/3 alfalfa silage and 1/3 corn silage. Potential supplemental feeds were corn grain, soybean meal and distiller's grain, with prices of \$100, \$220 and \$154/T DM, respectively. All characteristics of the supplemental feeds and corn silage are included in Table 5.2. Degradability and acid detergent insoluble protein (ADIP) concentrations of alfalfa were as listed in Table 5.2. The Neutral detergent fiber (NDF) content of alfalfa was varied from 0.36 to 0.56 in increments of 0.03; the crude protein (CP) content was varied from 0.12 to 0.24 in increments of 0.03.

Because alfalfa CP and NDF contents are inversely related, not all combinations of CP and NDF are realistic. Based on typical composition (Rohweder et al., 1978), the following equation gives realistic combinations of CP and NDF:

$$CP = 0.44 - 0.6NDF \qquad [6.8]$$

Obviously other combinations exist, this relationship simply gives approximate values that are reasonable. Table 6.1 gives the CP/NDF combinations used to formulate rations; these combinations encompass combinations suggested by equation [6.8].

For this analysis of forage value, it was assumed that the same forage source was fed throughout the year, regardless of stage of lactation. That is, to evaluate the value of alfalfa containing 45% NDF and 18% CP, it was assumed that the forage available to the animal through all three stages of lactation contained alfalfa containing 45% NDF and 18% CP. This differs from the allocation scheme of DAFOSYM and

Table 6.1 Combinations of crude protein and neutral detergent fiber for which rations were balanced for three stages of lactation.

Crude protein (fraction of DM)	Neutral detergent fiber (fraction of DM)							
	0.36	0.39	0.42	0.45	0.48	0.51	0.54	0.57
0.12						X	X	X
0.15				X	X	X	X	X
0.18		X	X	X	X	X	X	
0.21	X	X	X	X	X			
0.24	X	X	X					

most farms, where forage allocation is based on animal requirements and forage quality.

6.2 Effect of alfalfa quality on value

6.2.1 Moderate milk production

For a fixed milk production level of 7,940 kg/cow-y, the fiber content of alfalfa affects only supplemental feed costs. Because fiber content is inversely related to energy content, increases in alfalfa fiber content result in increased supplemental feed costs over the lactation cycle. Increased protein content, on the other hand, reduces supplemental feed costs because increased alfalfa protein content reduces the need for supplemental feeds.

Alfalfa value was computed as outlined in Section 6.1.1, then converted to a relative value by dividing the computed value by the value of the reference alfalfa ($0.05/kg DM for alfalfa with 45% NDF, 18% CP). Figure 6.1 illustrates the effects of fiber and protein contents on the value of the alfalfa fed over the lactation cycle of a 600 kg cow. Because milk production was fixed, the differences in value among alfalfa qualities is solely attributed to the change in supplemental feed costs. From Figure 6.1, it is evident that the reduction in supplemental feed costs associated with a 1% increase in CP content are approximately equal to those associated with a 2% decrease in NDF content; i.e., the slope with respect to CP is double that with respect to NDF and of opposite sign.

6.2.2 High milk production -- determined by forage quality

At high production levels, the effect of forage fiber on value is twofold. As fiber content increases, energy concentration decreases; this results in higher supplemental feed costs. More importantly, fiber content can limit milk production and so decreases income. Though the former is true regardless of milk production, the latter can have a much more dramatic consequence with high producing animals.

To determine the effect of fiber content on potential milk production, the simulated data were analyzed using linear regression. For alfalfa fed in a mixed forage diet to a 600 kg cow, potential milk production (PMP) was related to NDF content by (Figure 6.2):

$$PMP = 12360 - 7940NDF \qquad [6.9]$$

$$(r^2 = 0.991)$$

If the genetic potential or ability of the cow is lower than a given point of interest on Figure 6.2, the effect of fiber on alfalfa value is

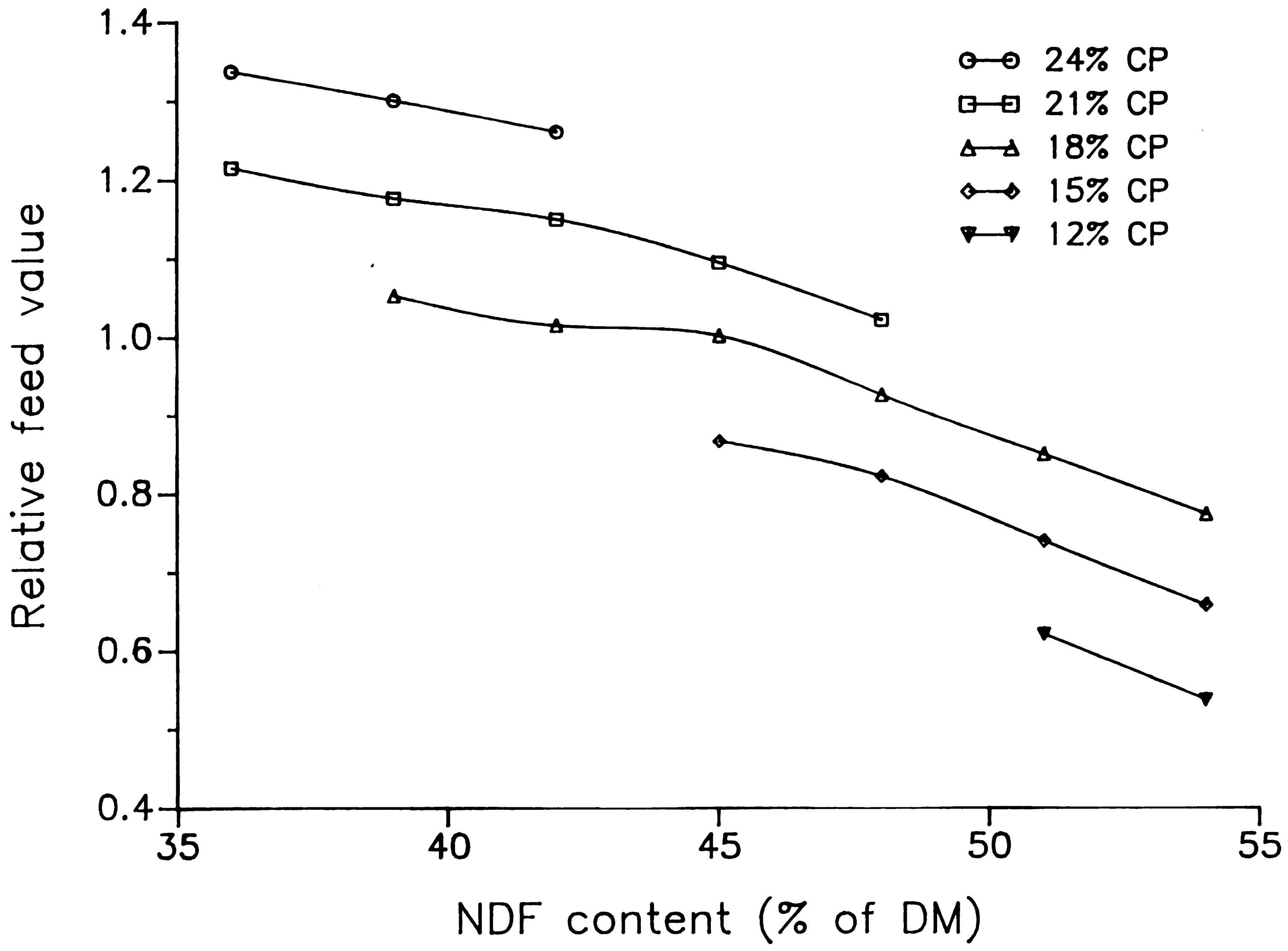

Figure 6.1 Effect of alfalfa quality on relative value of alfalfa in a mixed forage diet fed to a 600 kg cow producing 7,940 kg of milk/y.

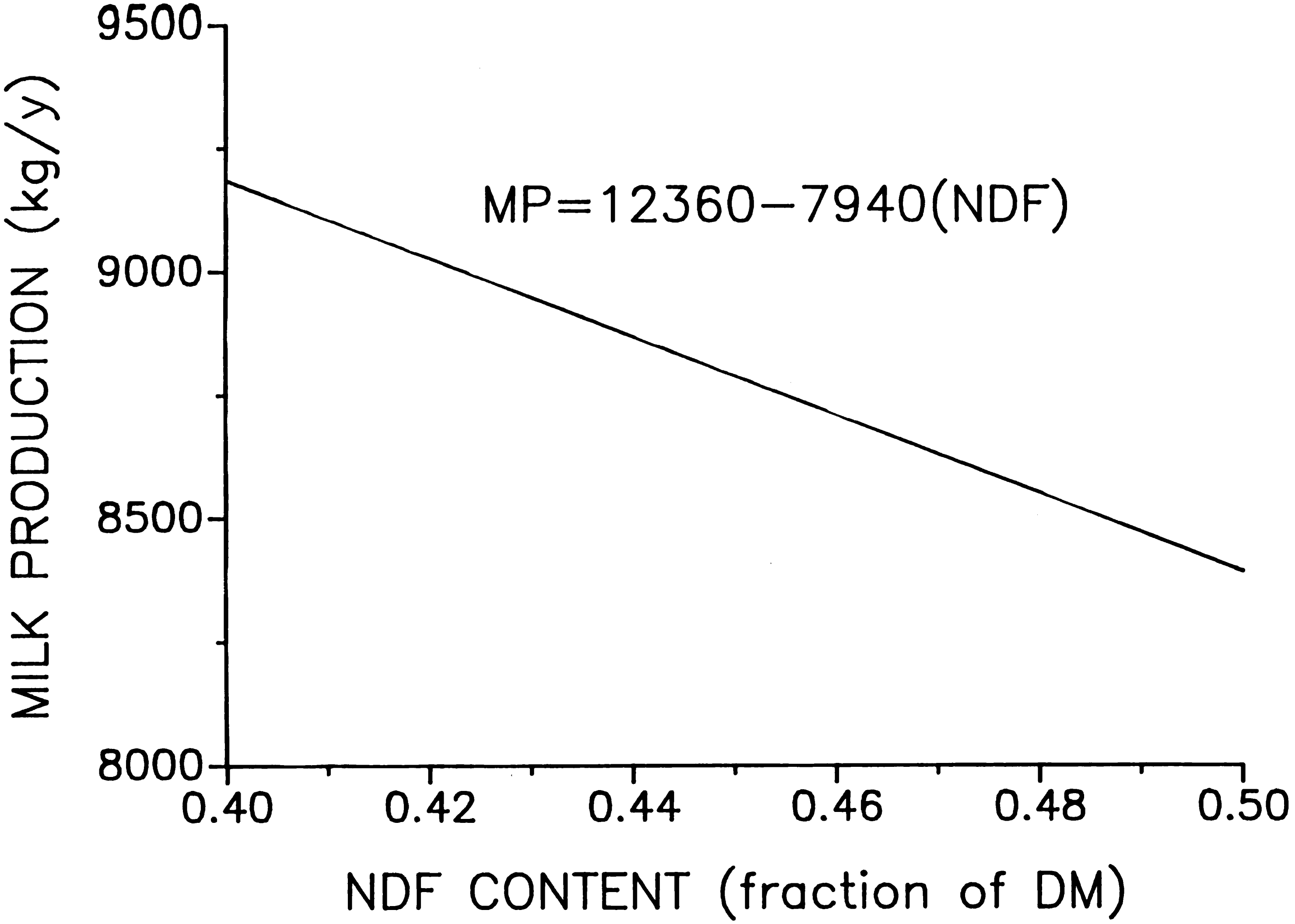

Figure 6.2 Effect of alfalfa quality on potential milk production from a 600 kg cow fed a mixed forage diet.

due to a reduction in feed costs only. In those cases where forage quality limits milk production, a change of 1% in NDF content of the alfalfa results in a change of approximately 80 kg/cow-y in milk production. For a typical herd of 100 cows, this corresponds to an increase in gross income of approximately $2000 for each 1% decrease in alfalfa NDF content. In these cases where the lactating animal can utilize increased quality alfalfa (lowered NDF) to increase milk production, the fiber content dramatically affects economic value of the alfalfa.

Figure 6.3 illustrates the effect of alfalfa quality on relative value when forage quality determines milk production. Because fiber content affects milk income as well as supplemental feed costs, the effect of fiber content is much more dramatic in this case than for a fixed milk production level (Section 6.2.1). The effect of increased alfalfa protein content is primarily a decrease in supplemental feed cost. The slight effect on milk production is negligible. For this case of an animal with high production potential, the increase in value associated with a 1% increase in CP content is approximately equal to the increase in value associated with a 0.5% decrease in NDF content.

6.3 Relative feed value

Rohweder et al. (1978) proposed a relative feed value system for alfalfa hay. The intent was to relate economic value to laboratory quality measures. The system of Rohweder et al. (1978) was based on dry matter intake (a function of NDF) and dry matter digestibility (a function of acid detergent fiber -- ADF). Protein effects on alfalfa value were not considered or were eliminated from the model because of

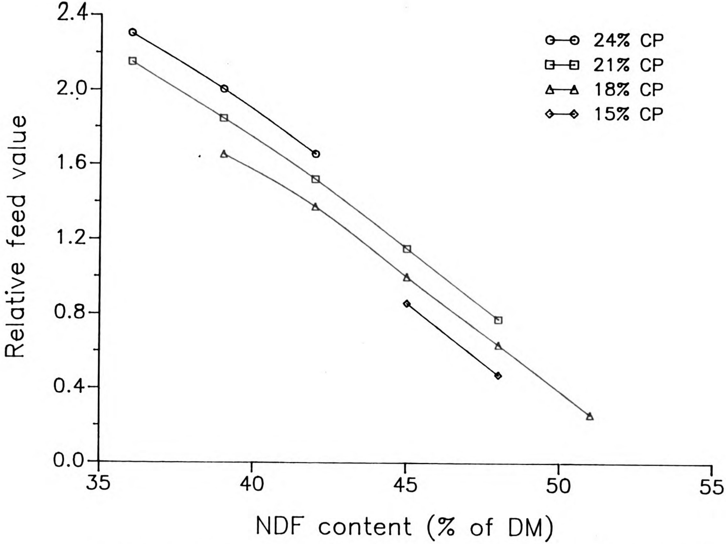

Figure 6.3 Effect of alfalfa quality on relative value of alfalfa in a mixed forage diet fed to a 600 kg cow producing as much milk as the forage will allow.

correlation among quality characteristics. Another shortcoming of the Rohweder et al. system was that the equations developed are applicable only when forage is the only source of dietary energy and protein. The relative feed value for legumes was modeled as:

$$RFV = 0.025(65.5+97.5ADF-2.77ADF^2)(39+268NDF-4.1NDF^2) \quad [6.10]$$

A better assessment of relative value would include effects of protein content and energy and protein supplementation of a balanced ration. The relative feed values determined in the previous sections incorporated both these factors and are based on the economics of feeding a lactating cow throughout the lactation cycle.

For comparison purposes, the Rohweder system was converted to the following equation by assuming ADF concentration is 10% lower than NDF concentration (i.e., ADF=NDF-0.10) and rescaling the relative value so that the relative value of alfalfa with 45% NDF was 1.00:

$$RFV = 0.025[65.5+97.5(NDF-0.1)-277(NDF-.1)^2] [39+268NDF-410NDF^2]/126 \quad [6.11]$$

where 126 is the RFV of alfalfa with 45% NDF, 35% ADF according to the Rohweder system. Figure 6.4 illustrates the range in RFV using the procedure outlined above compared with the Rohweder system as approximated by equation [6.11]. The current cow model indicates that alfalfa value is more sensitive to quality than the relative feed value system of Rohweder et al. suggests. For high milk production, the effects of fiber on milk production dominate the determination of alfalfa value.

Clearly, much work could be done to extend the range of applicability of such a relative feed value model, but this is beyond the scope and intent of this dissertation. The procedure is outlined

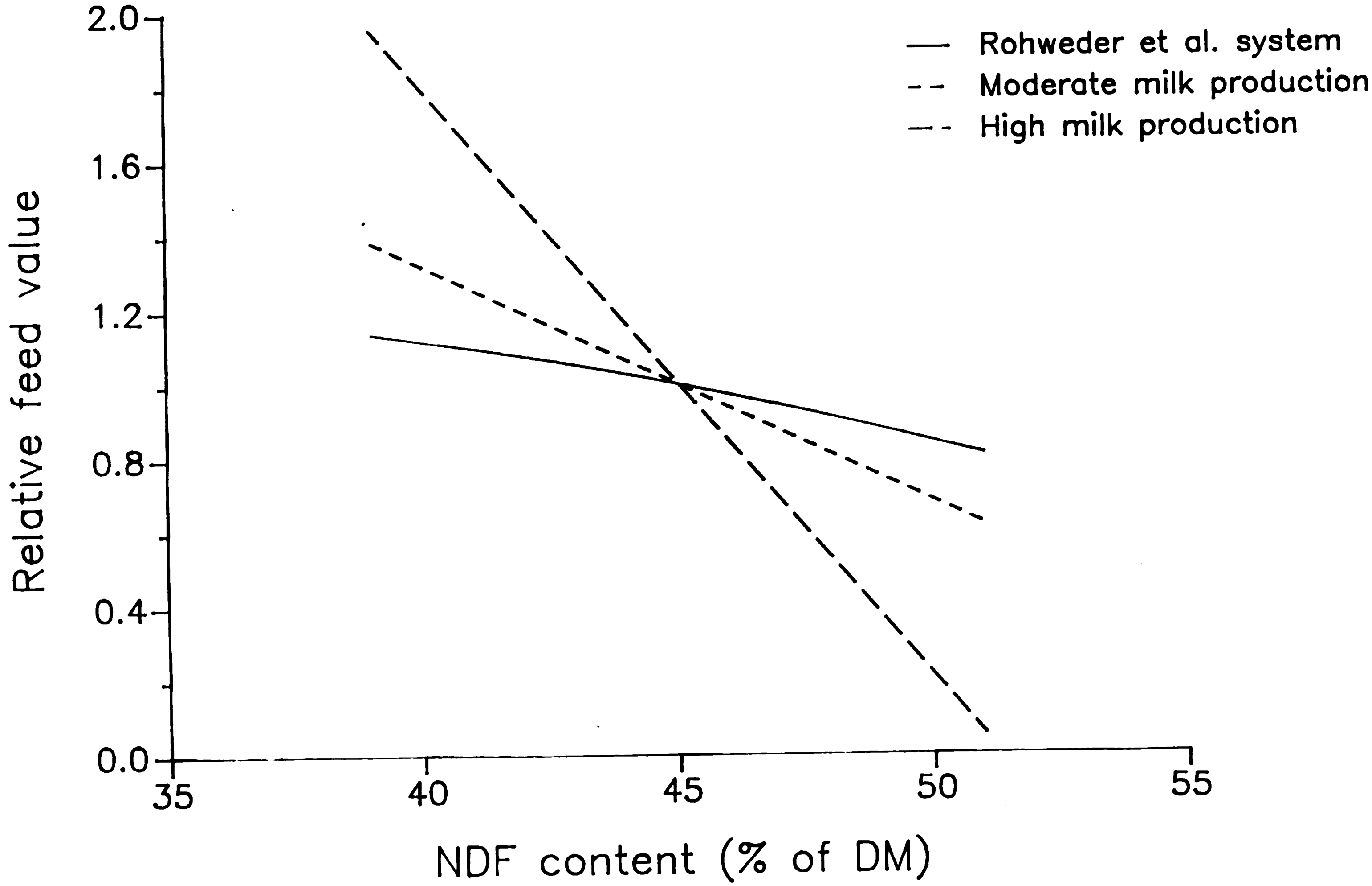

Figure 6.4 Range in alfalfa's relative feed value from three methods of determination.

here to illustrate that the cow model developed in the previous chapter can be used to develop such a model of relative feed value and that alfalfa value depends on both feed and animal characteristics.

6.4 Sensitivity

The approach outlined in Section 6.1.1 for determining alfalfa value is sensitive to many factors. The partial budgeting concept works in the context of comparing two alternatives, but more work is needed to improve the concept for its use in the context of determining the value of alfalfa. For example, the relative feed value curves (Figures 6.1 and 6.3) can be changed dramatically with changes in the reference forage, the value of the reference forage or the coefficient concerning costs of producing more milk (L). With the sensitivity of the analysis to these economic issues it is difficult to adequately address the topic of alfalfa value.

The value of alfalfa is also sensitive to assumptions made about the animal and the type of forage in the diet. One critical assumption is the size of the lactating cow. Repetition of the analysis for a larger cow illustrated that a larger cow can produce more milk from a given forage than can a smaller cow. Linear regression of simulated data indicated that milk production from a 10% larger cow was approximately 1000 kg more per year, given the same alfalfa quality fed in balanced, mixed forage diets (Figure 6.5):

$$PMP_{660\ kg\ cow} = 13510 - 8430NDF \qquad [6.12]$$
$$(r^2 = 0.991)$$

The production of extra milk requires more feed, so the increase in milk income would be partially offset by an increase in supplemental feed

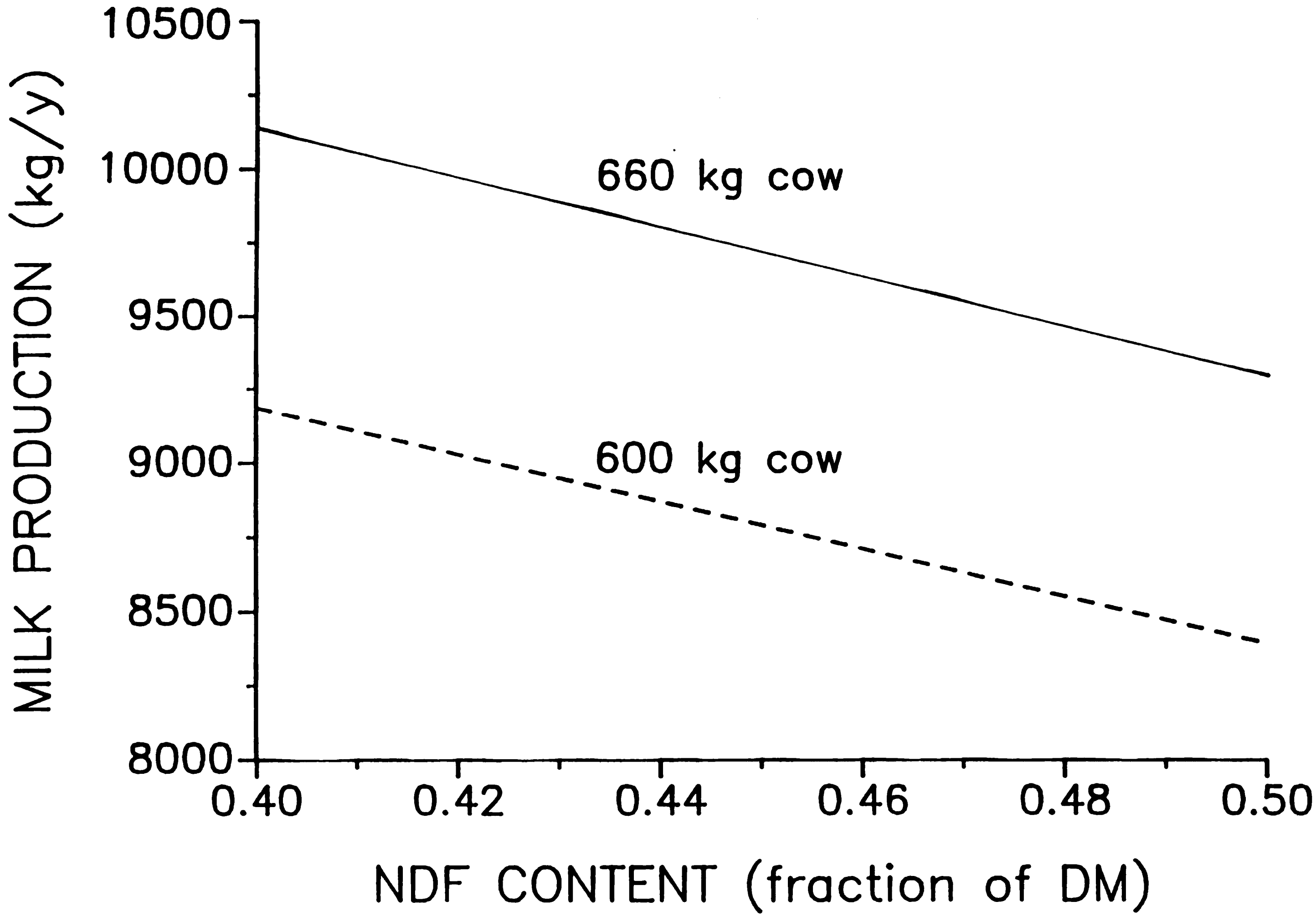

Figure 6.5 Impact of increased cow size on the effect of alfalfa quality on potential milk production from a cow fed a mixed forage diet.

costs.

It was suspected that the type of forage in the diet also affects potential milk production. For this reason, diets were formulated in which the forage source was either all alfalfa hay or all alfalfa silage. For alfalfa hay- and silage-based diets, maximum milk production fit the following models:

$$PMP_{all\ hay} = 14480 - 12380NDF \qquad [6.13]$$

$$(r^2 = 0.983)$$

$$PMP_{all\ silage} = 14140 - 11880NDF \qquad [6.14]$$

$$(r^2 = 0.985)$$

Figure 6.6 illustrates the effect of forage type on potential milk production. Note that for poor quality alfalfa (>47% NDF), adding corn silage to the diet increased milk production. At high quality levels (<45% NDF), alfalfa as a forage source resulted in the highest milk production. Alfalfa hay-based diets had slightly higher milk production levels than alfalfa silage-based diets, regardless of alfalfa quality.

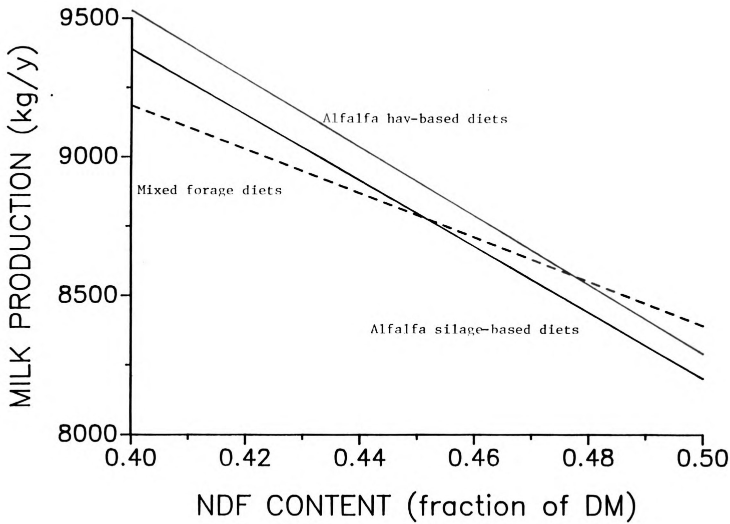

Figure 6.6 Impact of forage source on the effect of alfalfa quality on potential milk production from a 600 kg cow.

7. PROCEDURE FOR DETERMINING THE ECONOMIC VALUE OF FORAGE LOSSES

The models of harvesting and storage losses (Chapters 3 and 4) and the model of animal conversion of feedstuffs into milk (Chapter 5) were the foundation for determining the value of forage losses. These models were incorporated into DAFOSYM to perform a simulation study of alfalfa losses. (After these modifications, the level of detail in the submodels of DAFOSYM was increased to the equivalent of a 3 in Table 2.1). This chapter includes an outline of the approach toward determining the value of alfalfa losses and a description of the simulated farm. The following chapter contains results from the analysis as well as some results showing the sensitivity of forage loss value to various parameters.

7.1 Simulation approach

The dairy forage system model (DAFOSYM[1]) was used for the simulation study to properly model the interaction among losses during harvest, storage and animal conversion. With alfalfa harvest driven by weather and machinery available, the impact of machinery set (harvest rate) on respiration and rain losses is considered. Because crop growth is also a part of the model, the changing effects of harvest losses as the crop becomes more mature are inherently considered. The greatest

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[1] DAFOSYM Version 3.5, the latest version as of December 1988, which included all models developed in Chapters 3, 4 and 5, was used for this study.

benefit of the simulation approach is that animal performance (feed conversion) depends on the value of the crop available to the animal. With all losses and quality changes between growth and feeding simulated, animal performance becomes dependent on every factor influencing alfalfa production. The value of losses is determined by the subsequent milk production potential and the total feed cost necessary for producing the given amount of milk.

The previous chapter briefly outlined an approach for using the animal model of Chapter 5 to determine feed value. The value of losses was determined in a different manner, which is best illustrated with an example. To determine the value of raking loss under a describable set of farm, animal and economic conditions, the net return above feed costs from a simulation with raking loss eliminated (raking loss set equal to 0.0) was compared with net return above feed costs where raking loss was modeled (Chapter 3). The difference in net return above feed costs was attributed to raking loss. This approach was applied to each source of loss (Table 7.1) independently. Some combinations of losses were also eliminated to determine their combined impact on net return.

7.2 Farm description

A medium-sized farm located in East Lansing, Michigan was modeled as the representative farm. The farm consisted of 50 ha of alfalfa and 30 ha of corn. The animal herd included 100 lactating cows (26% primiparous), 36 heifers less than one year old and 30 heifers over one year old. Two levels of milk production potential were used: 8,000 kg/y herd average and milk production limited by forage quality only. The lower milk production level was used to illustrate the impact of forage

Table 7.1 Sources of loss analyzed in this study.

Loss	Abbreviation
Respiration	RESP
Rain	RAIN
Mowing/conditioning	MOW
Baling	BALE
Chopping	CHOP
Hay storage	HAY
Silo storage	SILO
Feeding	FEED

losses on a typical dairy farm. The higher milk production level was used to show the effect of milk production level on the value of losses and to illustrate the impact of forage losses on the animals of the future. For the higher milk production level, an unrealistic target (12,000 kg milk/y) was set. (The author recognizes that 12,000 kg/y is not unrealistic on some dairy farms; however, with a herd of 600 kg cows split into four groups, 12,000 kg/y simply cannot be achieved using only total mixed rations.) When the target milk production level was not met, it was reduced to a level that could be supported with the available feeds. Because animals with higher production potential could utilize higher quality forages more effectively (Section 6.2), response to increases in forage quality was always greater for the 12,000 kg/y herd.

Crops were grown on a clay loam soil with a water-holding capacity of 130 mm. A four-cut alfalfa harvesting system was used, with first and fourth cuttings harvested as silage; second and third cuttings were harvested as dry hay. All alfalfa was mowed with a mower-conditioner and field cured. Alfalfa intended for silage was laid into narrow swaths until harvest; alfalfa intended for hay harvest was laid into full-width swaths and raked before baling. First, second and third cutting alfalfa harvest was begun on May 25, July 5 and August 20, respectively, or when the crude protein of the growing plant dropped to 21%, whichever was earlier. Fourth cutting was started on October 14 regardless of quality level.

All feeds produced were stored on the farm. Storage structures (Table 7.2) include an open-front hay shed, two stave silos for alfalfa silage, one stave silo for corn silage and a stave silo for high moisture ear corn. Prices of the storage structures reflect 1988 values (Table 7.2). Useful life for the structures was 20 years.

The machinery complement for the medium-sized farm is listed in Table 7.3. Included are four tractors (35, 35, 65 and 100 kW), a 3.7 m mower-conditioner, a 2.7 m rake, a medium-sized baler and a medium-sized forage chopper. The useful life of all machinery was 10 years.

Prices of other farm inputs and feeds are listed in Table 7.4. Farm and machinery input files containing this and all other simulation information are included in Appendix D. All simulations were performed over 26 years of historical weather data for East Lansing, Michigan, so loss values reported are averages over 26 years.

7.3 Evaluation

Each pair of simulations (with and without simulating a particular loss or set of losses) gives information including milk income, total feed costs and net return above feed costs as well as information on production and use of feeds. Though net return above feed costs is a

Table 7.2 Storage structures on the representative 100 ha farm.

Structure	Capacity (T DM)	No. of units	Initial cost ($)
Hay shed	300	1	17000
Corn silage silo (stave)	142	1	23000
Alfalfa silage silo (stave)	112	1	19000
Alfalfa silage silo (stave)	175	1	26000
High moisture ear corn silo (stave)	112	1	19000

Table 7.3 Machinery available on the representative 100 ha farm.

Machine	Size	No. of units	Initial cost ($)
Tractor	35 kW	2	15800
Tractor	65 kW	1	29250
Tractor	100 kW	1	45000
Mower-conditioner	3.7 m	1	13200
Rake	2.7 m	1	3150
Baler	Medium	1	9500
Bale elevator	--	1	3600
Bale wagons	4.5 T DM	3	1900
Forage chopper	Medium	1	11300
Forage blower	30 T/h	1	3150
Forage wagons	9 T DM	3	7200
Corn planter	6 row	1	12600

Table 7.4 Prices of various inputs and feeds in the simulation studies.

Item	Price	Units
Labor	8.00	\$/h
Diesel fuel	0.31	\$/l
Electricity	0.08	\$/kWh
Corn drying	1.00	\$/pt./T
Milk	0.25	\$/kg
Annual cost of tillage and ground preparation		
- for corn grain production	84.00	\$/ha
- for alfalfa production	100.00	\$/ha
Annual cost of fertilizer seeds and chemicals		
- for new alfalfa production	260.00	\$/ha
- for established alfalfa	130.00	\$/ha
- for silage corn production	250.00	\$/ha
- for corn grain production	190.00	\$/ha
Annual cost for corn grain harvest	55.00	\$/ha
Selling price of feeds		
- corn grain	100.00	\$/T DM
- high moisture ear corn	85.00	\$/T DM
- alfalfa hay	65.00	\$/T DM
- corn silage	48.00	\$/T DM
Buying price of feeds		
- soybean meal	220.00	\$/T DM
- distillers grain	154.00	\$/T DM
- corn grain	106.00	\$/T DM
- alfalfa hay	69.00	\$/T DM

useful number, it should be used with the definition in mind. It is <u>not</u> the profit that can be realized on the described farm; rather, it is the income left after covering feed costs. Expense items not included are barns, milking labor, manure hauling, milking parlor, etc. Recognizing that these expenses are likely to be constant for a farm, the differences in net return above feed costs for different scenarios represent the differences in farm profit. The actual value of the profit is unknown, but the difference is simulated.

The value of each loss was the change in net return above feed costs realized when the loss was eliminated. To make loss values more general, two other units of comparison were also used: loss value per unit of alfalfa available ($/T DM) and reduction of total feed costs (%). While loss value in dollars represents the profit potential of eliminating a given loss, loss value per unit of alfalfa available indicates the value of loss in proportion to production. The loss value per unit of production was computed with the source of loss defining the amount of alfalfa available. For example, rake, baler and hay storage loss per unit of alfalfa available was the difference in net return divided by the amount of alfalfa hay available (i.e., silage is not raked nor baled). Similarly, chopper and silo loss value per unit available were determined as the difference in net return divided by the amount of alfalfa silage available. The value of respiration, rain, mower and feeding loss was determined using the total amount of alfalfa available to the animal.

Reduction of total feed costs (RTFC) was computed as:

$$RTFC = 100\left[1 - \frac{(TFC/MP)_{without\ loss}}{(TFC/MP)_{with\ loss}}\right] \qquad [7.1]$$

This indicator of loss value illustrates the changes in feed efficiency and the impact losses can have on profit. For example, if total feed costs per unit of milk produced are reduced by 3% when a given loss is eliminated and if feed costs are approximately 40% of total production costs, then elimination of that loss decreases total costs (increases profit) by 1.2%.

Admittedly, the three methods of evaluating the value of losses are related; however, each gives its own insight into the interpretation of loss value.

8. VALUE OF ALFALFA LOSSES

The value of alfalfa losses was determined by comparing net return above feed costs with and without a given loss or set of losses simulated. With all losses simulated on a representative medium-sized farm (Section 7.2), the net return above feed costs averaged $116,338 when milk production was 8,000 kg/cow-y and $143,115/y when production was determined by forage quality[1] (Appendix E). Milk production limited by forage quality ranged from 8,609 to 9,569 kg/cow-y and averaged 9,300 kg/cow-y. Alfalfa available to the animals averaged 479 T DM. Alfalfa was nearly equally divided between hay and silage, with more hay being of low quality (> 41% NDF) than of high quality (< 41% NDF). The quality split of alfalfa silage is determined by the silo capacities, but the quality within each silo varied from year to year. Corn production -- in the form of corn silage, high moisture ear corn (HMEC) and corn grain -- averaged 123, 98 and 137 T DM, respectively. The total feed costs (including the sale of excess alfalfa and corn grain and purchase of protein supplements) averaged $83,663 and $89,390/y for low and high production levels, respectively. The lower producing herd utilized more alfalfa, and in doing so, required less corn grain and protein supplement.

For this base case in which all losses were simulated, feed cost

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[1] For discussion purposes, 8,000 kg/cow-y will be called low production. Milk production as determined by forage quality will be called high production.

per unit of milk production was $0.0961/kg of milk produced when forage quality limited milk production. If animal potential limited milk production to 8,000 kg/cow-y, feed cost was $0.1046/kg of milk produced; thus, with the milk price at $0.25/kg, 38 to 42% of milk income went toward feed costs.

8.1 In-field and harvest

8.1.1 Respiration

Simulating a scenario in which respiration loss was eliminated increased net return for the high producing herd by $2,987/y (Table 8.1, Figure 8.1). Because material lost during respiration is totally digestible, respiration loss decreases quality as well as quantity. The change in quality due to respiration loss resulted in 110 kg less milk per cow per year (Appendix E); this in combination with increased feed costs resulted in an increase in total feed cost per unit of milk produced of 1.4%. For each tonne of alfalfa available to the animal, respiration loss costs $6.24 (Table 8.1). With a high producing herd, respiration caused the third largest loss of value during harvest.

For the 8,000 kg/cow-y herd, response to respiration loss was not as great. Because the lower producing herd is less sensitive to quality, and because the amount of material lost during respiration is relatively small, net return increased only $630/y with the elimination of respiration loss (Table 8.1, Figure 8.1). This change in net return above feed costs corresponded to a decrease in feed costs per unit of milk produced of 0.8%. Respiration loss reduced the value of alfalfa available to the animal by $1.32/T DM. With the low producing herd, the

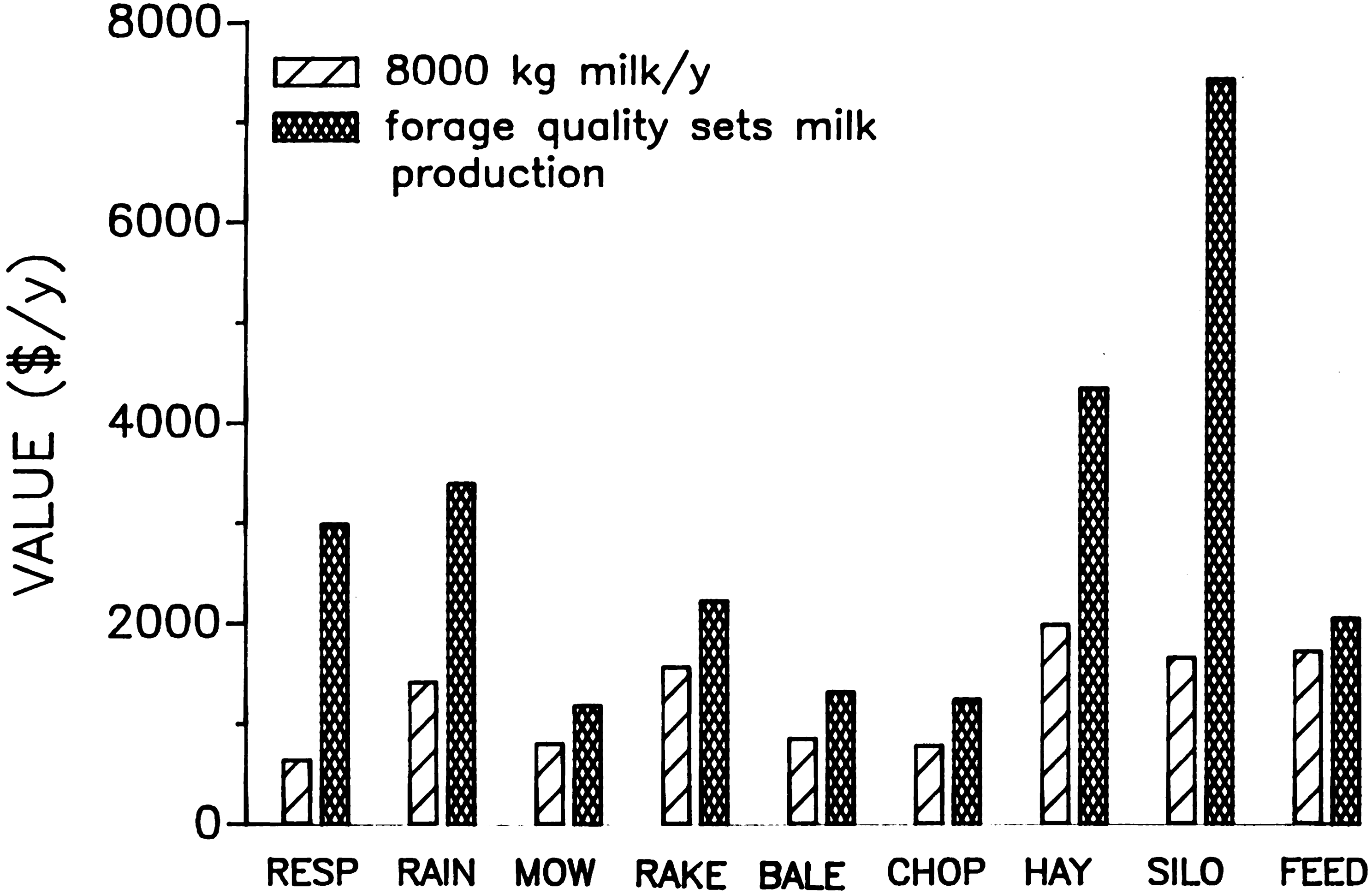

Figure 8.1 Value of alfalfa losses attributable to single sources for two milk production levels.

Table 8.1 Value of individual harvest losses and their effect on total feed costs for a medium-sized farm*.

Parameter	Unit	Loss					
		Resp.	Rain	Mower	Rake	Baler	Chopper
If forage quality set milk production							
Value of loss	($/y)	2,987	3,392	1,180	2,222	1,317	1,239
Value of loss	($/T DM)†	6.24	7.08	2.46	10.00	5.93	4.82
Feed cost reduction per unit milk produced§	(%)	1.4	2.2	1.0	1.9	1.1	1.0
If milk production was 8,000 kg/cow-y							
Value of loss	($/y)	630	1,409	794	1,557	842	770
Value of loss	($/T DM)	1.32	2.94	1.66	7.01	3.79	3.00
Feed cost reduction per unit milk produced	(%)	0.8	1.7	0.9	1.9	1.0	0.9

* This farm with 50 ha of alfalfa, 50 ha of corn and 100 lactating cows is described in detail in Tables 7.2, 7.3 and 7.4 and Appendix D.
† Value per tonne of alfalfa dry matter available for animal use.
§ If this loss were eliminated.

loss of value due to respiration was lower than the loss of value due to any other process during harvest or storage.

8.1.2 Rain

Eliminating rain loss increased net return by $3,392/y if forage quality limited milk production (Table 8.1, Figure 8.1). Rain loss reduced the value of the alfalfa available to the animal by $7.08/T DM and elimination of rain loss reduced feed cost per unit of milk production by 2.2%. If forage quality limited milk production, the loss in value due to rain damage was higher than that due to any other source of loss during harvest.

For a milk production level of 8,000 kg/cow-y, eliminating rain loss increased net return by $1,409/y (Table 8.1, Figure 8.1). With a value of $2.94/T DM, loss attributable to rain was more valuable than loss attributable to respiration or mowing. Machinery treatments of raking, baling and chopping each caused losses that reduced alfalfa value more than the loss due to rain damage. Eliminating rain damage reduced total feed costs by 1.7%.

8.1.3 Machinery

Machinery-induced losses included losses caused by the mower-conditioner, rake, baler and chopper. Of the machinery-induced losses, raking loss reduced value (expressed in $/T DM available) the most. This was followed by loss caused by the baler, the chopper and, lastly, the mower-conditioner. This ranking of value reduction held true regardless of milk production. Ranking machinery-induced losses by value lost per year ($/y) gave nearly the same ranking, and the value lost ($/y) was nearly the same for the mower, baler and chopper (Table 8.1, Figure 8.1). Ranking machinery losses by reduction in total feed costs showed that eliminating mowing, baling or chopping losses resulted in approximately the same effect on feed costs. Raking still reduced value more than other machine operations.

When forage quality determined milk production, loss during mowing-conditioning had an annual value of $1,180 (Table 8.1, Figure 8.1).

Expressed per unit of alfalfa available to the animal, mower-conditioner loss was $2.46/T DM. Eliminating mower-conditioner loss reduced feed costs by 1.0%. For the low producing herd, mower-conditioner loss was worth only $794/y. This corresponded to a value of $1.66/T DM available to the animal. With milk production fixed at 8,000 kg/cow-y, eliminating mower-conditioner loss reduced total feed costs by 0.9%.

If forage quality limited milk production, annual raking loss was valued at $2,222, or $10.00/T DM raked (Table 8.1, Figure 8.1). If milk production were limited to 8,000 kg/cow-y, raking loss was valued at $1,557/y or $7.01/T DM raked. Eliminating raking loss decreased total feed costs per unit of milk produced by 1.9% regardless of milk production.

The alfalfa value lost annually due to baling was $1,317 if forage quality determined milk production. At $5.93/T DM baled, baling loss was worth more than mower- or chopper-induced losses. Eliminating baling losses reduced feed costs 1.1%. Baler-induced loss was worth $842/y if the milk production potential of the cows was 8,000 kg/cow-y. Eliminating baler loss reduced total feed costs by 1.0% for the low producing herd.

Alfalfa value lost during chopping was slightly lower than that lost during baling. The increases in net return achieved by eliminating chopper loss were $1,239 and $770/y for the high and low producing herds, respectively (Table 8.1, Figure 8.1). If forage quality determined milk production, chopper loss was valued at $4.82/T DM chopped. For a herd average of 8,000 kg milk/cow-y, chopper loss was valued at $3.00/T DM chopped. Eliminating chopper loss reduced total feed costs by 0.9% for the 8,000 kg/cow-y herd; 1% for the high producing herd.

When all machinery-induced losses were eliminated, annual net return increased by $6,522 (when forage quality determined milk production) and $4,081 (at 8,000 kg milk/cow-y). The value of eliminating all machinery losses simultaneously was greater than the sum of the values when each was eliminated independently. If forage quality limited milk production, machinery-induced losses reduced value by $13.62/T DM. If milk production were set to 8,000 kg/cow-y, machinery-induced losses reduced alfalfa value by $8.52/T DM. In either case, feed costs per unit of milk produced were reduced approximately 5%.

8.1.4 Total harvest loss

When forage quality limited milk production, eliminating all harvest losses -- respiration, rain, mowing, raking, baling and chopping -- increased net return by $12,173/y or $25.41/T DM produced (Table 8.2, Figure 8.2). The increased quality resulting from eliminating all harvesting losses resulted in 266 kg more milk per cow per year. This, in combination with the reduction in total feed costs, illustrates the impact of harvest losses on farm net return. Eliminating harvest losses increased profitability by $0.01/kg of milk produced because feed costs were reduced 8.8% (Table 8.2).

If milk production was limited to 8,000 kg/cow-y, the effect of eliminating harvest losses was less: an increase in net return above feed costs of $6,426/y ($13.42/T DM, Figure 8.3). For the 8,000 kg milk/cow-y production level, eliminating all harvesting losses reduced total feed costs by 7.7%.

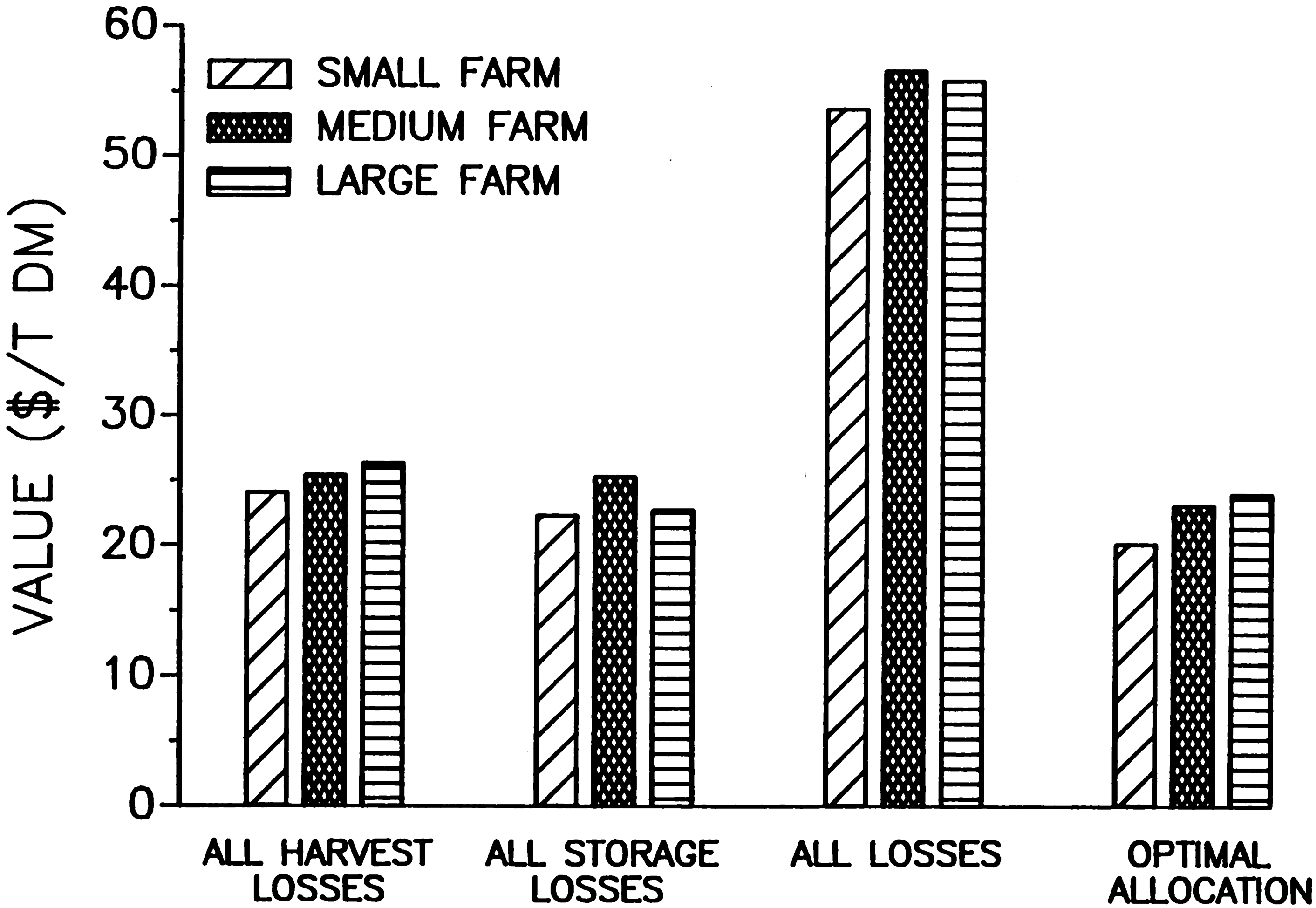

Figure 8.2 Value of combined harvest, storage and all alfalfa losses and optimal feed allocation on three sizes of farms when forage quality determines milk production.

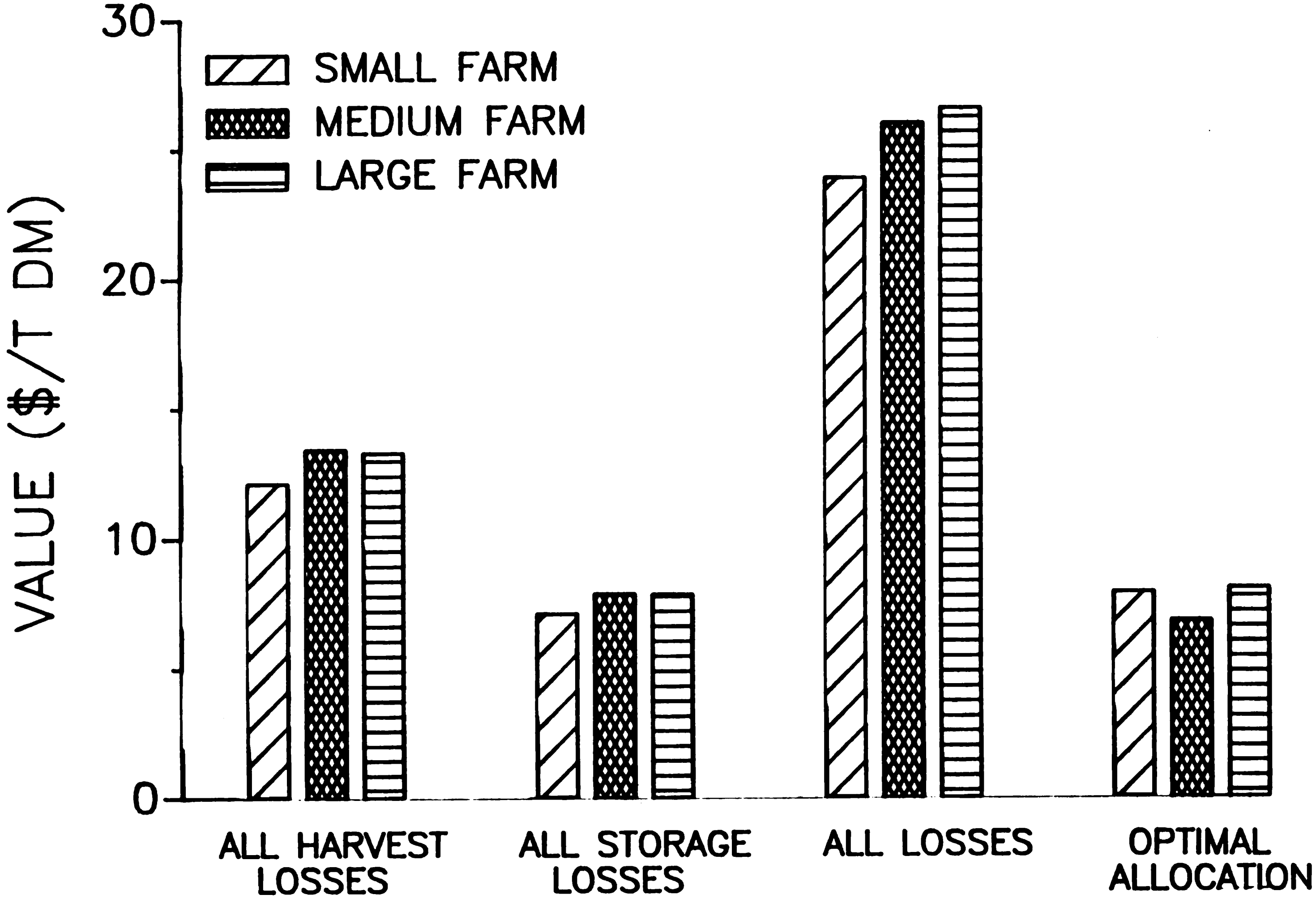

Figure 8.3 Value of combined harvest, storage and all alfalfa losses and optimal feed allocation on three sizes of farms when milk production is 8,000 kg/y per cow.

Table 8.2 Value of storage and combined losses and their effect on total feed costs for a medium-sized farm*.

Parameter	Unit	Loss(es)					
		Hay storage	Silo storage	Feeding	All harvest	All storage	All
If forage quality set milk production							
Value of loss	($/y)	4,346	7,435	2,053	12,173	12,089	27,081
Value of loss	($/T DM)†	19.58	28.93	4.29	25.41	25.24	56.54
Feed cost reduction per unit milk produced§	(%)	2.8	3.7	2.0	8.8	6.4	17.2
If milk production was 8,000 kg/cow-y							
Value of loss	($/y)	1,978	1,648	1,715	6,426	3,768	12,448
Value of loss	($/T DM)	8.91	6.42	3.58	13.42	7.87	25.99
Feed cost reduction per unit milk produced	(%)	2.4	2.0	2.0	7.7	4.5	14.9

* This farm with 50 ha of alfalfa, 50 ha of corn and 100 lactating cows is described in detail in Tables 7.2, 7.3 and 7.4 and Appendix D.
† Value per tonne of alfalfa dry matter available for animal use.
§ If this loss were eliminated.

8.2 Storage

When forage quality limited milk production, the loss of value during silo storage of alfalfa was higher than the loss during dry hay storage. In the case of milk production limited by the animals' potential (8,000 kg/cow-y), the loss during hay storage was more costly (Table 8.2, Figure 8.1).

8.2.1 Hay storage[2]

When forage quality limited milk production, eliminating hay storage losses increased net return by $4,346 (Table 8.2, Figure 8.1). This corresponds to a reduction in value of $19.58/T DM stored as hay. If milk production were limited to 8,000 kg/cow-y, hay storage losses reduced net return by only $1,978/y -- a reduction in value of $8.91/T DM stored as hay. For the higher milk production level, eliminating hay storage losses decreased total feed costs 2.8%; for the lower milk production level, it decreased total feed costs by 2.4%. For the lower production level, value lost during hay storage was higher than loss due to any other source ($/y or $/T DM).

8.2.2 Silo storage

Comparing the base simulation with one in which silo losses were eliminated indicated that silo storage losses reduced net return by $7,435/y when forage quality determined milk production (Table 8.2, Figure 8.1). This corresponded to a reduction in value of $28.93/T DM stored as silage. If forage quality determined milk production, silo storage caused more value loss than any other source of loss, and more value lost per unit available than that caused by all machine operations combined. When milk production was capped at 8,000 kg/cow-y, eliminating silo storage losses increased net return by $1648/y; this corresponded to a value of $6.42/T DM stored as silage. Eliminating

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2 Value lost during hay storage reflects effects of dry matter loss including the increase in acid detergent insoluble protein (which occurs because of heat generation that is caused by the oxidation of dry matter).

silo storage losses reduced total feed costs by 2.0% while maintaining a milk production level of 8,000 kg/cow-y.

8.2.3 Total storage loss

Comparing the base simulation run with one in which all hay and silage storage losses were eliminated indicated that, when forage quality determined milk production, net return increased $12,089/y when storage losses were eliminated (Table 8.2). This is approximately equal to the $12,173/y increase realized when all harvest losses were eliminated. Expressed per unit of alfalfa available to the animal, storage losses reduced alfalfa value by $25.24/T DM (Figure 8.2).

If milk production was limited to 8,000 kg/cow-y, eliminating storage losses increased net return by $3,768/y or increased alfalfa value by $7.87/T DM (Table 8.2, Figure 8.3). For the lower producing herd, harvest losses ($6,426/y) were approximately 70% more costly than storage losses.

8.3 Feeding

Eliminating feeding loss increased net return by $2,053/y for the high producing herd (Table 8.2, Figure 8.1). With a value of $4.29/T DM fed, value lost during feeding is approximately equal to the value lost during the harvest operations of baling and chopping. For the low producing herd, net return increased by $1,715/y if feeding loss was eliminated (Figure 8.3). Regardless of production level, elimination of feeding loss reduced total feed costs per unit of milk produced by 2.0% (Table 8.2).

8.4 Total loss

The loss in alfalfa value due to separate operations as well as some combinations of operations has been discussed. To determine the combined value of all losses, all losses were set to zero (eliminated). Elimination of all losses increased net return by $27,081/y when forage quality determined milk production (Table 8.2). At $56.54/T DM available to the animal, it is clear that the combination of all losses significantly affects farm profit (Figure 8.2). Elimination of all losses increased milk production by 690 kg/cow per year and increased the profitability of the milk production enterprise by reducing feed costs $0.018/kg milk produced (17.2%).

The value of all losses combined for the lower producing herd was less at $12,448/y (Table 8.2). Elimination of all losses increased the value of the alfalfa by $25.99/T DM (Figure 8.3). For the lower producing herd, eliminating all losses decreased total feed costs per unit of milk produced by 14.9%.

8.5 Feed allocation

Although improper (or at least suboptimal) feed allocation is not a true loss of alfalfa or alfalfa quality, it certainly is an economic loss to the farmer. To place a value on this loss, the linear programming (LP) allocator (described in Figure 5.2) was used to allocate feeds. Table 8.3 contains summary information on the improvement in net return above feed costs and the value of optimal allocation, which compares the LP allocator to the decision rules outlined in Section 5.5.2.1. It should be understood that the reported value of improvement through allocation is strictly a comparison of the

Table 8.3 Increase in net return and value of optimal feed allocation on different sized farms.

Parameter	Unit	Farm size*		
		Small	Medium	Large
If forage quality sets milk production				
Net return increase	($/y)	5775	11059	16845
Value of optimal allocation	($/T DM)†	20.05	23.09	23.96
Feed cost reduction per unit milk produced	(%)	5.7	5.3	5.9
If milk production is 8000 kg/cow-y				
Net return increase	($/y)	2279	3271	5696
Value of optimal allocation	($/T DM)	7.91	6.83	8.10
Feed cost reduction per unit milk produced	(%)	4.2	3.9	4.9

* Small farm had 30 ha of alfalfa, 30 ha of corn and 60 lactating cows. Medium farm had 50 ha of alfalfa, 50 ha of corn and 100 lactating cows. Large farm had 70 ha of alfalfa, 70 ha of corn and 150 lactating cows. (See Appendix D.)

† Value per tonne of alfalfa dry matter available for animal use.

two methods. For the farmer who allocates his or her feeds using better rules, the gain would be less substantial.

For the medium-sized farm with milk production determined by forage quality, optimal allocation improved net return above feed costs by $11,059/y over the decision rule allocation. Using the decision rules to allocate forages resulted in a loss (expressed per unit of alfalfa available) of $23.09/T DM. Figure 8.2 places this value into perspective by illustrating that the economic loss from improper allocation nearly equals the loss during harvest or storage. When milk production is capped at 8,000 kg/cow-y, the benefit of optimal allocation is not as great -- $3,271/y. Still, the value of this loss is approximately equal to the value lost during storage (Figure 8.3).

The decision rule allocation scheme forced maximum use of forage. It is somewhat misleading, therefore, to compare the decision rule allocation to optimal allocation because the optimal allocator does not force maximum use of forage. To determine how much of the net return increase was attributable to "smart allocation" and how much was attributable to not using maximum forage diets, the optimal allocator was used in a case in which maximum forage use was forced. The results showed that 60 to 70% of the gain from optimal allocation was due to "smart allocation," with the remainder coming from less than maximum use of forages.

This author recognizes that the optimal allocator used in this study could be improved and thus is not optimal in itself; however, its use here illustrates that proper allocation can have as much impact on feed value and farm net return as eliminating some of the largest losses. The optimal allocation as illustrated is also an upper bound on the potential gain, because practical limitations of feeding may render some strategies unreasonable.

8.6 Sensitivity of feed loss value

Up to this point, the value of alfalfa losses has been discussed for a medium-sized farm on which both alfalfa hay and silage are made. Feed loss value depends not only on the animal utilizing the feed, but also on many of the other characteristics describing the farm. This section is an attempt to illustrate how the value of alfalfa losses is affected by some of the key farm, animal and economic parameters. The sensitivity study also indicates how the value of alfalfa losses may vary from farm to farm.

8.6.1 Farm parameters

8.6.1.1 Farm size

The medium-sized farm used for the study of loss values is typical of Great lakes-states dairy operations. It seemed reasonable to suspect that farm size might affect the value of alfalfa losses. This is indeed true when expressing value in dollars per year because of the difference in scale. To determine the effect of farm size on alfalfa loss value, a smaller farm (30 ha of alfalfa, 30 ha of corn and 60 lactating cows) and a larger farm (70 ha of alfalfa, 70 ha of corn and 150 lactating cows) were modeled. The input files giving a complete description of the farms are included in Appendix D. In short, the medium-sized farm was simply scaled up or down; i.e., the size of storage structures and machinery were adjusted accordingly.

Figures 8.2 and 8.3 illustrate that farm size does not significantly affect the value of losses when it is expressed in dollars per tonne available. Although differences exist, there are no clear trends (e.g., storage loss was not correlated to farm size) because the machinery complement and storage structures are sized according to farm needs. Although it was not simulated, given an identical set of machinery, the value of harvest loss on a medium-sized farm would be larger than that on a smaller farm because of timeliness.

Figures 8.4 and 8.5 illustrate how farm size affected the value reduction due to each single loss. Again, there are no clear interactions.

8.6.1.2 Type of alfalfa harvest

The type of alfalfa harvest -- hay vs. silage -- affects the value of losses (Figures 8.6 and 8.7). Harvest losses are lower in a silage system because fewer operations are involved (no raking before harvest), the crop is curing in the field for a shorter period of time (less respiration and chance of rain damage) and chopping losses are generally lower than baling losses. However, silo storage losses are more valuable when forage quality limits milk production.

To evaluate the impact of harvest type on loss value, three alfalfa harvest systems were compared. The first -- a hay and silage system -- was the medium-sized farm described in Chapter 7. First and fourth cuttings were harvested as silage; second and third cuttings as hay. The second system was an all hay system. Only three cuttings were harvested because weather conditions during October were not conducive to hay harvest (i.e., many plots were destroyed after mowing). The third system -- all silage harvest -- consisted of a similar farm on which all alfalfa was ensiled. Detailed information on storage structures and machinery set can be found in the data files (Appendix D).

When forage quality limited milk production, the value lost during harvest and storage were approximately equal for the mixed harvest system (Table 8.2). In the silage system, silo storage accounted for nearly two-thirds ($23.00/T DM) of the value lost ($33.00/T DM). As expected, harvest losses decreased value less in the all silage system.

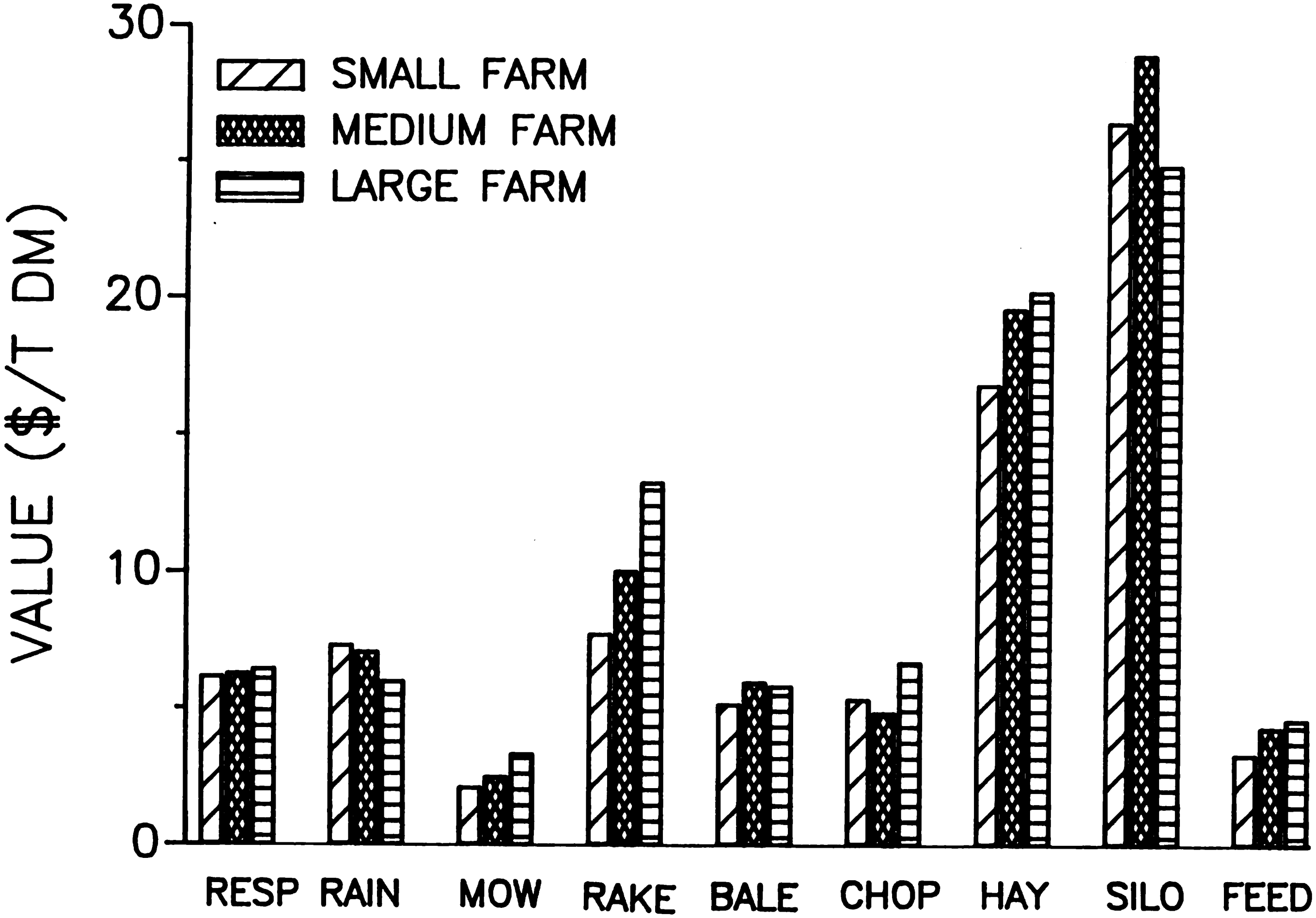

Figure 8.4 Effect of farm size on alfalfa value lost during individual processes through harvest, storage and feeding when forage quality determines milk production.

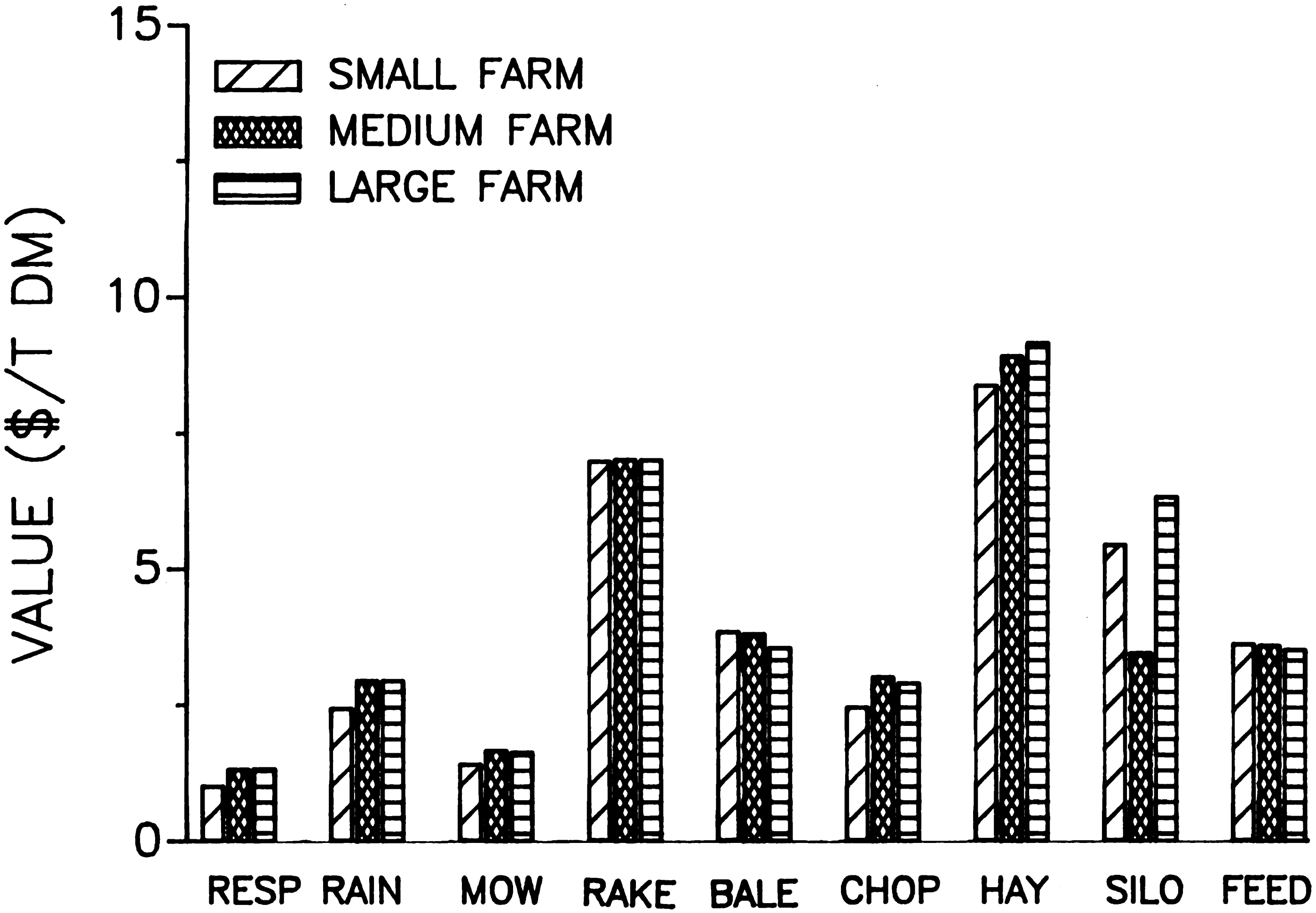

Figure 8.5 Effect of farm size on alfalfa value lost during individual processes through harvest, storage and feeding when milk production is 8,000 kg/y per cow.

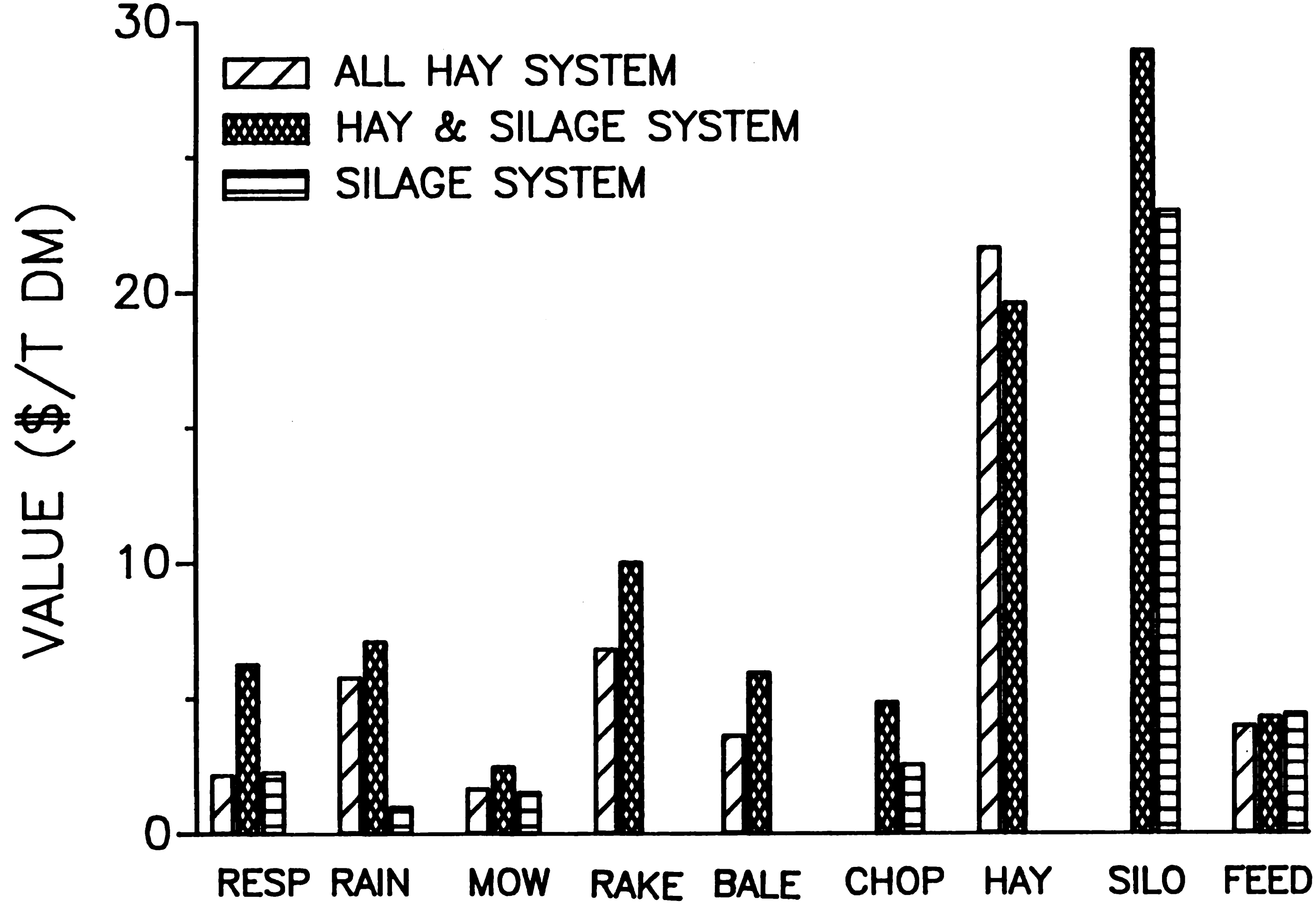

Figure 8.6 Effect of type of alfalfa harvest on alfalfa value lost during individual processes through harvest, storage and feeding when forage quality determines milk production.

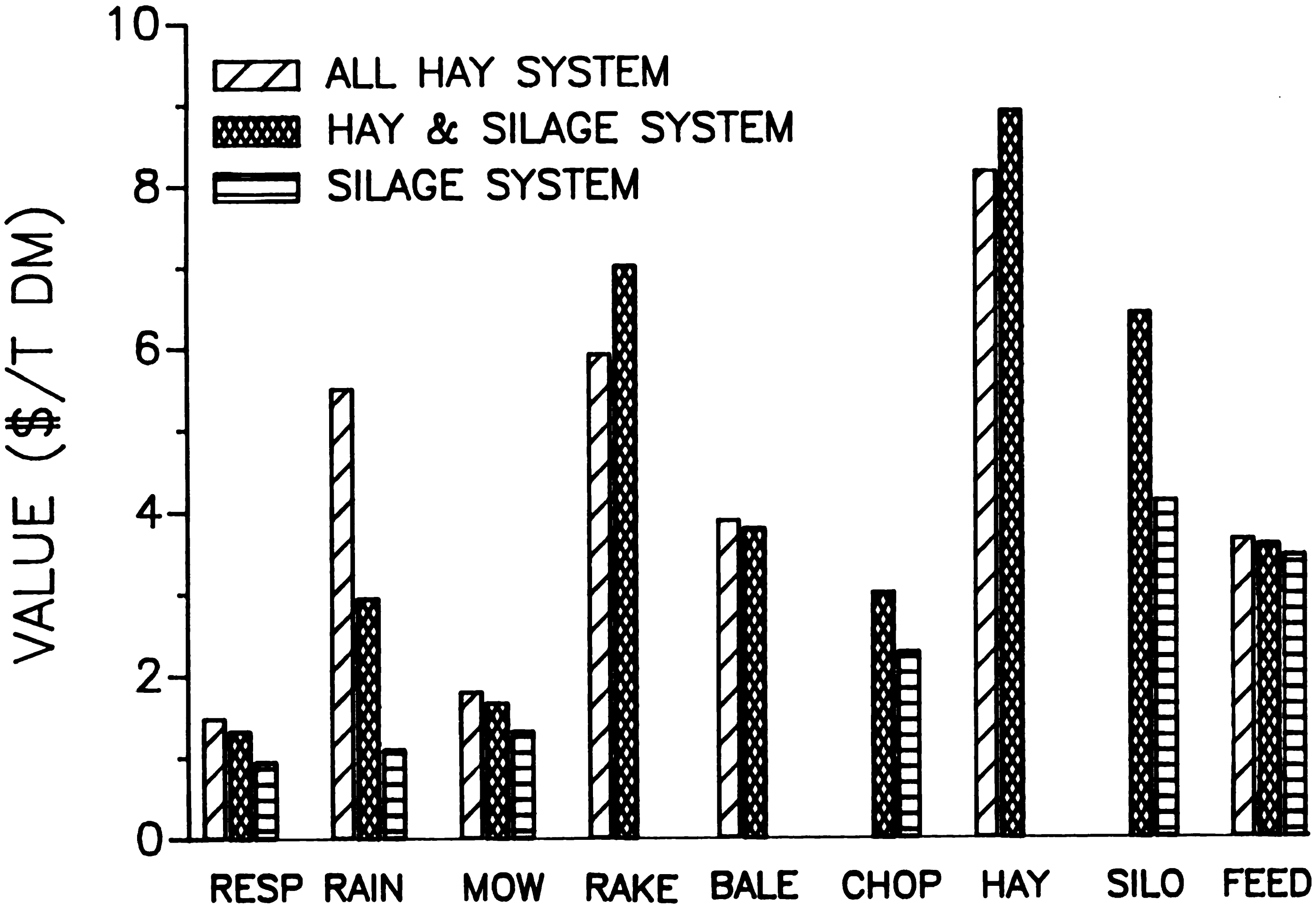

Figure 8.7 Effect of type of alfalfa harvest on alfalfa value lost during individual processes through harvest, storage and feeding when milk production is 8,000 kg/y per cow.

In the all hay system, harvest losses decreased value by $26.66/T DM available to the animal. Because storage losses decreased value by only $21.59/T DM in the all hay system, harvest losses were relatively more important in the all hay system. Figure 8.6 illustrates the impact of harvest type on the value of the losses from individual processes. All losses except hay storage had greater value on the farm with the mixed harvest system than on the farms with either the all hay or the all silage system. Total value lost was highest for the all hay system ($57.43/T DM), followed by the mixed harvest system ($56.54/T DM) and the all silage system ($33.00/T DM).

When milk production was limited by cow potential to 8,000 kg/cow-y, the results were slightly different. In the all silage system, the value lost was nearly equally divided between harvest ($5.67/T DM) and storage ($4.12/T DM). For the mixed harvest and all hay systems, losses during storage decreased value more than losses during harvest. The total value of losses was highest for the all hay system ($36.64/T DM), followed by the mixed harvest system ($25.99/T DM) and the all silage system ($14.01/T DM). Because the value of feeding loss does not vary greatly with milk production, it becomes relatively more important with lower milk production. In the all silage system, feeding loss accounted for nearly 25% of the value lost through harvest, storage and feeding if milk production was limited to 8,000 kg/cow-y.

8.6.1.3 Type of baler

Since the inception of the large round baler, the pros and cons of rectangular and round bales have been debated. Though the intention of this study was not to determine which is more economical, it did consider the impact of baler type on value of losses. To determine the impact of baler type, the medium-sized rectangular baler on the medium-sized farm was replaced with a medium-sized round baler. Other changes in bale handling and transport were also made to accommodate the round bales. (Detailed farm descriptions are included in Appendix D.) Two round bale scenarios were simulated: inside storage of the round bales and outside storage of the round bales. In the latter case, there was no cost for a hay storage structure. Harvest and storage losses were simulated as outlined in Chapters 3 and 4. Feeding losses were assumed to be 5% for rectangular bales, 14% for round bales stored inside and 25% for round bales stored outside.

Figures 8.8 and 8.9 illustrate the impact of baler type on baler loss, storage loss and feeding loss for two milk production levels. The value of baler loss did not change significantly with baler type. The value of storage losses when round bales were stored inside was not different from the value of storage losses for rectangular bales stored inside. Outside storage of round bales decreased value from $8 to $45/T DM more than indoor storage, depending on milk production. The value lost during feeding of round bales stored inside was approximately $12.50/T DM more than the value lost during feeding of rectangular bales. The feeding loss of round bales stored outside was even more severe: $25 to 30/T DM lost above the value of feeding loss for rectangular bales.

8.6.1.4 Harvest moisture

Moisture content at the time of harvest affects losses. To determine the sensitivity of loss value to harvest moisture, simulations

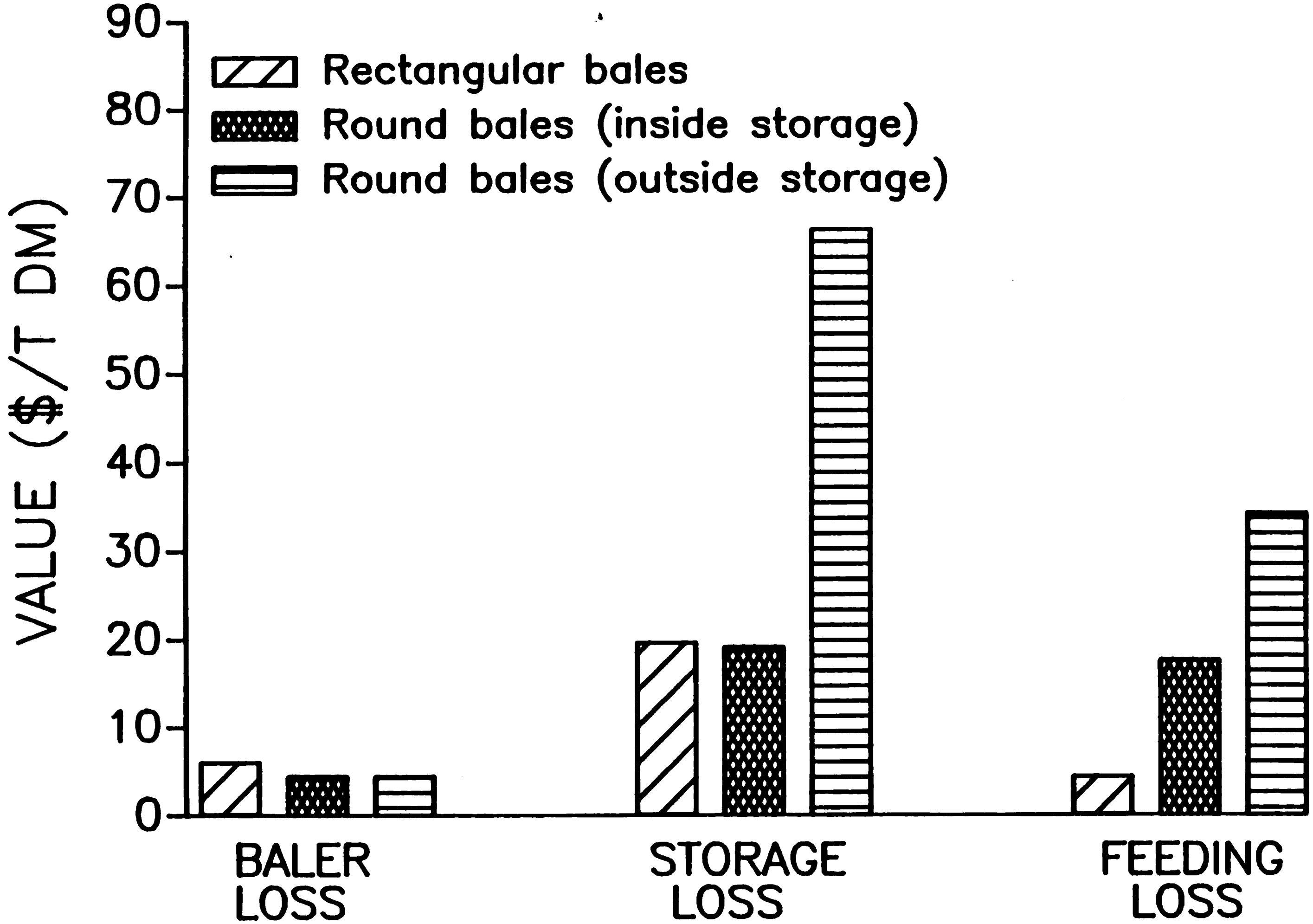

Figure 8.8 Effect of baler type and storage location on alfalfa value lost during baling, storage and feeding when forage quality determines milk production.

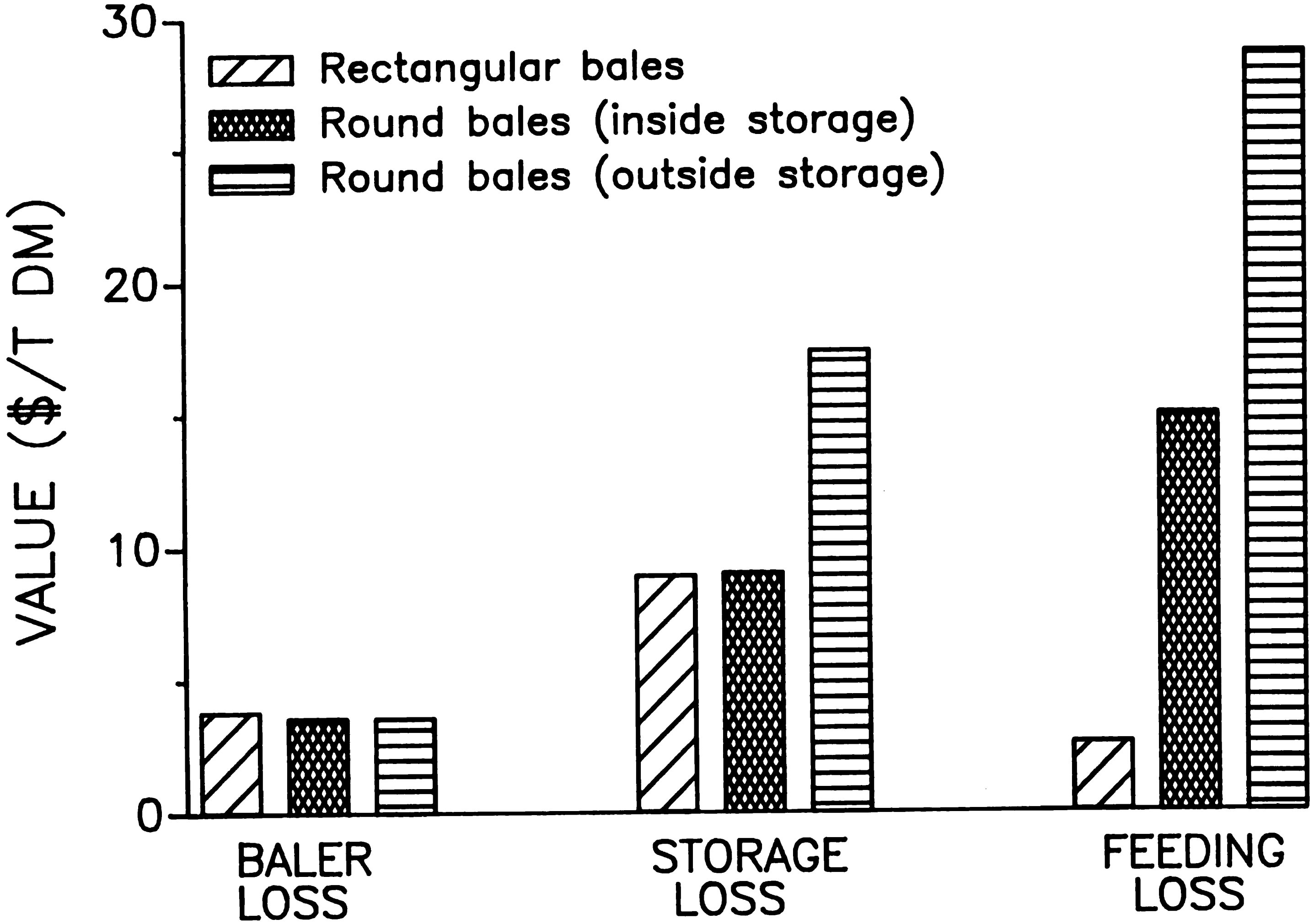

Figure 8.9 Effect of baler type and storage location on alfalfa value lost during baling, storage and feeding when milk production is 8,000 kg/y per cow.

were performed in which the hay and silage were harvested 5 percentage units drier. The typical harvest moisture contents used in the base simulations were 20% for hay and 65% for silage[3]. For the drier scenario, hay was harvested at 15%; silage, at 60%.

Figures 8.10 and 8.11 illustrate the effect of harvest moisture on the value of harvest, storage and all losses. Decreased harvest moisture increases the harvest losses, so more value is lost. Similarly, decreased moisture decreases the value lost during storage, particularly in hay storage. The two effects offset each other, but the total value lost was higher when alfalfa was harvested at 15 and 60% for hay and silage, respectively; i.e., value lost increased as harvest moisture decreased.

8.6.1.5 Silo type

To determine the effect of silo type on the value of silo losses, the two stave alfalfa silos on the medium-sized farm were replaced with oxygen-limiting and bunker silos of the same capacity. Silage placed in the stave, oxygen-limiting and bunker silos had maximum moisture contents of 65, 60 and 70%, respectively. As with other sensitivity studies presented here, this is not an economic analysis of which is best for optimal farm net return; rather, it is an analysis showing the effect of silo type on the value of silo losses.

Table 8.4 includes the total value lost during ensiling and the value lost during each phase for three types of alfalfa silos on the medium-sized farm. The permeabilities of the silo walls (the cover, in

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3 The moisture contents given here are those at which harvest was begun. Average moisture content was 2 to 3 percentage units lower.

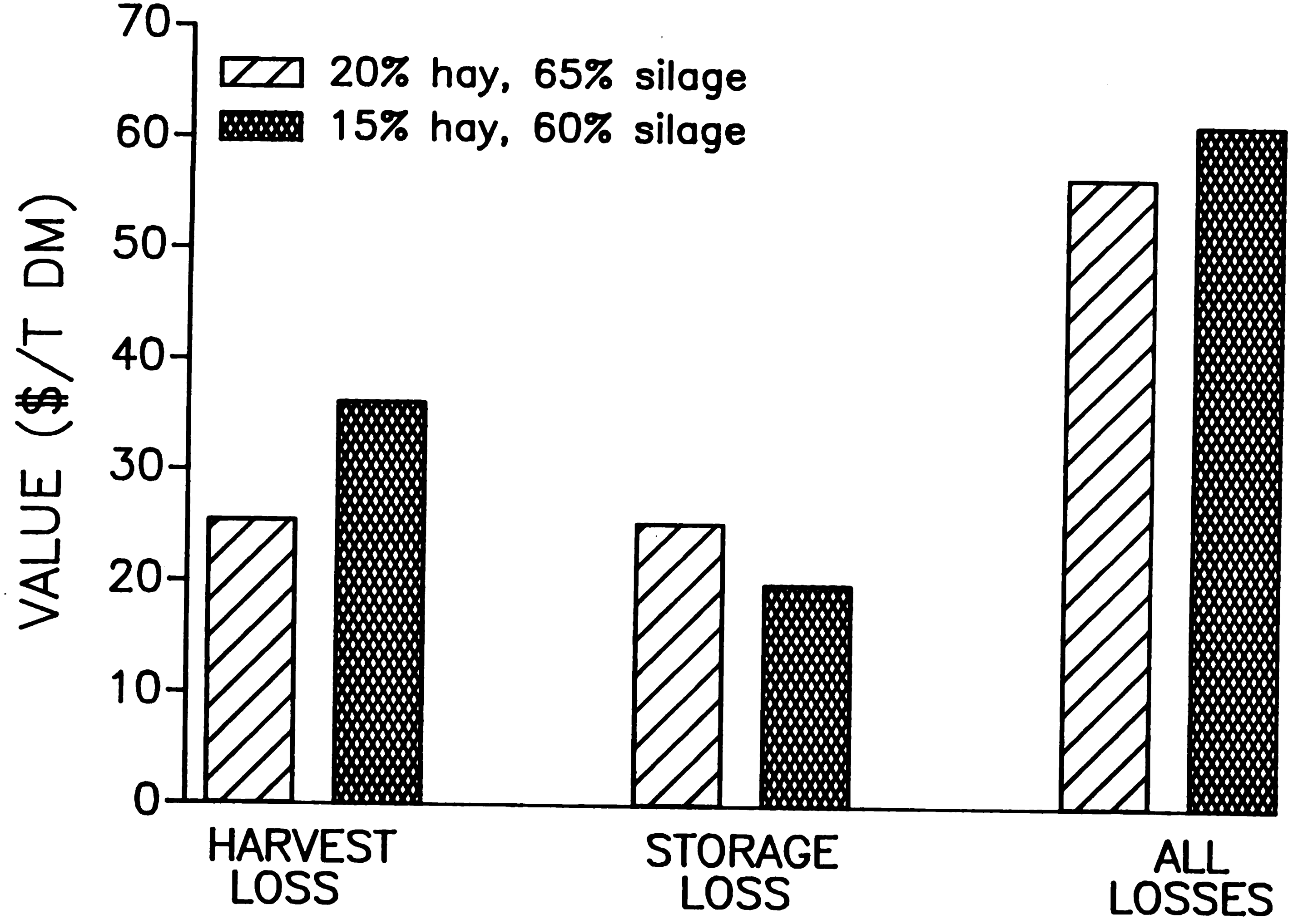

Figure 8.10 Impact of harvest moisture content on the value of combined harvest, storage and all alfalfa losses when forage quality determines milk production.

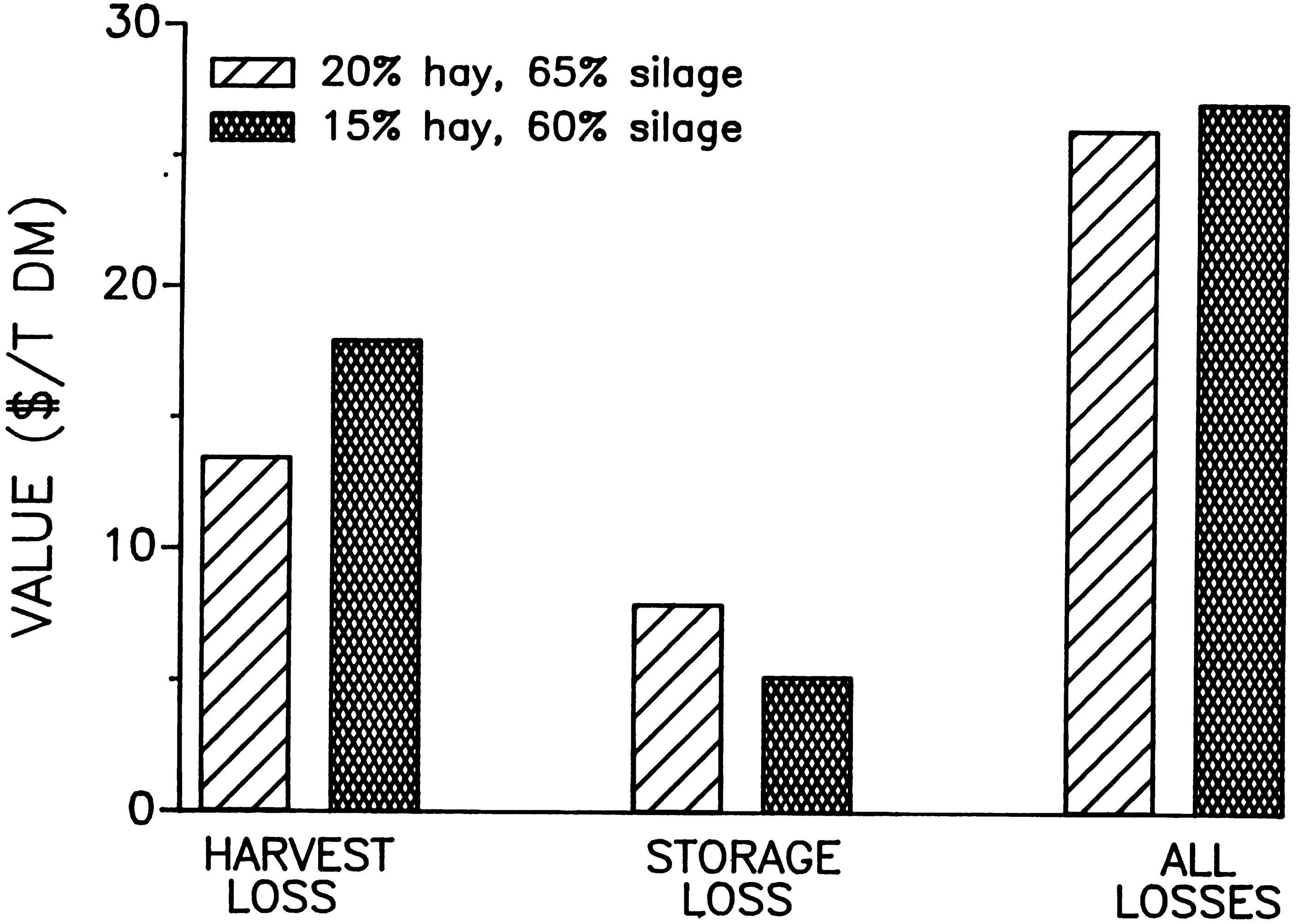

Figure 8.11 Impact of harvest moisture content on the value of combined harvest, storage and all alfalfa losses when milk production is 8,000 kg/y per cow.

Table 8.4 Value of losses during ensiling of alfalfa in three types of silos on the medium-sized farm*.

Phase	Milk production level	
	8000 kg/y	determined by forage quality
CONCRETE STAVE SILO		
Preseal	0.05	0.06
Fermentation	0.61	1.68
Infiltration	4.54	20.34
Feedout	1.44	4.39
Total	6.42	28.93
OXYGEN LIMITING SILO		
Preseal	0.05	0.06
Fermentation	0.53	1.73
Infiltration	4.78	20.37
Feedout	1.25	4.57
Total	6.38	28.51
BUNKER SILO		
Preseal	0.09	0.11
Fermentation	0.79	3.75
Infiltration	4.66	21.31
Feedout	1.67	6.68
Total	6.85	30.58

* This farm with 50 ha of alfalfa, 50 ha of corn and 100 lactating cows is described in detail in Tables 7.2, 7.3 and 7.4 and Appendix D.

the case of the bunker) were 2, 4 and 6 cm/atm-h for the bottom-unloaded oxygen-limiting, top-unloaded stave and bunker silos, respectively. Total value lost was highest with bunker silos and lowest with oxygen-limiting silos, regardless of milk production. When forage quality determined milk production, value lost during ensiling ranged from \$28.51 to \$30.58/T DM stored as silage (Table 8.4). If milk production was capped at 8,000 kg/cow-y, value lost during ensiling was approximately $6.50/T DM stored as silage.

A breakdown of the alfalfa value lost during ensiling indicates that the loss during the preseal phase is negligible -- $16 to $26/y. This may be partly due to the machinery size/silo size combinations, which were conducive to quick filling. An understanding of the preseal phase supports this conclusion, because the preseal phase typically lasts less than one day and at most 3 or 4 days. Expressed per unit of silage stored, the value of preseal loss ranged from $0.05 to $0.11/T DM (Table 8.4), with the highest value loss occurring in bunker silos because of their higher surface area.

Elimination of the dry matter loss occurring during fermentation of alfalfa increased net return from $433 to $911/y when forage quality determined milk production. With bunker silos, alfalfa value was reduced $3.75/T DM (Table 8.4). If forage quality determined milk production, value of fermentation loss was nearly 30 times the value of preseal loss. For a production level of 8,000 kg/cow-y, eliminating fermentation losses increased net return above feed costs by only $135 to $193/y, which corresponds to a value for fermentation loss of $0.53 to $0.79/T DM stored as silage.

Proteolysis (non-protein nitrogen formation) and hemicellulose breakdown occur during fermentation. Though these processes do not contribute to any alfalfa loss, they affect value by changing the chemical nature of the alfalfa. When fermentation losses were eliminated throughout this study, proteolysis and hemicellulose breakdown were not eliminated. Although this study is concerned primarily with the value of losses, the impact of these processes on alfalfa value was determined by shutting off each process individually.

In a top-unloaded tower silo on the medium-sized farm, eliminating hemicellulose breakdown reduced net return by $5,353/y when forage quality determined milk production; hence, the breakdown of hemicellulose increased value by $20.82/T DM. For lower milk production (8,000 kg/cow-y), hemicellulose breakdown during fermentation increased value by only $1.97/T DM.

Elimination of proteolysis resulted in an increase in farm net return of $5,768/y when forage quality determined milk production. The value loss due to proteolysis was nearly equal to the gain from hemicellulose breakdown. With lower milk production (8,000 kg/cow-y), proteolysis reduced net return by $2,717/y. With a value of $10.57/T DM, the quality change due to proteolysis caused more reduction in value than any single source of dry matter loss through harvest, storage and feeding.

Infiltration is the largest source of dry matter loss during ensiling; consequently, it is the largest source of value loss during ensiling of alfalfa. When forage quality determined milk production, eliminating infiltration loss in stave silos increased farm net return by $5,236/y. Expressed on a per unit of alfalfa basis ($20.34/T DM stored as silage, Table 8.4), infiltration during ensiling caused more value loss than any other source of dry matter loss from harvest through feeding.

The impact of infiltration loss was less when milk production was limited to 8,000 kg/cow-y. Eliminating infiltration loss in this case increased net return by $1,167/y (stave silos). Infiltration loss reduced the value of the alfalfa by $4.54/T DM stored as silage (Table

8.4).

Eliminating the feedout loss during ensiling increased net return by $1,127/y when forage quality determined milk production (stave silos). At $4.39/T DM stored as silage, the value lost during feedout was more than the value lost during fermentation (Table 8.4). When milk production was limited to 8,000 kg/cow-y, eliminating feedout loss increased farm net return by $370/y (value of $1.44/T DM). Feedout losses were more costly in bunker silos than the other two types even though the bunker silos were sized so that the feedout and infiltration losses would be small (i.e., they were long and narrow).

The value of total silo loss was greatest with bunker silos, but the value was only about $2.00/T DM greater than with the tower silos. The total value lost is not the sum of the value lost during each phase because losses during a given phase depend on the quality when the phase begins and thus depend on previous losses.

8.6.2 Animal parameters

8.6.2.1 Body weight

To determine the effect of animal body weight on the value of alfalfa losses, the body weights of all animals on the medium-sized farm were increased 10%. The consequences of the change were higher maintenance requirements and higher intake. With the increased intake capacity, milk production increased. The 10% increase in body weights increased the value of all combined losses by 11% if milk production were determined by forage quality. With milk production limited to 8,000 kg/cow-y, the 10% increase in body weight caused an increase of 9%

in value lost. Because a larger cow can obtain more value from a given forage, she can also obtain more value when losses are eliminated.

8.6.2.2 Ingestive capacity

An increase in the ingestive capacity of an animal increases its ability to eat without affecting its maintenance requirements. The result of an increase in ingestive capacity of 10% for all animals on the medium-sized farm was that the value of all losses together increased 6% regardless of milk production. Although not simulated, it was expected that changes in ingestive capacity would not significantly affect the value of individual losses relative to each other. The sensitivity of loss value to animal size and ingestive capacity illustrates that the parameters of the animal model are very crucial in this type of analysis.

8.6.3 Economic parameters

When alfalfa losses occur, the value lost can be attributed to two effects: decreased milk production and increased feed costs. Thus, the value of alfalfa losses depends somewhat on the price received for milk produced and the price paid for supplemental feeds.

8.6.3.1 Milk price

The value of alfalfa losses did not depend on milk price when milk production was fixed because only differences in net return were considered. When forage quality determined milk production, an increase in milk price from $0.25/kg to $0.275/kg (a 10% increase) caused the value of all combined losses to increase by 6%. Obviously, any loss that causes a reduction in milk production is more costly when the milk price is higher.

8.6.3.2 Price of protein supplements

To determine the sensitivity of loss value to protein supplement costs, the prices of soybean meal and distiller's grain were both increased 10%. The result was increased use of soybean meal and decreased use of distiller's grain. With the increased prices, a corn grain/soybean meal mix became more economical in some rations. Although feed use changed, the value of all combined losses did not change appreciably. With milk production limited by forage quality, the increase in protein supplement prices did not affect value at all. For the lower herd average, the value of losses increased 2% with the 10% increase in protein supplement prices.

The predicted use of distiller's grain does not reflect actual use on farms in the United States. It has yet to be determined whether the model or ration consultants (if either) are wrong. It is clear, however, that in certain parts of the country, distiller's grain is not available at a reasonable cost. To simulate this case, distiller's grain is given an unreasonably high cost within the LP ration balancer. This means that distiller's grain will never enter the diet and leaves soybean meal as the lone protein supplement.

Removal of distiller's grain as a potential protein supplement did not affect loss value when forage quality limited milk production. The value of all losses combined increased 5% when soybean meal was the only protein supplement in the diets of the lower producing herd.

8.7 Summary

The value of individual alfalfa losses depends on many factors, including harvest moisture, harvest type, herd description, machinery set, storage structures and economic conditions. Table 8.5 ranks the value loss due to individual processes for a 100-cow dairy farm. Regardless of the milk production potential of the dairy herd, storage losses were costly. All losses were more costly on the farm that included animals of high production potential.

Table 8.5 Ranking of alfalfa value losses on a medium-sized farm* due to individual processes.

	Milk production determined by forage quality		Milk production level of 8,000 kg/cow-y	
Rank	Loss	Value ($/T DM)	Loss	Value ($/T DM)
1	Silo storage	28.93	Hay storage	8.91
2	Hay storage	19.58	Raking	7.01
3	Raking	10.00	Silo storage	6.42
4	Rain	7.08	Baling	3.79
5	Respiration	6.24	Feeding	3.58
6	Baling	5.93	Chopping	3.00
7	Chopping	4.82	Rain	2.94
8	Feeding	4.29	Mowing	1.66
9	Mowing	2.46	Respiration	1.32

* This farm with 50 ha of alfalfa, 50 ha of corn and 100 lactating cows is described in detail in Tables 7.2, 7.3 and 7.4 and Appendix D.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

9.1.1 Loss models

Dry matter losses caused by respiration, rain damage, machinery treatment, storage as hay or silage, and feeding were modeled along with the changes in neutral detergent fiber and crude protein. Respiration loss, consisting of non-protein, non-fiber material, is a function of drying rate because the rate of respiration is a linear function of moisture content and an exponential function of temperature. Rain loss consists of non-fiber components and is a function of rainfall amount and alfalfa quality at the time of rain occurrence.

Machinery-induced losses due to mowing, raking, baling and chopping are functions of moisture content and yield. Quality changes due to mechanical handling are modeled by keeping track of the leaf to stem ratio of the plant because machinery treatments result in differential loss of leaves and stems.

Loss during indoor hay storage is modeled as a function of initial moisture content. Loss during outdoor storage of round bales is a fixed percentage. A comprehensive model of the ensiling process was developed by combining mathematical models of individual processes and incorporating several factors that describe the loading and unloading of silos. The individual phases of preseal, fermentation, infiltration and feedout were modeled sequentially.

9.1.2 Animal utilization model

The animal model combines requirements for energy, protein and fiber with an intake predictor to form a ration formulator. The model predicts animal response to forage quality and incorporates a description of a complete dairy herd. The whole-herd model can be used to predict total feed disappearance and potential milk production from a given quality of forage. Decision rule and optimal allocation schemes can be compared using the whole-herd model.

The animal model was used to determine the effect of alfalfa quality on its value. Neutral detergent fiber content affects potential milk production (income) as well as feed costs; protein content affects only feed costs.

9.1.3 Value of alfalfa losses

The value of alfalfa losses was determined by simulating the change in net return above feed costs on a representative 100-cow dairy farm when individual losses and combinations of losses were eliminated. Because the value of alfalfa depends on the production potential of the animals to which the alfalfa is fed, the value of losses depends on the animals.

If forage quality determined milk production, harvest and storage losses were almost of equal value -- each reduced alfalfa value by approximately $25/T DM. Eliminating all losses increased the net return of a representative medium-sized farm by $27,081/y. The value of all losses combined was simulated to be $56.54/T DM. When milk production was limited to 8000 kg/cow-y by animal potential, eliminating all losses increased net return by $12,448/y. The value of harvest losses

(\$13.42/T DM) was higher than the value of storage losses (\$7.87/T DM).

When forage quality affected milk production, silo storage losses caused the largest decrease in value (\$28.93/T DM). For lower milk production, hay storage caused the most loss in value (\$8.91/T DM). Losses associated with raking reduced alfalfa value by \$7.01 to 10.00/T DM; this was more than the value reduction associated with other machinery treatments, regardless of milk production. Value lost during the baling and chopping operations were similar (\$3.00 to 5.93/T DM). Value lost during the mowing operation (\$1.66 to 2.46/T DM) was smallest. If forage quality limited milk production, value lost because of rain damage (\$7.08/T DM) or respiration (\$6.24/T DM) was more than that lost because of individual machinery operations. For lower milk production, respiration loss reduced the value very little (\$1.32/T DM); rain damage was still relatively costly (\$2.94/T DM).

Non-optimal allocation, though not a true loss of feeds, is an economic loss. A comparison of allocation methods indicated that improving the allocation methods used by a typical dairy farmer could reduce feed costs 4 to 6% per unit of milk production. This corresponded to an annual net return increase of \$11,059 on the medium-sized farm if forage quality determined milk production. For a herd average of 8,000 kg/cow-y, improvement in feed allocation increased annual net return by \$3,271.

Farm size did not have a significant impact on the value of losses other than scaling the difference in annual net return. The type of alfalfa harvest (hay vs. silage) affects the ranking of operations in terms of value lost during each operation. Because curing time is longer and more machinery operations are involved, harvest losses are more costly in a hay system than in a silage system. The total value lost was much higher when rectangular bales were replaced with round bales because of the high storage and feeding losses associated with round bales, especially those stored outside. Though the value of storage losses decreased when harvest moisture content was decreased, the value of all losses increased because the increase in value lost during harvest was of higher magnitude.

Silo type had a relatively small impact on value lost during ensiling, but silo losses were more costly when bunker silos were used. The value of alfalfa losses was sensitive to the animal parameters of body weight and ingestive capacity. The price of supplemental feeds had a relatively small effect on the value of losses. Milk price had an impact on loss value only when forage quality limited milk production.

9.2 Recommendations for future work

The work begun here, though complete in some senses, must be continued. As further experimental data become available, the animal and silo models should be fine-tuned and validated. It is expected that new relationships will replace those in this dissertation. Even so, the structures outlined for the loss and animal models should lay the groundwork for the next generation of models.

Comparing allocation schemes (optimal vs. decision rule) identifies an area that is currently inefficient. Work should be done to implement optimization methods (linear or non-linear) applied to the task of simultaneous feed allocation and ration formulation for the complete dairy herd. This tactical approach to improving the overall efficiency of the dairy forage system should not require much labor or experimental research, but simply the application of the mathematical modeling methods already available. Another application of the animal models would be to ascribe relative feed value to alfalfa with respect to quality. Ascribing alfalfa value while considering the lactation cycle, the make-up of the dairy herd and properly balanced rations would be an improvement over the methods now available.

It is hoped that determining the value of losses through harvest and storage will help focus future research in the forage area. For high herd production levels, silo losses cause a great loss in value. The silo model indicates that the loss is due mainly to oxygen infiltration into the forage material over time. Research investigating methods of reducing oxygen permeability of silos should be performed. The silo model can be used to determine the economic feasibility of silo repair and improvement.

As the production potential of dairy animals increases, rain damage and respiration become more costly. It is obvious that fast curing helps eliminate these losses; thus, research directed toward decreased field curing time is suggested. The maceration process (Koegel et al., 1988) is an example of such work.

The value of losses from various processes has been identified. Engineers and farm operators should use this information to economically incorporate corrective measures; e.g., if chopper loss can be reduced by 50% with a $1200 modification, it would pay for itself in two years on a farm with a high herd production potential.

Though improvement research is important and necessary, knowledge must be extended beyond current technology so that the forages, processes and animals of the future can be combined in ways that result in maximum efficiency of the total system. The animal model should be useful for analyzing the available crop from new forage systems.

Simulation is a powerful tool for evaluating large, complex systems. Applications of systems modeling in the forage area (DAFOSYM, in particular) should be continually updated and, as time and resources allow, made more generic in their range of applicability. Though such large models are many times not intended for tactical decision support, a model such as DAFOSYM can be used to give accurate advice on long-term decisions. Though much care should be taken when using DAFOSYM to analyze large investment, long-term decisions, ancillary models of smaller entities (e.g., the silo or animal feeding) should be developed, validated and made available to producers so they can do some "what if" studies on their own with reduced consequences. With further validation and fine-tuning, the silo model has great potential for use as a tactical decision-making tool. Its ability to predict quality throughout the silo would enable more frequent ration formulation than would be economical when forage analysis is the only source of quality characterization.

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APPENDIX A

FORTRAN code for the hay and silo storage models in DAFOSYM.

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C PARTIAL GLOSSARY FOR STORAGE MODEL
C
C INCLUDED ARE KEY VARIABLES EXCLUSIVE TO STORAGE MODEL
C
C --- SUBROUTINE HAY ---
C
C   BP        BOUND PROTEIN CONTENT (ADIP), FRACTION OF D.M.
C   BPFCP     BOUND PROTEIN CONTENT, FRACTION OF CRUDE PROTEIN
C   DO        INITIAL DENSITY, KG/CUBIC METER
C   DD        HEATING IN DEGREE DAYS > 35 C
C   DPCPL     DIGESTIBLE PART OF THE CRUDE PROTEIN LOST
C   FMHY      FEEDING METHOD FOR HAY
C             THE FEEDING METHODS ARE
C                 1  RECTANGULAR BALES, HAND FED (0.05 DM LOSS)
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   MO        INITIAL MOISTURE, FRACTION
C   MF        FINAL MOISTURE, FRACTION
C   NFEED     FEEDING METHOD (FMHY OR FMHL+5)
C   NPL       NUMBER OF PLOT CURRENTLY CONSIDERED
C   NPSS      NUMBER OF PLOTS IN CURRENT STORAGE STRUCTURE
C   NSTR      STRUCTURE INDICATOR
C                 1  H.Q. ALF SILAGE
C                 2  H.Q. ALF SILAGE
C                 3  L.Q. ALF SILAGE
C                 4  L.Q. ALF SILAGE
C                 5  H.Q. ALF HAY INSIDE
C                 6  L.Q. ALF HAY INSIDE
C                 7  H.Q. ALF HAY OUTSIDE
C                 8  L.Q. ALF HAY OUTSIDE
C                50  CORN SILAGE
C                60  CORN SILAGE
C   QSTOR     TOTAL HEAT GENERATED OVER STORAGE PERIOD, KJ/KG
C   SDML      STORAGE DRY MATTER LOSS, FRACTION
C
C --- SUBROUTINE SILO ---
C
C   A         DIMENSIONLESS PARAMETER USED TO PREDICT DENSITY
C                (SEE PITT, 1983)
C   ACP       AMOUNT OF CRUDE PROTEIN, TONNE
C   ADIG      AMOUNT OF DIGESTIBLE FORAGE, TONNE
C   ADIGI     AMOUNT OF DIGESTIBLE FORAGE INITIALLY, TONNE
C   AHR       AIR TO HERBAGE RATIO
C   AMTDM     AMOUNT OF DRY MATTER, TONNE
C   AMTIN     AMOUNT OF DRY MATTER IN THE SILO, TONNE
C   ANDF      AMOUNT OF NEUTRAL DETERGENT FIBER, TONNE
C   ANPN      AMOUNT OF NON-PROTEIN NITROGEN, TONNE
C   ASH       ASH CONTENT, FRACTION OF D.M.
C   AVCP      AVERAGE CRUDE PROTEIN CONTENT, FRACTION OF D.M.
C   AVDIG     AVERAGE DIGESTIBILITY, FRACTION OF D.M.
C   AVDIGI    AVERAGE DIGESTIBILITY INITIALLY, FRACTION OF D.M.
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C   AVNDF      AVERAGE NEUTRAL DETERGENT FIBER CONTENT, FRACTION OF D.M.
C   AVNPN      AVERAGE NON-PROTEIN CONTENT, FRACTION OF D.M.
C   CAP        SILO CAPACITY, KG D.M.
C   CROP       CROP TYPE INDICATOR (1 FOR ALFALFA SILAGE,
C                 2 FOR CORN SILAGE)
C   CSA        CROSS SECTIONAL AREA, SQ METERS
C   CSAF       CROSS SECTIONAL AREA OF FEEDOUT SURFACE, SQ METERS
C   CSFDRT     CORN SILAGE FEEDRATE, KG/DAY
C   CSTBE      TIME BEFORE (STARTING TO) EMPTY THE CORN SILAGE SILO, DAYS
C   DENS       SILAGE DENSITY, KG/CUBIC METER
C   DENSC      SILAGE DENSITY AT CENTER OF SILO, KG/CUBIC METER
C   DENSE      SILAGE DENSITY AT EDGE OF SILO, KG/CUBIC METER
C   DEPTH      DEPTH OF CURRENT PLOT IN SILO, M
C   DIM1       DIAMETER (TOWER) OR WIDTH (BUNKER), M
C   DIM2       HEIGHT OF A BUNKER, M
C   DM         DRY MATTER CONTENT, FRACTION
C   DMAX       MAXIMUM POSSIBLE DENSITY (AT ZERO VOID SPACE), KG/CUBIC M
C   DMLEFT     AMOUNT OF DM HARVESTED "NOT IN SILO YET", KG
C   DRHO       DRY MATTER DENSITY, KG/CUBIC M
C   EXPAR      EXPOSED AREA DURING PRESEAL, SQ M
C   FDRTE      FEED RATE, KG D.M./DAY
C   FDTMP      TEMPERATURE AT FEEDING TIME, DEGREES C
C   FMHL       FEEDING METHOD FOR HAYLAGE
C               THE FEEDING METHODS ARE
C                  1  AUTOMATIC FEEDING
C                  2  CART OR TRUCK FEEDING
C   GAMO       UNCOMPACTED FORAGE DENSITY, KG/CUBIC M
C   NPSTAR     NUMBER OF PLOT WHICH MAKES THE SILO FULL
C   NSILO      INDICATOR FOR WHICH SILO IS CONSIDERED
C                  1,2  H.Q. ALF SILAGE
C                  3,4  L.Q. ALF SILAGE
C                  5,6  CORN SILAGE
C   NVS        NUMBER OF VERTICAL SECTIONS (IN BUNKER SILO)
C   NVSCS      NUMBER OF VERTICAL SECTIONS IN CORN SILAGE BUNKER SILO
C   PLOT(I,J)  QUALITY AND QUANTITY OF PLOT ARRAY
C              I= PLOT NUMBER;  J=INFORMATION TYPE AS FOLLOWS
C                  1   CROP TYPE (1.=ALFALFA SILAGE, 2.= CORN SILAGE)
C                  2   AMT OF DM IN PLOT INITIALLY, KG
C                  3   DRY MATTER CONTENT, DECIMAL
C                  4   NDF CONTENT, FRACTION OF D.M.
C                  5   CRUDE PROTEIN CONTENT, FRACTION OF D.M.
C                  6   NPN CONTENT, FRACTION OF CRUDE PROTEIN
C                  7   ADF CONTENT, FRACTION OF D.M.
C                  8   TEMPERATURE, DEGREES C
C                  9   EXPOSURE TIME OF THIS PLOT BEFORE BEING COVERED,
C                         DAYS
C                 10   PH OF THE SILAGE
C                 11   AMT OF DM AFTER PRESEAL, KG
C                 12   AMT OF DM AFTER FERMENTATION, KG
C                 13   AMT OF DM AFTER INFILTRATION, KG
C                 14   AMT OF DM AFTER FEEDOUT, KG
C   RAD        RADIUS OF TOWER SILO, M
C   REFILL     AMOUNT OF FORAGE PUT IN SILO DURING REFILL, KG D.M.
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C   RI          RADIUS TO INFILTRATION FRONT, M
C   RK          PARAMETER FOR COMPUTING DENSITY
C   RMUK        PARAMETER FOR COMPUTING DENSITY (GREEK MU TIMES K)
C   SILDAT(I,J) SILO INFORMATION ARRAY
C                   I = SILO NUMBER; J = INFORMATION TYPE AS FOLLOWS
C                     1  DIM1 ABOVE, M
C                     2  DIM2 ABOVE, M
C                     3  CAPACITY, TONNE
C                     4  COST, $
C                     5  PERMEABILITY TO OXYGEN, CM/ATM-H
C   SILTYP      SILO TYPE (1 UPRIGHT TOP UNLOADED, 2 UPRIGHT BOTTOM
C                            UNLOADED, 3 BUNKER)
C   SWETWT      SUM OF WET WEIGHT, KG
C   SWT         SUM OF DRY WEIGHT, KG D.M.
C   T3B         TIME TOP PLOT OF TOWER SILO IS IN THE SILO AND EXPERIENCES
C               TOP DOWN INFILTRATION, DAYS
C   TBE         TIME BEFORE EMPTYING CURRENT SILO, DAYS
C   TIME3       DURATION OF STAGE 3 (TIME PLOT IS IN THE SILO), DAYS
C   TOTDM       TOTAL AMOUNT OF DRY MATTER, KG
C   USILO       SILO PERMEABILITY TO OXYGEN, CM/ATM-H
C
C --- SUBROUTINE ENDSTR ---
C
C   FEEDLS      FEEDING LOSS FACTORS
C   IBUNK       INDICATOR FOR A BUNKER SILO
C   RESET       INDICATOR AS TO WHETHER OR NOT THIS IS THE FIRST SILO OF
C                  THE APPROPRIATE QUALITY OF FORAGE
C   VARCP       VARIANCE OF CRUDE PROTEIN CONTENT
C   VARDIG      VARIANCE OF DIGESTIBILITY
C   VARNDF      VARIANCE OF NEUTRAL DETERGENT FIBER CONTENT
C   VARNPN      VARIANCE OF NON-PROTEIN NITROGEN CONTENT
C   WSSCP       WEIGHTED SUM OF SQUARES FOR CRUDE PROTEIN CONTENT
C   WSSDIG      WEIGHTED SUM OF SQUARES FOR DIGESTIBILITY
C   WSSNDF      WEIGHTED SUM OF SQUARES FOR NDF CONTENT
C   WSSNPN      WEIGHTED SUM OF SQUARES FOR NON-PROTEIN NITROGEN CONTENT
C
C --- SUBROUTINE PRESEAL ---
C
C   C           TERM USED TO APPROXIMATE OXYGEN CONCENTRATION PROFILE
C   D           DIFFUSION COEFFICIENT OF OXYGEN THROUGH AIR, SQ CM/H
C   DELT        TEMPERATURE RISE, DEGREES C
C   DML1        DRY MATTER LOSS DURING STAGE 1, FRACTION
C   DMLPD       DRY MATTER LOSS PER DAY, FRACTION
C   DMLTD       DRY MATTER LOSS DURING CURRENT DAY, FRACTION
C   EXPTME      DURATION OF STAGE 1, DAYS
C   FC          RESPIRATION RATE AS DEPENDENT UPON CO2 CONCENTRATION
C   FD          RESPIRATION RATE AS DEPENDENT UPON DRY MATTER CONTENT
C   FPH         RESPIRATION RATE AS DEPENDENT UPON pH
C   FT          RESPIRATION RATE AS DEPENDENT UPON TEMPERATURE
C   GAMMA       TERM USED TO APPROXIMATE OXYGEN CONCENTRATION PROFILE
C   MUBAR       AVERAGE RESPIRATION RATE THROUGH DEPTH OF FORAGE
C   MUMAX       MAXIMUM RESPIRATION RATE OF FORAGE IN AIR,
C                  CUBIC CM OXYGEN/G SILAGE-H
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C   MUTAU     RESPIRATION RATE OF FORAGE, CUBIC CM OXYGEN/G SILAGE-H
C   PHI       POROSITY, FRACTION
C   RHO       DENSITY, G/CUBIC CM
C   RHOMAX    MAXIMUM DENSITY, G/CUBIC CM
C   TAU       TORTUOSITY OF DIFFUSIONAL PATHS
C   THICK     THICKNESS (OF CURRENT PLOT IN TOWER SILO, OF ALL MATERIAL
C                IN BUNKER), CM
C
C --- SUBROUTINE FERMENT ---
C
C   DML2      DRY MATTER LOSS DURING STAGE 2, FRACTION
C   HCCHG     CHANGE IN NDF DUE TO HEMICELLULOSE BREAKDOWN, FRACTION
C   NPN       NON-PROTEIN NITROGEN CONTENT, FRACTION OF CRUDE PROTEIN
C   PH        pH OF FORAGE
C   T         TEMPERATURE OF FORAGE, DEGREES C
C
C --- SUBROUTINE TOWER ---
C
C   A         AREA FOR INFILTRATION LOSS IN TOP PLOT (DOWNWARD
C                INFILTRATION), SQ M
C   ADJ       ADJUSTMENT TO AIR OXYGEN CONCENTRATION TO OXYGEN
C                CONCENTRATION
C             ON THE TOP SURFACE OF FORAGE IN THE SILO
C   AI        AREA OF INFILTRATION FRONT, SQ M
C   B         DISTANCE BETWEEN SILO WALL AND MOVING FRONT, M
C   BPAST     DISTANCE BETWEEN SILO WALL AND MOVING FRONT LAST TIME
C                PERIOD, M
C   DTAU      D*TAU (SEE ABOVE)
C   LDEC      DRY MATTER LOSS, FRACTION
C   LDECB     DRY MATTER LOSS DUE TO TOP PLOT DOWNWARD INFILTRATION,
C                FRACTION
C   LKGACB    ACCUMULATED LOSS OVER TIME IN TOP PLOT DOWNWARD
C                INFILTRATION, KG
C   LKGACC    ACCUMULATED LOSS OVER TIME, KG
C   PI        3.14159
C   PSIT      OXYGEN CONCENTRATION AT TOP OF FORAGE SURFACE
C   RI        RADIUS TO MOVING FRONT, M
C   RIPAST    RADIUS TO MOVING FRONT DURING LAST TIME PERIOD, M
C   RS        RESPIRABLE SUBSTRATE, FRACTION OF D.M.
C   T3        DURATION OF STAGE 3, DAYS
C   TME       TIME, DAYS
C   UCOV      OXYGEN PERMEABILITY OF SILO COVER, CM/ATM-H
C   UEFF      EFFECTIVE PERMEABILITY OF SILO WALL AND FORAGE MATERIAL
C                OUTSIDE THE MOVING FRONT, CM/ATM-H
C   UMAT      PERMEABILITY OF FORAGE MATERIAL OUTSIDE THE MOVING FRONT,
C                CM/ATM-H
C   USILO     PERMEABILITY OF SILO WALL, CM/ATM-H
C
C --- SUBROUTINE BUNKER ---
C
C   A         SURFACE AREA ON TOP OF 10 DAYS' WORTH OF MATERIAL, SQ M
C   AVGPH     AVERAGE PH OF FORAGE
C   AVGT      AVERAGE TEMPERATURE OF FORAGE, DEGREES C
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C   CCP        CRUDE PROTEIN CONTENT, FRACTION OF D.M.
C   CNDF       NEUTRAL DETERGENT FIBER CONTENT, FRACTION OF D.M.
C   CNPN       NON-PROTEIN NITROGEN CONTENT, FRACTION OF CRUDE PROTEIN
C   HEIGHT     HEIGHT OF BUNKER, M
C   IVS        COUNTER FOR VERTICAL SECTIONS
C   SPHXWT     SUM OF PH TIMES WEIGHT
C   STXWT      SUM OF TEMPERATURE TIMES WEIGHT
C   T          DISTANCE BETWEEN BUNKER TOP AND MOVING FRONT, M
C   TPAST      DISTANCE BETWEEN BUNKER TOP AND MOVING FRONT LAST TIME
C                 PERIOD, M
C   U          PERMEABILITY OF BUNKER SILO COVER, CM/ATM-H
C
C --- SUBROUTINE FEEDOUT ---
C
C   CSAF       CROSS SECTIONAL AREA OF FEEDOUT SURFACE, SQ M
C   DML4       DRY MATTER LOSS DURING STAGE 4, FRACTION
C   DML4A      DRY MATTER LOSS IN-SILO DURING STAGE 4, FRACTION
C   DML4B      DRY MATTER LOSS IN-BUNK DURING STAGE 4, FRACTION
C   DF         THICKNESS OF FORAGE FED PER DAY, CM
C   THICK      DEPTH AT WHICH OXYGEN CONCENTRATION GRADIENT IS ZERO, CM
C
C --- SUBROUTINE CSSILO ---
C
C   ADM(J)     AMOUNT OF DRY MATTER IN SILO J (J=1,2), TONNE
C   CLOSSS(3)  STORAGE DRY MATTER LOSS IN CORN SILAGE SILO, FRACTION
C   CSMC       CORN SILAGE MOISTURE CONTENT, DECIMAL WET BASIS
C   CSTBE      TIME BEFORE EMPTYING CORN SILAGE SILO, DAYS
C   JDAYCS     DAYS TO FILL CORN SILAGE SILO
C
C **********************************************************************
      SUBROUTINE HAY (NSTR,NPSS)
C **********************************************************************
C
C  DETERMINES THE LOSSES AND QUALITY CHANGES WHICH OCCUR DURING THE
C  STORAGE OF DRY HAY
C  (D.R. BUCKMASTER, AGRIC. ENGINEERING DEPT., MSU, JUNE 1988)
C
      LOGICAL FULL
      REAL MO,MF
      INTEGER*4 NYRS,JYEARF,IPRT1,MGMT,IRAIN,NCUTS,ISIL(7)
      INTEGER*4 IMOWER,IRAKE,IBALER,IFHRV,ICRNPL,IHMCHV,NMOWER,NRAKE,
     +          NBALER,NLOADE,NELEVA,NFHRV,NBLOWE,NCRNPL,NHMCHV,NTRANS,
     +          KMOWER,KRAKE,KBALER,KLOADE,KTRANS,KFHRV,KBLOWE,KCRNPL,
     +          KHMCHV,LHAY,LHAYLG,LSILG,LHMC
      COMMON /W3/ HFEED(8,160,8)
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),IRAIN
      COMMON /Z7/ ALHRFD(26,20),AFEED(2,26,33),FEEDUT(26,14)
      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,MGMT
      COMMON /STRG/ SILDAT(32,5),FCAP,ISIL,HAYST(3),FMHY,FMHL
      COMMON /OPER/ MOWER(5),JRAKE(2),JBALER(6),JFHRV(4),JCRNPL(4),
     +      JHMCHV(3),JTRAC(7),IMOWER,IRAKE,IBALER,IFHRV,ICRNPL,IHMCHV,
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     +       NMOWER,NRAKE,NBALER,NFHRV,NCRNPL,NHMCHV,NLOADE,NTRANS,
     +       NBLOWE,NELEVA,KMOWER,KRAKE,KBALER,KFHRV,KCRNPL,KHMCHV,
     +       KLOADE,KTRANS,KBLOWE,KELEVA,LHAY,LHAYLG,LSILG,LHMC
      COMMON /Z3/ HARDEX,TMSTO(8),RF(5),NPST(5,9),NCUM(9),OPUSE(5,9),
     +            FULL(4)
      COMMON /SDATA/ PLOT(52,14)
      COMMON /CSSIL/ AMTDM,CSFDRT,CSTBE,NVSCS
      COMMON/LOSS/ILOSS
      INTEGER*4 ILOSS(12)
      DATA MF/0.12/
C
C  DRY HAY STORED INSIDE OR SQUARE BALES STORED OUTSIDE
C       (COVERING ASSUMED IN THE LATTER CASE)
C
      IF( (NSTR.EQ.5).OR.(NSTR.EQ.6) .OR.
     + ((NSTR.GT.4).AND.(NSTR.LE.8).AND.(IBALER.GE.1).AND.
     +                  (IBALER.LE.6)) ) THEN
C   CONVERT MOISTURE TO WET BASIS FOR USE IN HAY STORAGE MODEL
         NFEED = FMHY
         DO 5 NPL=1,NPSS
           MO = HFEED(NSTR,NPL,5)/(1.+HFEED(NSTR,NPL,5))
           IF(MO.LT.0.12) MO=.12
           DO = 100. + 440.*MO
           QSTOR = 104.*MO**2.18 * DO**0.5 + 5.72*MO**1.23 * DO**0.94
C   DETERMINE DRY MATTER LOSS
           SDML = (QSTOR  +  2433. * (MO-MF*(1.-MO)/(1.-MF)))/
     +           ((1.-MO) * (14206. - 2433.*MF/(1.-MF)))
C
C TOGGLE FOR SHUTTING OFF HAY STORAGE LOSS
           IF(ILOSS(7).EQ.1) SDML = 0.
C   DETERMINE QUALITY CHANGES
           DPCPL = 0.4*HFEED(NSTR,NPL,2)*SDML
           HFEED(NSTR,NPL,1)=HFEED(NSTR,NPL,1)*(1.-SDML)
           HFEED(NSTR,NPL,2)=HFEED(NSTR,NPL,2)*(1.-0.4*SDML)/(1.-SDML)
           HFEED(NSTR,NPL,3)=(HFEED(NSTR,NPL,3) - DPCPL*0.929 -
     +                      (SDML-DPCPL)*1.)/(1.-SDML)
           IF(MO.GT.0.12) THEN
              DD = 48640. * (MO-.12)**1.836
           ELSE
              DD = 0.
           ENDIF
           IF(ILOSS(7).EQ.1) DD = 0.
           BP = .01*(0.8 + 0.00373*DD)/(1.-SDML)
           BPFCP = BP/HFEED(NSTR,NPL,2)
           HFEED(NSTR,NPL,4)=HFEED(NSTR,NPL,4)/(1.-SDML)
           HFEED(NSTR,NPL,5)=MF/(1.-MF)
           HFEED(NSTR,NPL,8) = BPFCP
    5    CONTINUE
C
C  ROUND BALES STORED OUTSIDE
      ELSEIF((NSTR.EQ.7).OR.(NSTR.EQ.8).AND.(IBALER.GE.7)) THEN
         NFEED = FMHY
         DO 7 NPL=1,NPSS
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          SDML = 0.14
          IF(ILOSS(7).EQ.1) SDML = 0.
          HFEED(NSTR,NPL,1)=HFEED(NSTR,NPL,1)*(1.-SDML)
C          HFEED(NSTR,NPL,2) = HFEED(NSTR,NPL,2)
C          HFEED(NSTR,NPL,3)=(HFEED(NSTR,NPL,3) - DPCPL*0.929 -
C     +                     (SDML-DPCPL)*1.)/(1.-SDML)
          HFEED(NSTR,NPL,3) = HFEED(NSTR,NPL,3) - SDML
          HFEED(NSTR,NPL,4)=HFEED(NSTR,NPL,4)/(1.-SDML)
          BP = 0.01*0.8
          BPFCP = BP/HFEED(NSTR,NPL,2)
          HFEED(NSTR,NPL,8) = BPFCP
    7   CONTINUE
C
C  HAY STACKS STORED OUTSIDE
C     ELSEIF((NSTR.EQ.7).OR.(NSTR.EQ.8).AND.(A STACKER)) THEN
C        NFEED = FMHY
C        DO 9 NPL=1,NPSS
C          SDML = 0.16
C          HFEED(NSTR,NPL,1)=HFEED(NSTR,NPL,1)*(1.-SDML)
C         ASSUMED NO QUALITY CHANGE IN STACKS
C    9   CONTINUE
      ENDIF
      CALL ENDSTR(NSTR,NPSS,0,0,NFEED)
      RETURN
      END
C
C ***********************************************************************
      SUBROUTINE SILO (NSTR,NPSS)
C ***********************************************************************
C  DETERMINES THE LOSSES AND QUALITY CHANGES WHICH OCCUR DURING THE
C  STORAGE OF SILAGE
C  (D.R. BUCKMASTER, AGRIC. ENGINEERING DEPT., MSU, JUNE 1988)
C
      LOGICAL FULL
      REAL RI(52)
      INTEGER*4 NYRS,JYEARF,IPRT1,MGMT,IRAIN,NCUTS,ISIL(7),SILTYP
      INTEGER*4 IMOWER,IRAKE,IBALER,IFHRV,ICRNPL,IHMCHV,NMOWER,NRAKE,
     +          NBALER,NLOADE,NELEVA,NFHRV,NBLOWE,NCRNPL,NHMCHV,NTRANS,
     +          KMOWER,KRAKE,KBALER,KLOADE,KTRANS,KFHRV,KBLOWE,KCRNPL,
     +          KHMCHV,LHAY,LHAYLG,LSILG,LHMC
      COMMON /W3/ HFEED(8,160,8)
      COMMON /Z1/ AREA(6),NBO(6),NOPSQ(5,9),CRTR(5,4,9),IRAIN
      COMMON /Z7/ ALHRFD(26,20),AFEED(2,26,33),FEEDUT(26,14)
      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,MGMT
      COMMON /STRG/ SILDAT(32,5),FCAP,ISIL,HAYST(3),FMHY,FMHL
      COMMON /OPER/ MOWER(5),JRAKE(2),JBALER(6),JFHRV(4),JCRNPL(4),
     +       JHMCHV(3),JTRAC(7),IMOWER,IRAKE,IBALER,IFHRV,ICRNPL,IHMCHV,
     +       NMOWER,NRAKE,NBALER,NFHRV,NCRNPL,NHMCHV,NLOADE,NTRANS,
     +       NBLOWE,NELEVA,KMOWER,KRAKE,KBALER,KFHRV,KCRNPL,KHMCHV,
     +       KLOADE,KTRANS,KBLOWE,KELEVA,LHAY,LHAYLG,LSILG,LHMC
      COMMON /Z3/ HARDEX,TMSTO(8),RF(5),NPST(5,9),NCUM(9),OPUSE(5,9),
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     +              FULL(4)
      COMMON /SDATA/ PLOT(52,14)
      COMMON /CSSIL/ AMTDM,CSFDRT,CSTBE,NVSCS
      INTEGER IBUNK
C
      IF(NSTR.LE.4) THEN
C       ALFALFA IN A SILO
         NSILO = NSTR
         CROP = 1.
         TOTDM = 1000.*TMSTO(NSILO)
C       EMPTY OUT SILOS OF "SAME" QUALITY OVER APPROX. 365 DAYS
         IF((NSILO.EQ.1).OR.(NSILO.EQ.2)) THEN
C       H.Q. HAYLAGE
            FDRTE = 1000.*(TMSTO(1)+TMSTO(2))/365.
C          IF 2ND SILO, ADD TIME OF EMPTYING 1ST SILO TO STORAGE TIME
            IF(NSILO.EQ.2) THEN
               TBE = TMSTO(1)*1000./FDRTE
            ELSE
               TBE = 0.0
            ENDIF
         ELSE
C          L.Q. HAYLAGE
            FDRTE = 1000.*(TMSTO(3)+TMSTO(4))/365.
            IF(NSILO.EQ.4) THEN
               TBE = TMSTO(3)*1000./FDRTE
            ELSE
               TBE = 0.0
            ENDIF
         ENDIF
         ASH = 0.07
C TRANSFER ALFALFA QUALITY DATA REGARDLESS OF SILO TYPE
         DO 100 NPL = NPSS,1,-1
            PLOT(NPL,1) = CROP
            PLOT(NPL,2) = HFEED(NSTR,NPL,1) * 1000.
            PLOT(NPL,3) = 1.  /  (1. + HFEED(NSTR,NPL,5))
            PLOT(NPL,4) = HFEED(NSTR,NPL,4)
            PLOT(NPL,5) = HFEED(NSTR,NPL,2)
C            PLOT(NPL,7) = 0.19
            PLOT(NPL,8) = 18.
            IF(NPL.EQ.NPSS) THEN
               PLOT(NPL,9) = 0.125
            ELSE
               PLOT(NPL,9) = HFEED(NSTR,NPL+1,7) - HFEED(NSTR,NPL,7)
            ENDIF
C          IF PLOT WAS EXPOSED FOR MORE THAN 3 DAYS, ASSUME IT WAS
C             CAPPED AFTER 3 DAYS:
            IF(PLOT(NPL,9).GT.3.) PLOT(NPL,9) = 3.
            IF(PLOT(NPL,9).LT.0.) PLOT(NPL,9) = 0.
            PLOT(NPL,10) = 5.8
  100    CONTINUE
      ELSE
C       WHOLE PLANT CORN SILAGE IN A SILO
         NSILO = NSTR/10
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          CROP = 2.
C        AMOUNT, FEED RATE AND CROP QUALITY ASSIGNED INTO PLOT ARRAY IN
C        SUBROUTINE CSSILO
          TOTDM = AMTDM*1000.
          FDRTE = CSFDRT
          TBE = CSTBE
          ASH = 0.05
       ENDIF
C INITIALIZATION OF IMPORTANT VARIABLES
       USILO = SILDAT(ISIL(NSILO),5)
       CAP = 1000.*SILDAT(ISIL(NSILO),3)
       FDTMP = 18.
       DATA RMUK/0.25/
       DIM1 = SILDAT(ISIL(NSILO),1)
       DIM2 = SILDAT(ISIL(NSILO),2)
       IF((ISIL(NSILO).GE.26).AND.(ISIL(NSILO).LE.32)) THEN
C        BUNKER
          IF(CROP.EQ.1.) THEN
C           ALFALFA
             DRHO = 190.
          ELSE
C           CORN
             DRHO = 225.
          ENDIF
          CSA = TOTDM/(DRHO*DIM2)
          CSAF = DIM1*DIM2
          EXPAR = SQRT(5.) * DIM1 * DIM2
       ELSE
C        TOWER
          IF(CROP.EQ.1) THEN
C          ALFALFA
            DRHO = 130.
            RK = 0.00003
          ELSE
C          CORN
            DRHO = 180.
            RK = 0.000012
          ENDIF
          RAD = DIM1/2.
          CSA = 3.14159*RAD**2
          CSAF = CSA
          EXPAR = CSA
       ENDIF
C
       IF((ISIL(NSILO).GE.2).AND.(ISIL(NSILO).LE.13)) THEN
C
C        TOWER WITH TOP UNLOADER
C
          SILTYP = 1
          NFEED = 5+FMHL
          IBUNK = 0
          TIME3 = TBE
          DEPTH = 0.5*(PLOT(NPSS,2)/(DRHO*CSA))
```

```
        REFILL = 0.
        DMLEFT = TOTDM
        DO 200 NPL = NPSS,1,-1
           DMAX = 1000./(1.-PLOT(NPL,3) + (PLOT(NPL,3)/1.5))
C
C     REFILL CHECKING ROUTINE
C
           IF((DMLEFT.GE.CAP).AND.(DMLEFT-PLOT(NPL,2).LE.CAP)) THEN
C            SWITCH FROM REFILL PLOTS TO ORIGINAL PLOTS
              TIME3 = 0.
              REFILL = TOTDM - DMLEFT
              DEPTH = 0.5*(PLOT(NPL,2)/(DRHO*CSA))
           ELSEIF((DMLEFT.GE.CAP-REFILL).AND.
     +     (DMLEFT-PLOT(NPL,3).LE.CAP-REFILL)) THEN
C            CONSIDER PLOTS WHICH WERE IN THE SILO BEFORE AND
C               AFTER REFILL
              TIME3 = TIME3  +  (TIME3 - TBE)
           ENDIF
           DMLEFT = DMLEFT - PLOT(NPL,2)
C
C     END OF REFILL CHECKING
C
           TIME3 = TIME3 + 0.5*PLOT(NPL,2)/FDRTE
           GAMO = DRHO/PLOT(NPL,3)
           A = 2. * RMUK / (RAD * RK * GAMO * 9.807)
           DENSE = GAMO * (1. + 1./(A-1.)
     +             *(1.-EXP((1.-A)*RK*GAMO*9.807*DEPTH)))
           IF(DENSE.GT.DMAX) DENSE = DMAX
           DENSC = GAMO*EXP(RK*GAMO*9.807*DEPTH)
           IF(DENSC.GT.DMAX) DENSC = DMAX
           DENS = (DENSE+DENSC)/2.
           AHR = DMAX/DENS - 1.
C  PRESEAL LOSS
           CALL PRESEAL(NPL,SILTYP,EXPAR,DRHO)
C  FERMENTATION CHANGES
           CALL FERMENT(NPL,AHR)
C  INFILTRATION LOSS
           RI(NPL) = 0.
           CALL TOWER(USILO,RAD,NPL,NPSS,DENS,TIME3,TBE,RI(NPL),ASH)
           TIME3 = TIME3 + 0.5*PLOT(NPL,2)/FDRTE
C  FEEDOUT LOSS
           CALL FEEDOUT(SILTYP,NPL,CSAF,FDTMP,FDRTE,DENS,ASH)
           IF(CROP.EQ.1.) THEN
              SDML = 1. - PLOT(NPL,14)/PLOT(NPL,2)
              HFEED(NSTR,NPL,1) = PLOT(NPL,14)/1000.
              HFEED(NSTR,NPL,2) = PLOT(NPL,5)
              HFEED(NSTR,NPL,3) = (HFEED(NSTR,NPL,3)-SDML)/(1.-SDML)
              HFEED(NSTR,NPL,4) = PLOT(NPL,4)
              HFEED(NSTR,NPL,5) = 1./PLOT(NPL,3)  -  1.
              HFEED(NSTR,NPL,8) = PLOT(NPL,6)
           ENDIF
           DEPTH = DEPTH + (PLOT(NPL,2)/(PLOT(NPL,3)*DENS*CSA))
C         READY FOR NEXT PLOT TO BE CONSIDERED
```

```
  200    CONTINUE
         IF(CROP.EQ.2.) RETURN
C    ALL PLOTS CONSIDERED
      ELSEIF( (ISIL(NSILO).GE.14).AND.(ISIL(NSILO).LE.25) ) THEN
C
C       TOWER WITH BOTTOM UNLOADER
C
         SILTYP = 2
         NFEED = 7+FMHL
         IBUNK = 0
         REFILL = 0.
         AMTIN = 0.

         DO 220 NPL = 1,NPSS
            IF(AMTIN + PLOT(NPL,2).GT.CAP) THEN
C             THERE WAS SOME REFILLING -- DETERMINE WHAT PLOTS WERE
C                IN THE SILO ORIGINALLY
               REFILL = TOTDM - CAP
               T3B = CAP/FDRTE
               GO TO 235
            ELSE
C             WE HAVE NOT GOTTEN THE SILO FILLED YET
               AMTIN = AMTIN + PLOT(NPL,2)
               NPSTAR = NPL
               T3B = AMTIN/FDRTE
            ENDIF
  220    CONTINUE
C  NPSTAR IS THE TOP PLOT BEFORE REFILLING
  235    TIME3 = TBE + CAP/FDRTE
         IF(NPSTAR.NE.NPSS) THEN
C          THERE WAS REFILLING, SIMULATE INFILTRATION FOR THE TIME
C          PERIOD PRIOR TO REFILL
            DEPTH = 0.5*(PLOT(NPSTAR,2)/(DRHO*CSA))
            DO 250 NPL = NPSTAR,1,-1
               DMAX = 1000./(1.-PLOT(NPL,3) + (PLOT(NPL,3)/1.5))
               TIME3 = TIME3 - 0.5*PLOT(NPL,2)/FDRTE
               IF(TIME3.GT.TBE+REFILL/FDRTE) THEN
C                 SHORTEN TIME3 TO TIME BEFORE REFILL
                  TIME3 = TBE+REFILL/FDRTE
               ENDIF
               GAMO = DRHO/PLOT(NPL,3)
               A = 2. * RMUK / (RAD * RK * GAMO * 9.807)
               DENSE = GAMO * (1. + 1./(A-1.)
     +              *(1.-EXP((1.-A)*RK*GAMO*9.807*DEPTH)))
               IF(DENSE.GT.DMAX) DENSE = DMAX
               DENSC = GAMO*EXP(RK*GAMO*9.807*DEPTH)
               IF(DENSC.GT.DMAX) DENSC = DMAX
               DENS = (DENSE+DENSC)/2.
               AHR = DMAX/DENS - 1.
C  PRESEAL LOSS FOR ORIGINAL PLOTS
               CALL PRESEAL(NPL,SILTYP,EXPAR,DRHO)
C  FERMENTATION CHANGES FOR ORIGINAL PLOTS
               CALL FERMENT(NPL,AHR)
```

```
C  INFILTRATION LOSS FOR ORIGINAL PLOTS BEFORE REFILL
              RI(NPL) = 0.
              CALL TOWER(USILO,RAD,NPL,NPSS,DENS,TIME3,T3B,RI(NPL),ASH)
              TIME3 = TIME3 - 0.5*PLOT(NPL,2)/FDRTE
              IF(NPL.LE.NPSS-NPSTAR) THEN
C  IT WAS A "REPLACED" PLOT, SO SIMULATE FEEDOUT ETC.
                 CALL FEEDOUT(SILTYP,NPL,CSAF,FDTMP,FDRTE,DENS,ASH)
                 IF(CROP.EQ.1.) THEN
                    SDML = 1. - PLOT(NPL,14)/PLOT(NPL,2)
                    HFEED(NSTR,NPL,1) = PLOT(NPL,14)/1000.
                    HFEED(NSTR,NPL,2) = PLOT(NPL,5)
                    HFEED(NSTR,NPL,3) = (HFEED(NSTR,NPL,3)-SDML)/
     +                                  (1.-SDML)
                    HFEED(NSTR,NPL,4) = PLOT(NPL,4)
                    HFEED(NSTR,NPL,5) = 1./PLOT(NPL,3)  -  1.
                    HFEED(NSTR,NPL,8) = PLOT(NPL,6)
                 ENDIF
              ENDIF
              DEPTH = DEPTH + (PLOT(NPL,2)/(PLOT(NPL,3)*DENS*CSA))
C            READY FOR NEXT PLOT TO BE CONSIDERED
  250        CONTINUE
         ENDIF
C   SIMULATE INFILTRATION FOR EITHER PLOTS IN THE SILO AFTER
C   REFILL OR FOR A SILO THAT WAS NOT REFILLED.
C   IF REFILLED: DO NOT CONSIDER TIME BEFORE EMPTYING FOR REFILLED PLOTS
C   ELSE:  TIME3 = TBE + CAP/FDRTE   AS ABOVE
         IF(REFILL.GT.O.) TIME3 = CAP/FDRTE
         DEPTH = 0.5*(PLOT(NPSTAR,2)/(DRHO*CSA))
         DO 280 NPL=NPSS,NPSS-NPSTAR+1,-1
            DMAX = 1000./(1.-PLOT(NPL,3) + (PLOT(NPL,3)/1.5))
            TIME3 = TIME3 - 0.5*PLOT(NPL,2)/FDRTE
            GAMO = DRHO/PLOT(NPL,3)
            A = 2. * RMUK / (RAD * RK * GAMO * 9.807)
            DENSE = GAMO * (1. + 1./(A-1.)
     +              *(1.-EXP((1.-A)*RK*GAMO*9.807*DEPTH)))
            IF(DENSE.GT.DMAX) DENSE = DMAX
            DENSC = GAMO*EXP(RK*GAMO*9.807*DEPTH)
            IF(DENSC.GT.DMAX) DENSC = DMAX
            DENS = (DENSE+DENSC)/2.
            AHR = DMAX/DENS - 1.
            IF((NPL.GT.NPSTAR).OR.(NPSTAR.EQ.NPSS)) THEN
C  THESE PLOTS HAVE NOT BEEN CONSIDERED AT ALL YET.
C  PRESEAL LOSS FOR REFILL PLOTS ONLY, OR IN SILO WHICH WAS NOT REFILLED
              CALL PRESEAL(NPL,SILTYP,EXPAR,DRHO)
C  FERMENTATION CHANGES FOR REFILL PLOTS ONLY, OR IN SILO WHICH WAS NOT
C  REFILLED
              CALL FERMENT(NPL,AHR)
              RI(NPL) = 0.
            ENDIF
C  INFILTRATION LOSS FOR ALL PLOTS REMAINING AFTER REFILL -- EFFECT OF
C  PREVIOUS INFILTRATION IS TAKEN INTO CONSIDERATION BY THE RI(NPL)
C  VALUE.
            CALL TOWER(USILO,RAD,NPL,NPSS,DENS,TIME3,T3B,RI(NPL),ASH)
```

```
            TIME3 = TIME3 - 0.5*PLOT(NPL,2)/FDRTE
C STORAGE COMPLETED, SO SIMULATE FEEDOUT LOSS
            CALL FEEDOUT(SILTYP,NPL,CSAF,FDTMP,FDRTE,DENS,ASH)
            IF(CROP.EQ.1.) THEN
               SDML = 1. - PLOT(NPL,14)/PLOT(NPL,2)
               HFEED(NSTR,NPL,1) = PLOT(NPL,14)/1000.
               HFEED(NSTR,NPL,2) = PLOT(NPL,5)
               HFEED(NSTR,NPL,3) = (HFEED(NSTR,NPL,3)-SDML)/(1.-SDML)
               HFEED(NSTR,NPL,4) = PLOT(NPL,4)
               HFEED(NSTR,NPL,5) = 1./PLOT(NPL,3)  -  1.
               HFEED(NSTR,NPL,8) = PLOT(NPL,6)
            ENDIF
            DEPTH = DEPTH + 1.0*(PLOT(NPL,2)/(PLOT(NPL,3)*DENS*CSA))
  280    CONTINUE
         IF(CROP.EQ.2.) RETURN
      ELSE
C
C       BUNKER SILO
C
         SILTYP = 3
         NFEED = 10
         IBUNK = 1
         DO 300 NPL = NPSS,1,-1
            DENS = DRHO/PLOT(NPL,3)
            DMAX = 1000./(1.-PLOT(NPL,3) + (PLOT(NPL,3)/1.5))
            AHR = DMAX/DENS - 1.
C  PRESEAL LOSS
            CALL PRESEAL(NPL,SILTYP,EXPAR,DRHO)
C  FERMENTATION CHANGES
            CALL FERMENT(NPL,AHR)
  300    CONTINUE
C  INFILTRATION LOSSES
         CALL BUNKER(CSA,USILO,NPSS,DRHO,FDRTE,TBE,NVS,ASH)
C  RESET SUMMING VARIABLES
         ANDF = 0.
         ANPN = 0.
         ACP = 0.
C         AADF = 0.
C         STXWT = 0.
         SWT = 0.
C         SPHXWT = 0.
         SWETWT = 0.
C  FEEDOUT LOSSES AND SUM FOR WEIGHTED AVERAGE QUALITY DETERMINATION
         DO 330 IVS = 1,NVS
            CALL FEEDOUT(SILTYP,IVS,CSAF,FDTMP,FDRTE,DENS,ASH)
            IF(CROP.EQ.1.) THEN
               ANDF = ANDF + PLOT(IVS,14)*PLOT(IVS,4)
               ACP = ACP + PLOT(IVS,14)*PLOT(IVS,5)
               ANPN = ANPN + PLOT(IVS,14)*PLOT(IVS,5)*PLOT(IVS,6)
C               AADF = AADF + PLOT(IVS,14)*PLOT(IVS,7)
C               STXWT = STXWT + PLOT(IVS,14)*PLOT(IVS,8)
C               SPHXWT = SPHXWT + PLOT(IVS,14)*PLOT(IVS,10)
               SWT = SWT + PLOT(IVS,14)
```

```
            SWETWT = SWETWT + PLOT(IVS,14)/PLOT(IVS,3)
         ENDIF
 330    CONTINUE
        IF(CROP.EQ.2.) THEN
           NVSCS = NVS
           RETURN
        ENDIF
C GET AVERAGE QUALITY IN THE BUNKER -- EACH PLOT TO HAVE THE AVERAGE
C QUALITY SINCE YOU CANNOT EMPTY A BUNKER 1 PLOT AT A TIME
        DM = SWT/SWETWT
        AVCP = ACP/SWT
        AVNDF = ANDF/SWT
        AVNPN = ANPN/ACP
        ADIGI = 0.
        DO 365 NPL = 1,NPSS
           ADIGI = ADIGI + HFEED(NSTR,NPL,3)*HFEED(NSTR,NPL,1)
 365    CONTINUE
        AVDIGI = ADIGI/TMSTO(NSTR)
        SDML = 1. - SWT/(TMSTO(NSTR)*1000.)
        DO 370 NPL = 1,NPSS
           HFEED(NSTR,NPL,1) = SWT/(FLOAT(NPSS)*1000.)
           HFEED(NSTR,NPL,2) = AVCP
           HFEED(NSTR,NPL,3) = (AVDIGI-SDML)/(1.-SDML)
           HFEED(NSTR,NPL,4) = AVNDF
           HFEED(NSTR,NPL,5) = 1./DM  -  1.
           HFEED(NSTR,NPL,8) = AVNPN
 370    CONTINUE
C      END OF BUNKER
      ENDIF
      CALL ENDSTR(NSTR,NPSS,IBUNK,NVS,NFEED)
      RETURN
      END
C
C ***********************************************************************
      SUBROUTINE ENDSTR (NSTR,NPSS,IBUNK,NVS,NFEED)
C ***********************************************************************
C  GET AVERAGE QUALITY IN THE STRUCTURE IF WE ARE DEALING WITH ALFALFA
C
C   MATRIX AFEED(3,26,33) CONTAINS DM (TOTAL T), CP (DEC), IVDMD (DEC)
C   AND NDF (DEC) FOR ALL 4 STORAGE LOCATIONS.  LOCATION 1 IS FIRST
C   SILO, 2 IS SECOND SILO, 3 IS HIGH QUALITY HAY, 4 IS LOW QUALITY HAY.
C   THE LAST 12 COLUMNS ARE RESERVED FOR DRY MATTER AND QUALITY OF
C   CORN SILAGE, HIGH MOISTURE CORN AND DRY CORN GRAIN.
C
      DIMENSION FEEDLS(10)
      COMMON /SDATA/ PLOT(52,14)
      COMMON /W3/ HFEED(8,160,8)
      COMMON /Z7/ ALHRFD(26,20),AFEED(2,26,33),FEEDUT(26,14)
      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,MGMT
      INTEGER*4 ILOSS(12),NYRS,JYEARF,IPRT1,MGMT,NCUTS
      COMMON/LOSS/ILOSS
```

```
      INTEGER IBUNK
      DATA FEEDLS /0.05,0.14,0.05,0.16,0.05,0.05,0.05,0.05,0.05,0.05/
C
C TOGGLE FOR SHUTTING OFF FEEDING LOSS
      IF(ILOSS(12).EQ.1) THEN
         DO 100 K=1,10
            FEEDLS(K) = 0.
  100    CONTINUE
      ENDIF
C
C CALCULATE TOTAL DM, AVERAGE CP, BIASED STANDARD ERROR OF CP, AVERAGE
C   DIG AND BIASED STANDARD ERROR OF DIG.
C SET ACCUMULATING TERMS TO ZERO FOR FIRST NSTR OF NS, TO FORMER VALUE IF
C SECOND NSTR OF NS
      RESET = 0.
      IF((NSTR.EQ.1).OR.(NSTR.EQ.2)) THEN
         KK = 1
         IF(NSTR.EQ.2) RESET = 1.
      ELSEIF((NSTR.EQ.3).OR.(NSTR.EQ.4)) THEN
         KK = 6
         IF(NSTR.EQ.4) RESET = 1.
      ELSEIF((NSTR.EQ.5).OR.(NSTR.EQ.7)) THEN
         KK = 11
         IF(NSTR.EQ.7) RESET = 1.
      ELSE
         KK = 16
         IF(NSTR.EQ.8) RESET = 1.
      ENDIF
      IF(RESET.EQ.0.) THEN
         ANDF = 0.
         ACP = 0.
         ADIG = 0.
         ANPN = 0.
         TOTDM = 0.
         WSSNDF = 0.
         WSSCP = 0.
         WSSDIG = 0.
         WSSNPN = 0.
      ELSE
         TOTDM = AFEED(1,NTHYR,KK)
         ANDF = AFEED(1,NTHYR,KK+3)*TOTDM
         ACP = AFEED(1,NTHYR,KK+1)*TOTDM
         ADIG = AFEED(1,NTHYR,KK+2)*TOTDM
         ANPN = AFEED(1,NTHYR,KK+4)*ACP
         IF(AFEED(2,NTHYR,KK+3).EQ.0.) THEN
            WSSNDF = 0.
         ELSE
            WSSNDF = TOTDM*(AFEED(2,NTHYR,KK+3)**2)
         ENDIF
         IF(AFEED(2,NTHYR,KK+1).EQ.0.) THEN
            WSSCP = 0.
         ELSE
            WSSCP = TOTDM*(AFEED(2,NTHYR,KK+1)**2)
```

```
        ENDIF
        IF(AFEED(2,NTHYR,KK+2).EQ.0.) THEN
           WSSDIG = 0.
        ELSE
           WSSDIG = TOTDM*(AFEED(2,NTHYR,KK+2)**2)
        ENDIF
        IF(AFEED(2,NTHYR,KK+4).EQ.0.) THEN
           WSSNPN = 0.
        ELSE
           WSSNPN = ACP*(AFEED(2,NTHYR,KK+4)**2)
        ENDIF
     ENDIF
     IF(IBUNK.EQ.1) THEN
C  A BUNKER SILO: IN A BUNKER, PLOTS ARE NOT REMOVABLE ONE AT A TIME,
C  QUALITY IS AVERAGED AND EACH PLOT IS ASSIGNED THE AVERAGE QUALITY
C  ACCOUNT FOR FEEDING LOSS (NO CHANGE IN QUALITY) AT THIS TIME
        DO 590 J=1,NPSS
           HFEED(NSTR,J,1) = HFEED(NSTR,J,1) * (1.-FEEDLS(NFEED))
           ADIG = ADIG + HFEED(NSTR,J,3)*HFEED(NSTR,J,1)
  590   CONTINUE
        DO 600 IVS=1,NVS
           PLOT(IVS,14) = PLOT(IVS,14) * (1.-FEEDLS(NFEED))
           TOTDM = TOTDM + PLOT(IVS,14)/1000.
           ACP = ACP + PLOT(IVS,5)*PLOT(IVS,14)/1000.
           ANDF = ANDF + PLOT(IVS,4)*PLOT(IVS,14)/1000.
           ANPN = ANPN + PLOT(IVS,6)*PLOT(IVS,5)*PLOT(IVS,14)/1000.
  600   CONTINUE
        AVCP = ACP/TOTDM
        AVDIG = ADIG/TOTDM
        AVNDF = ANDF/TOTDM
        AVNPN = ANPN/ACP
        DO 615 IVS=1,NVS
           WSSCP = WSSCP + PLOT(IVS,14)*(PLOT(IVS,5)-AVCP)**2/1000.
           WSSNDF = WSSNDF + PLOT(IVS,14)*(PLOT(IVS,4)-AVNDF)**2/1000.
           WSSNPN = WSSNPN + PLOT(IVS,14)*PLOT(IVS,5)*
     +                       (PLOT(IVS,6)-AVNPN)**2/1000.
  615   CONTINUE
        DO 620 J=1,NPSS
           WSSDIG = WSSDIG + HFEED(NSTR,J,1)*(HFEED(NSTR,J,3)-AVDIG)**2
  620   CONTINUE
     ELSE
C  NOT A BUNKER SILO
        DO 560 J=1,NPSS
C  ACCOUNT FOR FEEDING LOSS (NO CHANGE IN QUALITY) AT THIS TIME
           HFEED(NSTR,J,1) = HFEED(NSTR,J,1)*(1.-FEEDLS(NFEED))
           TOTDM = TOTDM + HFEED(NSTR,J,1)
           ACP = ACP + HFEED(NSTR,J,2)*HFEED(NSTR,J,1)
           ADIG = ADIG + HFEED(NSTR,J,3)*HFEED(NSTR,J,1)
           ANDF = ANDF + HFEED(NSTR,J,4)*HFEED(NSTR,J,1)
           ANPN = ANPN + HFEED(NSTR,J,2)*HFEED(NSTR,J,1)*
     +                   HFEED(NSTR,J,8)
  560   CONTINUE
        AVCP = ACP/TOTDM
```

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        AVDIG = ADIG/TOTDM
        AVNDF = ANDF/TOTDM
        AVNPN = ANPN/ACP
        DO 580 J=1,NPSS
           WSSCP = WSSCP + HFEED(NSTR,J,1)*(HFEED(NSTR,J,2)-AVCP)**2
           WSSDIG = WSSDIG + HFEED(NSTR,J,1)*(HFEED(NSTR,J,3)-AVDIG)**2
           WSSNDF = WSSNDF + HFEED(NSTR,J,1)*(HFEED(NSTR,J,4)-AVNDF)**2
           WSSNPN = WSSNPN + HFEED(NSTR,J,2)*HFEED(NSTR,J,1)*
     +                       (HFEED(NSTR,J,8)-AVNPN)**2
  580   CONTINUE
      ENDIF
      VARCP = AMAX1(0.,(WSSCP/TOTDM))
      VARDIG = AMAX1(0.,(WSSDIG/TOTDM))
      VARNDF = AMAX1(0.,(WSSNDF/TOTDM))
      VARNPN = AMAX1(0.,(WSSNPN/ACP))
      AFEED(1,NTHYR,KK)=TOTDM
      AFEED(1,NTHYR,KK+1)=AVCP
      AFEED(1,NTHYR,KK+2)=AVDIG
      AFEED(1,NTHYR,KK+3)=AVNDF
      AFEED(1,NTHYR,KK+4)=AVNPN
      AFEED(2,NTHYR,KK+1)=SQRT(VARCP)
      AFEED(2,NTHYR,KK+2)=SQRT(VARDIG)
      AFEED(2,NTHYR,KK+3)=SQRT(VARNDF)
      AFEED(2,NTHYR,KK+4)=SQRT(VARNPN)
C  QUANTITY AND AVERAGE QUALITY IN STORAGE COMPUTED
      RETURN
      END
C
C ***********************************************************************
      SUBROUTINE PRESEAL(NPL,SILTYP,EXPAR,DRHO)
C ***********************************************************************
C PRE-SEALING SURFACE LOSS (DML1)
      COMMON /SDATA/ PLOT(52,14)
      COMMON/LOSS/ILOSS
      INTEGER*4 ILOSS(12),SILTYP
      REAL MUTAU,MUMAX,KM,MUBAR,K
C INITIALIZE EXPOSURE TIME AND STAGE 1 DRY MATTER LOSS
      EXPTME = PLOT(NPL,9)
      DML1 = 0.
      IF(PLOT(NPL,1).EQ.1.) THEN
C       HAYLAGE
        MUMAX=4.8*PLOT(NPL,3)
      ELSE
C       CORN SILAGE
        MUMAX = 2.9*PLOT(NPL,3)
      ENDIF
C FOR A BUNKER, THE DEPTH (THICK) IS THE TOTAL DEPTH SO FAR
      IF(SILTYP.EQ.3) THEN
C      BUNKER
        TOTDM = 0.
        DO 10 I = 1,NPL
           TOTDM = TOTDM + PLOT(I,2)
   10   CONTINUE
```

```
      ELSE
C      TOWER
         TOTDM = PLOT(NPL,2)
      ENDIF
      THICK = 100.*TOTDM/(EXPAR*DRHO)
      D = .0086*(273.+PLOT(NPL,8))**2
      TAU = .6667
      RHO = 0.001*DRHO/PLOT(NPL,3)
      RHOMAX = 3./(3.-PLOT(NPL,3))
      PHI = 1. - RHO/RHOMAX
      IF(PLOT(NPL,3).GT.0.693) THEN
         FD = 0.0384
      ELSEIF(PLOT(NPL,3).GT.0.20) THEN
         FD = 1.93 - 5.46*PLOT(NPL,3) + 3.94*PLOT(NPL,3)**2.
      ELSE
         FD = 1.0
      ENDIF
C
C REPEAT WHAT FOLLOWS WHEN EXPTME > 1 DAY
C
   40 IF(PLOT(NPL,8).GE.25.0) THEN
         FT = 1.0
      ELSE
         FT = 0.178*EXP(0.069*PLOT(NPL,8))
      ENDIF
      FPH = (PLOT(NPL,10)-3.)/3.5
      MUTAU = MUMAX*FD*FT*FPH
      DATA K,KM,FC,PSIA/9.0,0.055,0.756,0.21/
      GAMMA = RHO*MUTAU*(KM+PSIA)*FC/(D*PHI*TAU*PSIA)
      C = SQRT(K*GAMMA)
      MUBAR = -MUTAU*FC*(KM+PSIA)*(LOG(KM+PSIA*EXP(-C*THICK))-
     +         LOG(KM+PSIA))/(PSIA*C*THICK)
      DMLPD = 0.0299*MUBAR/PLOT(NPL,3)
      IF(EXPTME.GT.1.) THEN
         DMLTD = DMLPD
         DML1 = DML1 + DMLTD
         EXPTME = EXPTME - 1.
      ELSE
         DMLTD = EXPTME*DMLPD
         DML1 = DML1 + DMLTD
         EXPTME = 0.
      ENDIF
C
C  TEMPERATURE RISE ASSUMING NO HEAT LOSS FROM THE PLOT
C
      DELT = 8436.*DMLTD / (2.22/PLOT(NPL,3) - 1.22)
C
   75 PLOT(NPL,8) = PLOT(NPL,8) + DELT
C REPEAT THE ABOVE FOR ADDITIONAL LOSS IF EXPTME NOT USED UP YET
      IF(EXPTME.GT.0.) GOTO 40
C
C DML IN BUNKER IS ALLOTED TO TOP PLOT ONLY
C
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C
C TOGGLE FOR SHUTTING OFF PRESEAL LOSS
      IF((ILOSS(8).EQ.1).AND.(PLOT(NPL,1).EQ.1.)) DML1 = 0.
C
      PLOT(NPL,11) = ( 1.-DML1*TOTDM/PLOT(NPL,2) ) * PLOT(NPL,2)
      PLOT(NPL,3) = (1.-DML1)*PLOT(NPL,3)/(1.-DML1*PLOT(NPL,3)*72./180.)
      PLOT(NPL,4) = PLOT(NPL,4)/(1.-DML1)
      PLOT(NPL,5) = PLOT(NPL,5)/(1.-DML1)
C      PLOT(NPL,7) = PLOT(NPL,7)/(1.-DML1)
      RETURN
      END
C
C ********************************************************************
      SUBROUTINE FERMENT(NPL,AHR)
C ********************************************************************
C FERMENTATION LOSSES AND CHANGES (DML2)
      COMMON /SDATA/ PLOT(52,14)
      COMMON/LOSS/ILOSS
      INTEGER*4 ILOSS(12)
C     REAL NH3
      REAL NPN
      DM = 100.*PLOT(NPL,3)
      T = PLOT(NPL,8)
      IF(PLOT(NPL,1).EQ.1.) THEN
C       HAYLAGE
C         NH3 = ( 13.86 - 0.199*(DM-20.) )/100.
         HCCHG = ( 0.609 + 0.00546*(T-5.) )/100. + 0.02
         DML2 = ( 1.56 - 0.0364*(DM-20.) )/100.
         IF(T.LT.45.) THEN
            NPN = ( 41.87 + 1.14*(T-5.) - 0.169*(DM-20.) +
     +      0.0128*(T-5.)*(DM-20.) - 0.000515*(T-5.)*(DM-20.)**2 )/100.
         ELSE
            NPN = 76.5 /100.
         ENDIF
         IF(NPN.GT.0.765) NPN = 0.765
         IF(DM.LE.33.) THEN
            IF(T.LE.18.) THEN
               PH = 4.43
            ELSE
               PH = 4.43 - 0.00164*(T-18.)*(DM-33.)
            ENDIF
         ELSEIF(DM.LE.46.) THEN
            PH = 4.43 + 0.051*(DM-33.)
         ELSE
            IF(T.LE.18.)THEN
               PH = 5.09 - 0.00538*(T-18.)*(DM-46.)
            ELSE
               PH = 5.09 + 0.021*(DM-46.)
            ENDIF
         ENDIF
      ELSE
C       CORN SILAGE
C         NH3 = ( 23.58 - 0.412*(DM-15.) )/100.
```

```
          HCCHG = ( 3.67 + 0.0333*T )/100.
          DML2 = ( 0.86 - 0.0193*(DM-15.) )/100.
          NPN = ( 20.03 + 0.753*T + 0.297*(DM-15.) -
     +            0.00879*(DM-15.)**2 )/100.
          PH = 3.82 + 0.0403*(DM-15.)
      ENDIF
C
C TOGGLE FOR SHUTTING OFF FERMENTATION LOSS
      IF((ILOSS(9).EQ.1).AND.(PLOT(NPL,1).EQ.1.)) DML2 = 0.
C
C ------ TOGGLES FOR SHUTTING OF HC BREAKDOWN AND PROTEOLYSIS --------
C      IF(PLOT(NPL,1).EQ.1.) HCCHG = 0.
C      IF(PLOT(NPL,1).EQ.1.) NPN = 0.33
C -------
      PLOT(NPL,12) = (1.-DML2)*PLOT(NPL,11)
      PLOT(NPL,4) = (PLOT(NPL,4)- HCCHG)*PLOT(NPL,11)/PLOT(NPL,12)
      PLOT(NPL,5) = PLOT(NPL,5)/(1.-DML2)
      PLOT(NPL,6) = NPN
C      PLOT(NPL,7) = PLOT(NPL,7)/(1.-DML2)
      PLOT(NPL,8) = PLOT(NPL,8) + AHR
      PLOT(NPL,10) = PH
      RETURN
      END
C
C **********************************************************************
      SUBROUTINE TOWER(USILO,RAD,NPL,NPSS,DENS,T3,T3B,RI,ASH)
C **********************************************************************
      REAL LKGACC,LDEC,LKGACB,LDECB
      COMMON /SDATA/ PLOT(52,14)
      COMMON/LOSS/ILOSS
      INTEGER*4 ILOSS(12)
C
      DATA PI/3.14159/
C  INFILTRATION LOSS ONLY IN A TOWER SILO.
C  CALLED ONCE FOR EACH PLOT
C    PRIMARILY A FUNCTION OF TIME PLOT IS IN THE SILO, THE SILO
C    WALL PERMEABILITY, AND DENSITY.
C
      CSA = PI*RAD**2
      DEPTH = ( (PLOT(NPL,12)/PLOT(NPL,3))/DENS ) / CSA
      IF(RI.EQ.0) RI = RAD
      RS = 1. - PLOT(NPL,4) - PLOT(NPL,5) - ASH
      LKGACC = RS*(CSA-PI*RI**2)*PLOT(NPL,12)/CSA
      UEFF = USILO
      DTAU = 492.
      RHOMAX = 3./(3.-PLOT(NPL,3))
      PHI = 1 - DENS/(1000.*RHOMAX)
C LOWER LIMIT ON PHI WILL ASSURE SOME INFILTRATION LOSS WHEN ALL AIR HAS
C BEEN REMOVED SINCE OXYGEN CAN STILL PERMEATE
      IF(PHI.LT.0.02) PHI= 0.02
C
C INFILTRATION LOSS DUE TO RADIAL DIFFUSION OF OXYGEN
C
```

```
      DO 100 TME=1,T3,10
         AI = 2.*PI*RI*DEPTH
         LKGACC = LKGACC + .21*UEFF*(AI*100.**2)*0.00133*(180./192.)
     +           *24.*10./1000.
         LDEC = LKGACC/PLOT(NPL,12)
         IF(LDEC.GT.RS) THEN
            LDEC = RS
            GO TO 200
         ENDIF
         RIPAST = RI
         RI = SQRT( RAD**2*(1.-LDEC/RS) )
         RI = RI - (RIPAST-RI)/2.
         UMAT = DTAU*PHI / (100.*RI*(LOG(RAD/RI)))
         UEFF = 1./(1./UMAT+1./USILO)
  100 CONTINUE
      IF(NPL.EQ.NPSS) THEN
C
C INFILTRATION LOSS DUE TO DOWNWARD DIFFUSION INTO THE TOP PLOT OF THE SILO
C
C AREA = AVG OF BEFORE RADIAL INF LOSS AND AFTER RADIAL INF LOSS
         A = (PI*RAD**2 + PI*RI**2)/2.
C PLASTIC COVER PERMEABILITY OF 6 CM/ATM-H
         UCOV = 6.
         UEFF = UCOV
C OXYGEN CONCENTRATION ON TOP SURFACE IS F(USILO). ADJUST INF LOSS COEFFICIENT
C ACCORDINGLY
         PSIT = 0.21*(1.-EXP(-0.17*USILO))
         ADJ = PSIT/0.21
         LKGACB = 0.
         B = 0.
         DO 150 TME=1,T3B,10
            LKGACB = LKGACB + 0.628*ADJ*UEFF*A
            LDECB = LKGACB/PLOT(NPL,12)
            LDEC = (LKGACC+LKGACB)/PLOT(NPL,12)
            IF(LDEC.GT.RS) THEN
               LDEC = RS
               GO TO 200
            ENDIF
            BPAST = B
            B = (LDECB/RS)*DEPTH*100.
            B = B + (B-BPAST)/2.
            UMAT = DTAU*PHI / B
            UEFF = 1./(1./UMAT+1./UCOV)
  150    CONTINUE
      ENDIF
C
C TOGGLE FOR SHUTTING OFF TOWER INFILTRATION LOSS
  200 IF((ILOSS(10).EQ.1).AND.(PLOT(NPL,1).EQ.1.)) LDEC = 0.
C
      PLOT(NPL,13) = (1.-LDEC)*PLOT(NPL,12)
      PLOT(NPL,4) = PLOT(NPL,4)/(1.-LDEC)
      PLOT(NPL,5) = PLOT(NPL,5)/(1.-LDEC)
C      PLOT(NPL,7) = PLOT(NPL,7)/(1.-LDEC)
```

```
      RETURN
      END
C
C ***********************************************************************
      SUBROUTINE BUNKER(CSA,U,NPSS,DRHO,FDRTE,TBE,NVS,ASH)
C ***********************************************************************
      COMMON /SDATA/ PLOT(52,14)
      COMMON/LOSS/ILOSS
      INTEGER*4 ILOSS(12)
C
      REAL LDEC,LKGACC
C  BUNKER SILO, INFILTRATION LOSSES ONLY.
C  CALLED ONCE FOR EACH BUNKER SILO.
C    SET QUALITY OF EACH VERTICAL SECTION AFTER PRESEAL AND FERMENTATION
      ANDF = 0.
      ANPN = 0.
      ACP = 0.
C      AADF = 0.
      STXWT = 0.
      SWT = 0.
      SPHXWT = 0.
      SWETWT = 0.
      DO 100 NPL=1,NPSS
         SWETWT = SWETWT + PLOT(NPL,12)/PLOT(NPL,3)
         ANDF = ANDF + PLOT(NPL,12)*PLOT(NPL,4)
         ANPN = ANPN + PLOT(NPL,12)*PLOT(NPL,5)*PLOT(NPL,6)
         ACP = ACP + PLOT(NPL,12)*PLOT(NPL,5)
C         AADF = AADF + PLOT(NPL,12)*PLOT(NPL,7)
         STXWT = STXWT + PLOT(NPL,12)*PLOT(NPL,8)
         SPHXWT = SPHXWT + PLOT(NPL,12)*PLOT(NPL,10)
         SWT = SWT + PLOT(NPL,12)
  100 CONTINUE
      DM = SWT/SWETWT
      CNDF = ANDF/SWT
      CCP = ACP/SWT
      CNPN = ANPN/ACP
C      CADF = AADF/SWT
      AVGT = STXWT/SWT
      AVGPH = SPHXWT/SWT
C BREAK THE BUNKER INTO A nUMBER OF vERTICAL sECTIONS OF EQUAL SIZE
C ONE VERTICAL SECTION IS REMOVED EVERY 10 DAYS
      NVS = IFIX(SWT/(10.*FDRTE))
      DO 200 IVS = 1,NVS
         PLOT(IVS,1) = PLOT(1,1)
         PLOT(IVS,3) = DM
         PLOT(IVS,4) = CNDF
         PLOT(IVS,5) = CCP
         PLOT(IVS,6) = CNPN
C         PLOT(IVS,7) = CADF
         PLOT(IVS,8) = AVGT
         PLOT(IVS,10) = AVGPH
         PLOT(IVS,12) = SWT/FLOAT(NVS)
  200 CONTINUE
```

```
      DENS = DRHO/DM
      HEIGHT = SWETWT/(DENS*CSA)
      LKGACC = 0.
C     A IS SURFACE AREA ON TOP OF 10 DAYS' WORTH OF FED MATERIAL
      A = 10.*FDRTE/(DRHO*HEIGHT)
      RS = 1. - PLOT(1,4) - PLOT(1,5) - ASH
      UEFF = U
      DTAU = 492.
      RHOMAX = 3./(3.-DM)
      PHI = 1 - DENS/(1000.*RHOMAX)
      T = 0.
C INFILTRATION LOSS BEFORE STARTING TO EMPTY THIS SILO
      IF(TBE.GT.0.) THEN
         DO 300 IDAY=1,TBE
            LKGACC = LKGACC + .0628*UEFF*A
            LDEC = LKGACC/PLOT(1,12)
            IF(LDEC.GT.RS) LDEC = RS
            TPAST = T
            T = (LDEC/RS)*HEIGHT*100.
            T = T + (T-TPAST)/2
            UMAT = DTAU*PHI / T
            UEFF = 1./(1./UMAT+1./U)
 300     CONTINUE
      ENDIF
C INFILTRATION LOSS DURING EMPTYING OF THE SILO (10 DAY TIME STEP)
      DO 400 IVS=1,NVS
            LKGACC = LKGACC + .628*UEFF*A
            LDEC = LKGACC/PLOT(IVS,12)
            IF(LDEC.GT.RS) LDEC = RS
            TPAST = T
            T = (LDEC/RS)*HEIGHT*100.
            T = T + (T-TPAST)/2
            UMAT = DTAU*PHI / T
            UEFF = 1./(1./UMAT+1./U)
C
C TOGGLE FOR SHUTTING OFF BUNKER INFILTRATION LOSS
            IF((ILOSS(10).EQ.1).AND.(PLOT(NPL,1).EQ.1.)) LDEC = 0.
C
            PLOT(IVS,13) = (1.-LDEC)*PLOT(IVS,12)
            PLOT(IVS,4) = PLOT(IVS,4)/(1.-LDEC)
            PLOT(IVS,5) = PLOT(IVS,5)/(1.-LDEC)
C            PLOT(IVS,7) = PLOT(IVS,7)/(1.-LDEC)
 400  CONTINUE
      RETURN
      END
C
C ***********************************************************************
      SUBROUTINE FEEDOUT(SILTYP,NN,CSAF,FDTMP,FDRTE,DENS,ASH)
C ***********************************************************************
C
C        FEEDOUT (SURFACE SPOILAGE) LOSSES (DML4)
C
      COMMON /SDATA/ PLOT(52,14)
```

```
      COMMON/LOSS/ILOSS
      INTEGER*4 ILOSS(12),SILTYP
      REAL MUTAU,MUMAX,K,KM,MUBAR
      RS = 1.-PLOT(NN,4)-PLOT(NN,5)-ASH
      DM = PLOT(NN,3)
      RHO = DENS/1000.
      RHOMAX = 3./(3.-DM)
      PHI = 1.-(RHO/RHOMAX)
      IF(PHI.LT.0.01) THEN
C       DENS = DMAX AND NO INFILTRATION CAN OCCUR
         DML4A = 0.
         GO TO 222
      ENDIF
      D = .0086*(273.+FDTMP)**2
      DATA TAU,THICK/0.6667,300./
      DF = 100.*(FDRTE/DM)/(DENS*CSAF)
      IF(PLOT(NN,1).EQ.1.) THEN
C       HAYLAGE
         MUMAX=4.8*DM
      ELSE
C       CORN SILAGE
         MUMAX = 2.9*DM
      ENDIF
      IF(DM.GT.0.693) THEN
         FD = 0.0384
      ELSEIF(DM.GT.0.20) THEN
         FD = 1.93 - 5.46*DM + 3.94*DM**2.
      ELSE
         FD = 1.0
      ENDIF
      IF(FDTMP.GE.25.0) THEN
         FT = 1.0
      ELSE
         FT = 0.178*EXP(0.069*FDTMP)
      ENDIF
C      FPH = (5.8-3.)/3.5
      FPH = (PLOT(NN,10)-3.)/3.5
      MUTAU = MUMAX*FD*FT*FPH
      DATA K,KM,FC/9.0,0.055,0.756/
      IF(SILTYP.EQ.2) THEN
         PSIA = 0.105
      ELSE
         PSIA = 0.21
      ENDIF
      GAMMA = RHO*MUTAU*(KM+PSIA)*FC/(D*PHI*TAU*PSIA)
      C = SQRT(K*GAMMA)
      MUBAR = -MUTAU*FC*(KM+PSIA)*(LOG(KM+PSIA*EXP(-C*THICK))-
     +         LOG(KM+PSIA))/(PSIA*C*THICK)
      DML4A = 0.0299*MUBAR*THICK/(DF*DM)
C 0.125 DAYS BUNK TIME ASSUMED
  222 DML4B = 0.0299*MUTAU*0.125/DM
      DML4 = DML4A + DML4B
      IF(DML4.GT.RS) DML4 = RS
```

```
C
C TOGGLE FOR SHUTTING OFF FEEDOUT LOSS
      IF((ILOSS(11).EQ.1.).AND.(PLOT(NN,1).EQ.1.)) DML4 = 0.
      PLOT(NN,14) = (1.-DML4)*PLOT(NN,13)
      PLOT(NN,4) = PLOT(NN,4)/(1.-DML4)
      PLOT(NN,5) = PLOT(NN,5)/(1.-DML4)
C      PLOT(NN,7) = PLOT(NN,7)/(1.-DML4)
      RETURN
      END
C
C ***********************************************************************
      SUBROUTINE CSSILO(NTHYR,CSMC,JDAYCS)
C ***********************************************************************
      INTEGER*4 ISIL(7)
      COMMON/CRNDT1/BTAGEN(26,17),RTPLT,HAPLTD(26,6),COSTCG(26,2),
     +      JFNHRV(26),JDPLT(6),JDHRV(7),JFNPLT(26),DMCORN(26,3),
     +      CRNYLD(26,3),COEFCS(6,5),COEFCG(6,5),JBGHRV(26),RTHRV(3),
     +      CLOSSH(3),HADSRD(4),STGCS,STGHMC,HPDHRV,HPDPLT,HACORN(26,4),
     +      JFNAL3(26),COEFMC(6,5),BASEMC,DMFEED(26,3),CRNFSC(26),
     +      TWATER(26),CLOSSF(3),CLOSSS(3)
      COMMON /Z7/ ALHRFD(26,20),AFEED(2,26,33),FEEDUT(26,14)
      COMMON /STRG/ SILDAT(32,5),FCAP,ISIL,HAYST(3),FMHY,FMHL
      COMMON /SDATA/ PLOT(52,14)
      COMMON /CSSIL/ AMTDM,CSFDRT,CSTBE,NVSCS
      INTEGER NSTR(2)
      REAL ADM(2)
      TOTDM = 1000.*DMCORN(NTHYR,1)
      CSFDRT = TOTDM/365.
      IF((ISIL(5).NE.1).AND.(ISIL(6).NE.1).AND.
     +   (TOTDM.GT.1000.*SILDAT(ISIL(5),3))) THEN
C       TWO SILOS CONTAINING CS
         NSTR(1) = 50
         ADM(1) = SILDAT(ISIL(5),3)
         NSTR(2) = 60
         ADM(2) = TOTDM - ADM(1)
         NPLOTS = 24
      ELSEIF(ISIL(5).NE.1) THEN
C       ONE SILO -- #5
         NSTR(1) = 50
         ADM(1) = TOTDM/1000.
         NSTR(2) = 0
         ADM(2) = 0.
         NPLOTS = 12
      ELSE
C       ONE SILO -- #6
         NSTR(1) = 0
         ADM(1) = 0
         NSTR(2) = 60
         ADM(2) = TOTDM/1000.
         NPLOTS = 12
      ENDIF
C INITIALIZE SUMMING VARIABLES TO GET AVERAGE QUALITY OF CORN SILAGE
      SNDF = 0.
```

```
      SCP = 0.
      SNPN = 0.
      SDM = 0.
      DO 200 JJ = 1,2
         IF(NSTR(JJ).NE.0) THEN
            NPSS = 12
            DO 50 NPL = 1,NPSS
               PLOT(NPL,1) = 2.
               PLOT(NPL,2) = TOTDM/FLOAT(NPLOTS)
               PLOT(NPL,3) = 1.-CSMC
               PLOT(NPL,4) = AFEED(1,NTHYR,24)
               PLOT(NPL,5) = AFEED(1,NTHYR,22)
               PLOT(NPL,8) = 8.
               PLOT(NPL,9) = FLOAT(JDAYCS)/FLOAT(NPLOTS)
               PLOT(NPL,10) = 5.8
   50       CONTINUE
            AMTDM = ADM(JJ)
            IF(JJ.EQ.1) THEN
               CSTBE = 0.
            ELSE
               CSTBE = ADM(1)/CSFDRT
            ENDIF
C USE PARTS OF SUBROUTINE STORE TO SIMULATE ENSILING OF WHOLE PLANT CORN
            CALL SILO(NSTR(JJ),NPSS)
            IF(ISIL(4+JJ).LE.25) THEN
C             TOWER SILO
               DO 100 NPL = 1,NPSS
                  SDM = SDM + PLOT(NPL,14)
                  SCP = SCP + PLOT(NPL,5)*PLOT(NPL,14)
                  SNDF = SNDF + PLOT(NPL,4)*PLOT(NPL,14)
                  SNPN = SNPN + PLOT(NPL,6)*PLOT(NPL,14)*PLOT(NPL,5)
  100          CONTINUE
            ELSE
C             BUNKER SILO
               DO 150 IVS = 1,NVSCS
                  SDM = SDM + PLOT(IVS,14)
                  SCP = SCP + PLOT(IVS,5)*PLOT(IVS,14)
                  SNDF = SNDF + PLOT(IVS,4)*PLOT(IVS,14)
                  SNPN = SNPN + PLOT(IVS,6)*PLOT(IVS,14)*PLOT(NPL,5)
  150          CONTINUE
            ENDIF
         ENDIF
  200 CONTINUE
      CLOSSS(1) = 1. - SDM/TOTDM
      AFEED(1,NTHYR,21) = SDM/1000.
      AFEED(1,NTHYR,22) = SCP/SDM
      AFEED(1,NTHYR,23) = (AFEED(1,NTHYR,23)-CLOSSS(1))/(1.-CLOSSS(1))
      AFEED(1,NTHYR,24) = SNDF/SDM
      AFEED(1,NTHYR,25) = SNPN/SCP
      RETURN
      END
```

APPENDIX B

FORTRAN code for the animal models in DAFOSYM.

```
C ********************************************************************
      SUBROUTINE COWFD(NTHYR)
C ********************************************************************
C                          WRITTEN BY
C                      DENNIS R. BUCKMASTER
C                   (LAST REVISION: SEPT 1988)
C
C THIS SUBROUTINE FEEDS A COW HERD FROM FEEDS IN STORAGE.  APPROPRIATE
C OUTPUT TABLES ARE PRINTED ALSO.  FEEDS ARE PURCHASED
C WHEN SUPPLY RUNS OUT.  FEED PRIORITIES ARE CLEAR IN THE SUBROUTINE
C "FEED".  SUBROUTINE "FEED" DECLARES WHICH FEEDS ARE PREFERRED FOR WHICH
C ANIMALS AND ASSURES THAT THEY WILL NOT BE FED WHEN SUPPLY HAS RUN OUT.
C SUBROUTINE "SINGLE" BALANCES THE RATION AND ADJUSTS MILK PRODUCTION WHEN
C POOR QUALITY FORAGES ARE FED TO HIGH PRODUCING COWS.  SUBROUTINE
C FEEDUM FEEDS THE ANIMALS THE RATION SPECIFIED BY "SINGLE" AND MAKES SURE
C THE FEED WHICH IS FED IS AVAILABLE.  WHEN A GIVEN FEED SUPPLY RUNS OUT,
C THE ANIMAL SET IS PARTIALLY FED, THE REMAINING ANIMALS ARE FED WITH
C ALTERNATIVE FEEDS AS SET IN SUBROUTINE "FEED".
C
C
C PARTIAL GLOSSARY FOR ANIMAL MODEL (LAST UPDATE: 11-23-88)
C INCLUDED ARE VARIABLES EXCLUSIVE TO ANIMAL MODEL
C
C SUBROUTINE COWFD
C
C   AFEED(I,J,K)  CONTAINS AMOUNT OF AND NUTRIENT INFORMATION FOR ALL FEEDS
C                 PRODUCED ON THE FARM.
C                   I=1: VALUES OF THE NUTRIENT CONCENTRATION
C                   I=2: STD. DEVIATION OF THE VALUES
C                   J  : NTHYR
C                   K  : FEED TYPE AND NUTRIENT INFO AS FOLLOWS
C                 K        FEED TYPE            NUTRIENT
C                ---    ---------------         --------
C                 1     H.Q. ALF SILAGE          AMOUNT, TONNE
C                 2     H.Q. ALF SILAGE          CP, FRACTION OF D.M.
C                 3     H.Q. ALF SILAGE          DIG, FRACTION OF D.M.
C                 4     H.Q. ALF SILAGE          NDF, FRACTION OF D.M.
C                 5     H.Q. ALF SILAGE          NPN, FRACTION OF D.M.
C                 6     L.Q. ALF SILAGE          AMOUNT
C                 7     L.Q. ALF SILAGE          CP
C                 8     L.Q. ALF SILAGE          DIG
C                 9     L.Q. ALF SILAGE          NDF
C                10     L.Q. ALF SILAGE          NPN
C                11     H.Q. ALF HAY             AMOUNT
C                12     H.Q. ALF HAY             CP
C                13     H.Q. ALF HAY             DIG
C                14     H.Q. ALF HAY             NDF
C                15     H.Q. ALF HAY             ADICP, FRACTION OF C.P.
C                16     L.Q. ALF HAY             AMOUNT
C                17     L.Q. ALF HAY             CP
C                18     L.Q. ALF HAY             DIG
C                19     L.Q. ALF HAY             NDF
C                20     L.Q. ALF HAY             ADICP
```

```
C                21     CORN SILAGE              AMOUNT
C                22     CORN SILAGE              CP
C                23     CORN SILAGE              DIG
C                24     CORN SILAGE              NDF
C                25     CORN SILAGE              NPN
C                26     HMEC                     AMOUNT
C                27     HMEC                     CP
C                28     HMEC                     DIG
C                29     HMEC                     NDF
C                30     CORN GRAIN               AMOUNT
C                31     CORN GRAIN               CP
C                32     CORN GRAIN               DIG
C                33     CORN GRAIN               NDF
C   AHRDAV    "HERD AVERAGE" OF AN ADULT ANIMAL IN THE HERD, KG/Y
C   ANIM1(J)  NUMBER OF ANIMALS IN GROUP(J)
C   ANIMAL(I,J,K) CHARACTERISTICS OF ANIMALS IN THE HERD
C                 I=1: 1ST LACTATION HEIFERS
C                 I=2: ALL OTHER COWS IN THE HERD
C                 I=3: WEIGHTED AVERAGE FOR WHOLE HERD
C                 J: GROUP AS FOLLOWS
C                   1  FIRST 60 DAYS OF LACTATION
C                   2  SECOND 90 DAYS OF LACTATION
C                   3  THIRD 180 DAYS OF LACTATION
C                   4  60 DAY DRY PERIOD
C                   5  YOUNG HEIFERS
C                   6  OLDER HEIFERS
C                 K: INFORMATION TYPE AS FOLLOWS
C                   1  NUMBER IN THE GROUP
C                   2  MILK PRODUCTION LEVEL (KG/DAY)
C                   3  MILK FAT (%)
C                   4  BODY WEIGHT (KG)
C                   5  FIBER INTAKE CAPACITY FACTOR (%BW NDF INTAKE/DAY)
C                   6  CHANGE IN BODY WEIGHT (KG/DAY)
C                   7  ACTUAL MILK PRODUCTION (KG/DAY)
C
C   BASEWT    AVERAGE WEIGHT OF A MATURE COW IN THE HERD DURING SECOND
C             STAGE OF LACTATION, KG
C   CALF      COST OF ALFALFA PURCHASED, $
C   CCORN     COST OF CORN PURCHASED, $
C   CDST      COST OF DISTILLERS GRAIN PURCHASED, $
C   CSOYM     COST OF SOYBEAN MEAL PURCHASED, $
C   DNDF      DIGESTIBILITY OF NDF, FRACTION
C   FCT1      FACTOR FOR ADJUSTING MILK PRODUCTION BASED ON ADULT HERD AVERAGE
C   FCT2      FACTOR FOR ADJUSTING ANIMAL SIZE BASED ON MATURE COW SIZE
C   FEEDUT(I,J) FEED UTILIZATION ARRAY
C               I: NTHYR
C               J: INFORMATION TYPE AS FOLLOWS
C                 1  ALFALFA PRODUCED ON FARM, TONNE
C                 2  CORN SILAGE PRODUCED ON FARM, TONNE
C                 3  HIGH MOISTURE EAR CORN PRODUCED ON FARM, TONNE
C                 4  CORN GRAIN PRODUCED ON FARM, TONNE
C                 5  ALFALFA HAYLAGE SOLD (NEGATIVE IF PURCHASED), TONNE
C                 6  ALFALFA HAY SOLD, TONNE
```

```
C                    7  CORN SILAGE SOLD, TONNE
C                    8  HIGH MOISTURE EAR CORN SOLD, TONNE
C                    9  CORN GRAIN SOLD, TONNE
C                   10  SOYBEAN MEAL SOLD, TONNE
C                   11  DISTILLERS GRAIN SOLD, TONNE
C                   12  AMOUNT OF FEED FED, TONNE
C                   13  AVERAGE MILK PRODUCTION PER ANIMAL, KG/YR
C   FFC         FRACTION OF LACTATING COWS EXPERIENCING FIRST LACTATION
C   IPR5        INDICATOR FOR DETAILED RATION OUTPUT
C   NCOWS       COUNTER FOR NUMBER OF COWS PRODUCING MILK
C   PALF        PURCHASE PRICE OF ALFALFA, $/TONNE
C   PCORN       PURCHASE PRICE OF CORN GRAIN, $/TONNE
C   PDST        PURCHASE PRICE OF DISTILLERS GRAIN, $/TONNE
C   PFCH        PERCENT OF LACTATING COWS WHICH ARE FIRST CALF HEIFERS
C   PMILK       PRICE OF MILK, $/KG
C   PRCE(I)     PRICE STRUCTURE TO BE USED WITHIN RATION BALANCER (RELATIVE
C                   PRICES) I = 1 TO 11
C   PSOYM       PRICE OF SOYBEAN MEAL, $/TONNE
C   REDFCTR     REDUCTION FACTOR FOR MILK PRODUCTION WHEN TARGET IS NOT MET
C               DURING FIRST STAGE OF LACTATION
C   SAFA        SELLING PRICE OF ALFALFA, $/TONNE
C   SCG         SELLING PRICE OF CORN GRAIN, $/TONNE
C   SCS         SELLING PRICE OF CORN SILAGE, $/TONNE
C   SHMC        SELLING PRICE OF HIGH MOISTURE EAR CORN, $/TONNE
C   STOR(I,J) FEED INFORMATION
C               I: FEED AS FOLLOWS
C                    1  H.Q. ALF SILAGE
C                    2  L.Q. ALF SILAGE
C                    3  H.Q. ALF HAY
C                    4  L.Q. ALF HAY
C                    5  CORN SILAGE
C                    6  HMEC
C                    7  CG PRODUCED ON FARM
C                    8  SOYBEAN MEAL
C                    9  PURCH. CORN GRAIN
C                   10  PURCH. ALF HAY
C                   11  DISTILLERS GRAIN
C               J: INFORMATION TYPE AS FOLLOWS
C                    1  AMOUNT OF D.M., KG
C                    2  CP CONTENT, FRACTION OF D.M.
C                    3  NEL CONTENT, MCAL/KG D.M.
C                    4  NDF CONTENT, FRACTION OF D.M.
C                    5  NPN OF SILAGES, ADICP OF HAY (FRACTION OF CP)
C   STOR1(I)    INITIAL AMOUNT IN STORAGE OF FEED I (SEE STOR ARRAY), KG
C   TMP         TOTAL MILK PRODUCTION, KG FROM HERD/Y
C   TTOKG       TONNE TO KG CONVERSION FACTOR
C   TYPE        ANIMAL TYPE ACCORDING TO STAGE OF LACTATION OR GROWTH
C   VALF        VALUE OF LEFTOVER ALFALFA, $
C   VCG         VALUE OF LEFTOVER CORN GRAIN, $
C   VCS         VALUE OF LEFTOVER CORN SILAGE, $
C   VHMEC       VALUE OF LEFT OVER HIGH MOISTURE EAR CORN, $
C   VMILK       VALUE OF MILK PRODUCED, $
C   XLCOWS      NUMBER OF LACTATING COWS
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C   XNEL      NET ENERGY OF LACTATION, MCAL/KG
C   XOHEIF    NUMBER OF OLDER HEIFERS
C   XYHEIF    NUMBER OF YOUNGER HEIFERS
C
C SUBROUTINE FEEDUM
C
C   ACCMP     ACCUMULATED MILK PRODUCTION, KG
C   CRNUSE    CORN SOURCE TO USE FOR RATION BALANCING (6, 7 OR 9)
C   FAIF      FRACTION OF FORAGE WHICH IS ALFALFA
C   FED       NUMBER OF ANIMALS FED CURRENT RATION
C   FHAYIA    FRACTION OF ALFALFA WHICH IS HAY
C   HAYUSE    HAY SOURCE TO USE IN RATION (3 OR 4)
C   HLGUSE    HAYLAGE SOURCE TO USE IN RATION (1 OR 2)
C   LIMF      FEED WHICH LIMITS THE NUMBER WHICH CAN BE FED CURRENT RATION
C   OTPT(I)   DETAILED OUTPUT ARRAY (I: INFORMATION TYPE AS FOLLOWS)
C                 1  ACTUAL MILK PRODUCTION, KG/DAY
C                 2  ENERGY CONTENT OF DIET, MCAL/KG
C                 3  NEUTRAL DETERGENT FIBER CONCENTRATION OF DIET
C                 4  CRUDE PROTEIN CONCENTRATION OF DIET
C   RATION(I) AMOUNT OF FEED I IN RATION (SEE STOR ARRAY ABOVE), KG D.M./DAY
C   XLIMF(I)  NUMBER OF ANIMALS WHICH COULD BE FED CURRENT RATION IF LIMITED
C             BY FEED I (SEE STOR ARRAY)
C
C SUBROUTINE FEED
C
C   ARV1      ANNUAL ROUGHAGE REQUIREMENT OF ALL ANIMALS IN HERD EXCEPT
C                STAGE 1 COWS, KG ANDF/Y
C   ARV2      ANNUAL ROUGHAGE REQUIREMENT OF ENTIRE HERD, KG ANDF/Y
C   CSRV      AMOUNT OF CORN SILAGE ROUGHAGE VALUE IN STORAGE, KG ANDF
C   GR        GRAIN TO TOTAL MASS RATIO IN CORN SILAGE
C   HAYNOW    AMOUNT OF HAY CURRENTLY LEFT IN STORAGE, KG
C   HLGNOW    AMOUNT OF ALFALFA SILAGE CURRENTLY LEFT IN STORAGE, KG
C   HLGRV     AMOUNT OF ALFALFA SILAGE ROUGHAGE VALUE IN STORAGE, KG ANDF
C   IQUAL     INDICATOR FOR WHICH QUALITY OF ALFALFA TO USE (1: HI, 2: LO)
C
C SUBROUTINE SINGLE
C
C   ADIP(L)   ACID DETERGENT INSOLUBLE PROTEIN CONTENT OF FEED L, FRACTION OF
C             CRUDE PROTEIN
C             FEEDS (L) ARE:
C                 1  ALFALFA SILAGE
C                 2  ALFALFA HAY
C                 3  CORN SILAGE
C                 4  CORN GRAIN OR HIGH MOISTURE EAR CORN
C                 5  SOYBEAN MEAL
C                 6  DISTILLERS GRAIN
C   ADMI      ACTUAL DRY MATTER INTAKE, KG/DAY
C   APREQ     ABSORBED PROTEIN REQUIREMENT WITH LEAD FACTOR INCLUDED, KG/DAY
C   APREQ2    ABSORBED PROTEIN REQUIREMENT WITHOUT LEAD FACTOR, KG/DAY
C   ATDN    ADJUSTED TOTAL DIGESTIBLE NUTRIENT CONTENT, FRACTION
C   BCP       BACTERIAL CRUDE PROTEIN PRODUCTION, KG/DAY
C   BTDN      BASELINE TOTAL DIGESTIBLE NUTRIENT CONTENT, FRACTION
C   C         APPROXIMATE AMOUNT OF CONCENTRATE IN DIET, KG/DAY
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C   COEF       COEFFICIENT FOR SOLVING FOR APPROXIMATE DIET
C   COST(L)    COST OF FEED L FOR OBJECTIVE FUNCTION IN LP SOLUTION SCHEME
C   COSTF      COST OF FORAGE MIX
C   CP(L)      CRUDE PROTEIN CONTENT OF FEED L, FRACTION OF D.M.
C   CPF        CRUDE PROTEIN CONTENT OF FORAGE MIX, FRACTION OF D.M.
C   CPID       CRUDE PROTEIN IN DIET, FRACTION OF D.M.
C   DED        DIGESTIBLE ENERGY CONTENT OF DIET, MCAL/KG
C   DEGR(L)    DEGRADABILITY OF FEED L, FRACTION
C   DPA        DIFFERENCE PROTEIN ABSORBED, KG/DAY
C   DPM        LP MATRIX OF COEFFICIENTS
C   DPREG      DAYS PREGNANT, DAYS
C   DUP        DIGESTIBLE UNDEGRADED PROTEIN, KG/DAY
C   ESCP(L)    AVAILABLE ESCAPE PROTEIN CONTENT OF FEED L, FRACTION OF D.M.
C   ESCPF      AVAILABLE ESCAPE PROTEIN CONTENT OF FORAGE MIX, FRACTION OF D.M.
C   ESCPID     AVAILABLE ESCAPE PROTEIN IN DIET, KG/DAY
C   FACTOR     ADJUSTMENT FACTOR TO INTAKE TO FOLLOW FEED DISAPPEARANCE FOR
C              AVERAGE ANIMAL IN THE GROUP
C   FLEAD      LEAD FACTOR
C   FPD(M)     AMOUNT OF FEED M PER DAY, KG/DAY
C              M CORRESPONDS TO THE FOLLOWING
C              1: FORAGE  2: CORN SOURCE  3: SOYBEAN MEAL  4: DISTILLERS GRAIN
C   FPN        FECAL PROTEIN NITROGEN REQUIREMENT, KG/DAY
C   IC         INGESTIVE CAPACITY, KG ADJUSTED NDF/DAY
C   IDM        INDIGESTIBLE DRY MATTER INTAKE, KG/DAY
C   INFEAS     LOGICAL VARIABLE NOTING WHEN THE LP PROBLEM DOES NOT HAVE A
C              FEASIBLE SOLUTION (INFEAS = TRUE IN THIS CASE)
C   IPR5       INDICATOR FOR DETAILED OUTPUT CONCERNING RATIONS
C              (0 FOR NO OUTPUT, 1 FOR DETAILED OUTPUT)
C   LPN        LACTATION PROTEIN NITROGEN REQUIREMENT, KG/DAY
C   MED        METABOLIZABLE ENERGY CONTENT OF DIET, MCAL/KG
C   MEREQ      METABOLIZABLE ENERGY REQUIREMENT, MCAL/DAY
C   MILK       MILK PRODUCTION PER DAY, KG/DAY
C   MMNT       MULTIPLE OF MAINTENANCE (BASED ON ENERGY REQUIREMENT)
C   MNTP       MAINTENANCE PROTEIN REQUIREMENT, KG/DAY
C   NDF(L)     NEUTRAL DETERGENT FIBER CONTENT OF FEED L, FRACTION OF D.M.
C   NDFF       NEUTRAL DETERGENT FIBER CONTENT OF FORAGE MIX, FRACTION OF D.M.
C   NDFID      NEUTRAL DETERGENT FIBER IN DIET, KG/DAY
C   NEGD       NET ENERGY FOR GAIN CONTENT OF DIET, MCAL/KG
C   NEGR       NET ENERGY FOR GAIN REQUIREMENT, MCAL,DAY
C   NEL(L)     NET ENERGY FOR LACTATION CONTENT OF FEED L, MCAL/KG
C   NELD       NET ENERGY FOR LACTATION CONTENT OF APPROXIMATE DIET, MCAL/KG
C   NELDD      APPROXIMATE NET ENERGY FOR LACTATION CONTENT OF DIET, MCAL/KG
C   NELF       NET ENERGY FOR LACTATION CONTENT OF FORAGE MIX, MCAL/KG
C   NELG       NET ENERGY FOR LACTATION REQUIREMENT FOR GAIN, MCAL/DAY
C   NELID      NET ENERGY FOR LACTATION IN DIET, MCAL/DAY
C   NELL       NET ENERGY FOR LACTATION REQUIREMENT FOR LACTATION
C   NELM       NET ENERGY FOR LACTATION REQUIREMENT FOR MAINTENANCE, MCAL/DAY
C   NELP       NET ENERGY FOR LACTATION REQUIREMENT FOR PREGNANCY, MCAL/DAY
C   NELR       NET ENERGY REQUIREMENT WITH LEAD FACTOR, MCAL/DAY
C   NELR2      NET ENERGY REQUIREMENT WITHOUT LEAD FACTOR, MCAL/DAY
C   NELRE2     ADJUSTED (FOR MMNT) NET ENERGY REQUIREMENT WITHOUT LEAD FACTOR, MCAL
C   NELREQ     ADJUSTED (FOR MMNT) NET ENERGY REQUIREMENT WITH LEAD FACTOR, MCAL/DA
C   NEMD       NET ENERGY FOR MAINTENANCE CONTENT OF DIET, MCAL/KG
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C    NEMR       NET ENERGY FOR MAINTENANCE REQUIREMENT, MCAL/DAY
C    NH3(L)     AMMONIA POOL CONTRIBUTION OF FEED L, FRACTION OF D.M.
C    NH3F       AMMONIA POOL CONTRIBUTION OF FORAGE MIX, FRACTION OF D.M.
C    NH3ID      AMMONIA POOL IN DIET, FRACTION OF D.M.
C    PDMI       APPROXIMATE (PREDICTED) DRY MATTER INTAKE, KG/DAY
C    RAPREQ     RUMEN AVAILABLE PROTEIN (AMMONIA) REQURIEMENT, KG/DAY
C    RELLW      RELATIVE LIVE WEIGHT
C    RELMBS     RELATIVE METABOLIC BODY SIZE
C    RPN        RETAINED PROTEIN NITROGEN REQUIREMENT, KG/DAY
C    RV(L)      ROUGHAGE VALUE OF FEED L, FRACTION OF D.M.
C    RVF        ROUGHAGE VALUE OF FORAGE, FRACTION OF D.M.
C    UIPREQ     UNDEGRADED INTAKE PROTEIN REQUIREMENT, KG/DAY
C
      INTEGER*4 IPR5
      INTEGER TYPE,I,J,NTHYR
      REAL STOR(11,5),ANIMAL(3,6,7),ANIM1(6),NCOWS,STOR1(11)
      COMMON /Z7/ ALHRFD(26,20),AFEED(2,26,33),FEEDUT(26,14)
      COMMON/FDCOW/XLCOWS,AHRDAV,PFCH,BASEWT,XOHEIF,XYHEIF,PMILK,
     +      PSOYM,PDST,PCORN,PALF,SCG,SHMC,SAFA,SCS,IFEED,IPR5,PRCE(11)
      COMMON/SUMRY2/TRESP(26,20),TCOSTP(26,20),TCOST(26,20),
     +               STCOST(4,20),TRES(26,20),SRES(4,20)
      COMMON /SUMRY3/ SALF(4,25),STFEED(4,33),SFDUT(4,13),STALHR(4,20)
      DATA TTOKG/1000./
C
C ENTER HERD DATA
C
C    MFAT, WT, FIC AND WT CHANGE FOR LACTATING AND DRY FIRST CALF HEIFERS
      DATA ((ANIMAL(1,J,K),K=3,6),J=1,4)/3.8,524.,0.94,-0.44,
     + 3.4,524.,1.06,0.30,3.6,588.,1.14,0.42,0.,658.,1.10,0.15/
C    MFAT, WT, FIC AND WT CHANGE FOR LACTATING AND DRY MATURE COWS
      DATA ((ANIMAL(2,J,K),K=3,6),J=1,4)/3.8,639.,1.07,-0.72,
     + 3.4,622.,1.20,0.10,3.6,664.,1.30,0.26,0.,722.,1.20,0.04/
C
C SET NUMBER OF ANIMALS IN EACH GROUP
C
      FFC = PFCH/100.
      ANIMAL(1,1,1) = FFC*(60./390.)*XLCOWS
      ANIMAL(2,1,1) = (1.-FFC)*(60./390.)*XLCOWS
      ANIMAL(1,2,1) = FFC*(90./390.)*XLCOWS
      ANIMAL(2,2,1) = (1.-FFC)*(90./390.)*XLCOWS
      ANIMAL(1,3,1) = FFC*(180./390.)*XLCOWS
      ANIMAL(2,3,1) = (1.-FFC)*(180./390.)*XLCOWS
      ANIMAL(1,4,1) = FFC*(60./390.)*XLCOWS
      ANIMAL(2,4,1) = (1.-FFC)*(60./390.)*XLCOWS
C    SET MILK PRODUCTION OF EACH GROUP
      FCT1 = AHRDAV/6996.
      ANIMAL(1,1,2) = 23.6*FCT1
      ANIMAL(1,2,2) = 21.3*FCT1
      ANIMAL(1,3,2) = 13.0*FCT1
      ANIMAL(2,1,2) = 29.0*FCT1
      ANIMAL(2,2,2) = 26.2*FCT1
      ANIMAL(2,3,2) = 16.1*FCT1
C    ADJUST ANIMAL SIZE FROM BASE WT (STAGE 2) OF A MATURE COW IN THE HERD
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      FCT2 = BASEWT/ANIMAL(2,2,4)
      DO 6 I = 1,2
         DO 5 J = 1,4
            ANIMAL(I,J,4) = ANIMAL(I,J,4)*FCT2
            ANIMAL(I,J,6) = ANIMAL(I,J,6)*FCT2
    5    CONTINUE
    6 CONTINUE
C     SET PARAMETERS FOR THE HERD AS A WHOLE BY WEIGHTED AVERAGE OF 1ST CALF
C     HEIFERS AND OTHER COWS
      DO 8 J = 1,4
         ANIMAL(3,J,1) = ANIMAL(1,J,1) + ANIMAL(2,J,1)
         ANIMAL(3,J,2) = (ANIMAL(1,J,1)*ANIMAL(1,J,2) +
     +                    ANIMAL(2,J,1)*ANIMAL(2,J,2)) / ANIMAL(3,J,1)
         ANIMAL(3,J,3) = (ANIMAL(1,J,1)*ANIMAL(1,J,3) +
     +                    ANIMAL(2,J,1)*ANIMAL(2,J,3)) / ANIMAL(3,J,1)
         ANIMAL(3,J,4) = (ANIMAL(1,J,1)*ANIMAL(1,J,4) +
     +                    ANIMAL(2,J,1)*ANIMAL(2,J,4)) / ANIMAL(3,J,1)
         ANIMAL(3,J,5) = (ANIMAL(1,J,1)*ANIMAL(1,J,5) +
     +                    ANIMAL(2,J,1)*ANIMAL(2,J,5)) / ANIMAL(3,J,1)
         ANIMAL(3,J,6) = (ANIMAL(1,J,1)*ANIMAL(1,J,6) +
     +                    ANIMAL(2,J,1)*ANIMAL(2,J,6)) / ANIMAL(3,J,1)
    8 CONTINUE
C SET PARAMETERS FOR OLD AND YOUNG GROWING HEIFERS
      ANIMAL(3,5,1) = XYHEIF
      ANIMAL(3,6,1) = XOHEIF
      DATA ANIMAL(3,5,2),ANIMAL(3,6,2),ANIMAL(3,5,4),ANIMAL(3,6,4),
     +     ANIMAL(3,5,6),ANIMAL(3,6,6) /0.,0.,198.,470.,.725,.60/
      ANIMAL(3,5,4) = ANIMAL(3,5,4)*FCT2
      ANIMAL(3,6,4) = ANIMAL(3,6,4)*FCT2
      ANIMAL(3,5,6) = ANIMAL(3,5,6)*FCT2
      ANIMAL(3,6,6) = ANIMAL(3,6,6)*FCT2
      DATA ANIMAL(3,5,5),ANIMAL(3,6,5)/1.05,1.10/
C SAVE NUMBER IN EACH GROUP AND MILK PRODUCTION OF EACH GROUP FOR LATER USE
      DO 10 I=1,6
         ANIM1(I) = ANIMAL(3,I,1)
   10 CONTINUE
C
C ----- PRINT HEADER TO DETAILED RATION OUTPUT -----
      IF(IPR5.EQ.1) THEN
         WRITE(6,900) NTHYR
  900 FORMAT(///,1X,'DETAILED RATION OUTPUT FOR YEAR ',I2,/,
     +       ' (ALL AMOUNTS ARE IN KG D.M PER DAY, NDF AND CP OF DIET',
     +       ' IN FRACTION OF DM)',/)
         WRITE(6,901)
  901 FORMAT(1X,'GROUP  #FED    HQ HL   LQ HL   HQHAY   LQHAY',
     +     '   C SIL   HMEC    CG      SBM     CG      MQHAY   DST',
     +     '   MILK/DAY   NELD    NDFD   CPD',/,
     +     13('----------'))
      ENDIF
C ----- END PRINTING OF DETAILED OUTPUT HEADER -----
C
C TRANSFER QUALITY AND QUANTITY OF STORED FEEDS FROM AFEED INTO STOR
C
```

```
      DO 15 K = 1,5
         J = 1 + 5*(K-1)
         STOR(K,1) = AFEED(1,NTHYR,J)
         STOR(K,2) = AFEED(1,NTHYR,J+1)
         STOR(K,3) = AFEED(1,NTHYR,J+2)
         STOR(K,4) = AFEED(1,NTHYR,J+3)
         STOR(K,5) = AFEED(1,NTHYR,J+4)
   15 CONTINUE
      DO 16 K = 6,7
         J = 26 + 4*(K-6)
         STOR(K,1) = AFEED(1,NTHYR,J)
         STOR(K,2) = AFEED(1,NTHYR,J+1)
         STOR(K,3) = AFEED(1,NTHYR,J+2)
         STOR(K,4) = AFEED(1,NTHYR,J+3)
   16 CONTINUE
C
C CONVERT FROM METRIC TONS TO KG AND SAVE THE INITIAL AMOUNT IN
C STORAGE FOR FEED UTILIZATION CALCULATIONS LATER.
C
      DO 17 I=1,7
         STOR(I,1) = STOR(I,1) * TTOKG
         STOR1(I) = STOR(I,1)
   17 CONTINUE
C
C ESTIMATE NEL OF FEEDS IN STORAGE
C
      DO 19 I=1,4
C FOR HAY AND HAYLAGE, USE MERTENS' LEGUME NDF EQUATION
         XNEL = 2.323 - 2.16*STOR(I,4)
         IF(STOR(I,4).GT.0) THEN
            DNDF = 1.*(0.98+(0.4082*XNEL-0.802)/STOR(I,4))
         ELSE
            DNDF = 0.0
         ENDIF
         STOR(I,3) = (STOR(I,4)*(DNDF-0.98)+0.802)/0.4082
C         STOR(I,4) = 0.94*STOR(I,4)
   19 CONTINUE
C FOR CORN SILAGE, USE EQUATION FROM DAVE HARLAN, UNH
      STOR(5,3) = 2.692 - 2.491*STOR(5,4)
C FOR CORN GRAIN AND HMEC, USE TYPICAL VALUES FROM NRC
      STOR(6,3) = 1.84
      STOR(7,3) = 2.03
C
C ESTABLISH QUALITY OF PURCHASED FEEDS (MAY BE THE SAME AS STORED FEEDS)
C
      DATA STOR(8,2),STOR(8,3),STOR(8,4)/0.518,1.86,0.14/
      DATA STOR(9,2),STOR(9,3),STOR(9,4)/0.10,2.03,0.12/
      DATA STOR(10,2),STOR(10,3),STOR(10,4)/0.170,1.30,0.48/
      DATA STOR(11,2),STOR(11,3),STOR(11,4)/0.295,1.90,0.14/
C
C SET QUANTITY OF PURCHASED FEEDS TO 0.0 INITIALLY
C
      DO 30 I=8,11
```

```
         STOR(I,1) = 0.0
         STOR1(I) = STOR(I,1)
   30 CONTINUE
C
C FEED DRY COWS FIRST
C
      TYPE = 4
      IF(ANIMAL(3,TYPE,1).GT.0.0)
     +   CALL FEEDUM (ANIMAL,TYPE,ANIM1,STOR,STOR1,IPR5)
C
C FEED OLDER HEIFERS SECOND
C
      TYPE = 6
      IF(ANIMAL(3,TYPE,1).GT.0.0)
     +   CALL FEEDUM (ANIMAL,TYPE,ANIM1,STOR,STOR1,IPR5)
C
C FEED YOUNG HEIFERS THIRD
C
      TYPE = 5
      IF(ANIMAL(3,TYPE,1).GT.0.0)
     +   CALL FEEDUM (ANIMAL,TYPE,ANIM1,STOR,STOR1,IPR5)
C
C FEED MILKING HERD LAST -- START W/ TOP PRODUCERS AND GO DOWN
C
      TYPE = 1
      IF(ANIMAL(3,TYPE,1).GT.0.0)
     +   CALL FEEDUM (ANIMAL,TYPE,ANIM1,STOR,STOR1,IPR5)
C ADJUST MAX MILK POSSIBLE DOWN IF TARGET NOT MET DURING THE FIRST PERIOD
C OF LACTATION
      IF(ANIMAL(3,1,7).LT.ANIMAL(3,1,2)) THEN
         REDFCTR = ANIMAL(3,1,7)/ANIMAL(3,1,2)
         ANIMAL(3,2,2) = ANIMAL(3,2,2) * REDFCTR
         ANIMAL(3,3,2) = ANIMAL(3,3,2) * REDFCTR
      ENDIF
C
C FEED SECOND SET OF LACTATING COWS
C
      TYPE = 2
      IF(ANIMAL(3,TYPE,1).GT.0.0)
     +   CALL FEEDUM (ANIMAL,TYPE,ANIM1,STOR,STOR1,IPR5)
C
C FEED THIRD SET OF LACTATING COWS
C
      TYPE = 3
      IF(ANIMAL(3,TYPE,1).GT.0.0)
     +   CALL FEEDUM (ANIMAL,TYPE,ANIM1,STOR,STOR1,IPR5)
C
C ALL COWS FED
C COMPUTE TOTAL AND AVERAGE MILK PRODUCTION
C
      NCOWS = 0
      TMP = 0.0
      DO 60 I=1,4
```

```
         TMP = TMP + ANIM1(I)*ANIMAL(3,I,7)*365.0
         NCOWS = NCOWS + ANIM1(I)
   60 CONTINUE
C
C COST INFORMATION
C
      VMILK = TMP*PMILK
      VALF = (STOR(1,1)+STOR(2,1)+STOR(3,1)+STOR(4,1))*SAFA/TTOKG
      VCS = STOR(5,1)*SCS/TTOKG
      VHMEC = STOR(6,1)*SHMC/TTOKG
      VCG = STOR(7,1)*SCG/TTOKG
      CSOYM = -STOR(8,1)*PSOYM/TTOKG
      CCORN = -STOR(9,1)*PCORN/TTOKG
      CALF = -STOR(10,1)*PALF/TTOKG
      CDST = -STOR(11,1)*PDST/TTOKG
C NET COST OF FEEDS  : SBM, DST, ALF MINUS INCOME FROM EXCESS ALF, CS, HMEC
      TCOST(NTHYR,11) = CSOYM + CDST + CALF - (VHMEC + VALF + VCS)
C NET COST OF CORN PURCHASES
      TCOST(NTHYR,12) = CCORN - VCG
      TCOST(NTHYR,14) = VMILK
C
C COMPUTE FEED UTILIZATION, LEFT OVER STOCKS, AND PURCHASED FEEDS
C CONVERT BACK TO METRIC TONS ALSO
C
      FEEDUT(NTHYR,1) = (STOR1(1)+STOR1(2)+STOR1(3)+STOR1(4))/TTOKG
      FEEDUT(NTHYR,2) = STOR1(5)/TTOKG
      FEEDUT(NTHYR,3) = STOR1(6)/TTOKG
      FEEDUT(NTHYR,4) = STOR1(7)/TTOKG
      FEEDUT(NTHYR,5) = (STOR(1,1) + STOR(2,1))/TTOKG
      FEEDUT(NTHYR,6) = (STOR(3,1) + STOR(4,1) + STOR(10,1))/TTOKG
      FEEDUT(NTHYR,7) = STOR(5,1)/TTOKG
      FEEDUT(NTHYR,8) = STOR(6,1)/TTOKG
      FEEDUT(NTHYR,9) = (STOR(7,1) + STOR(9,1))/TTOKG
      FEEDUT(NTHYR,10) = STOR(8,1)/TTOKG
      FEEDUT(NTHYR,11) = STOR(11,1)/TTOKG
      FEEDUT(NTHYR,12) = 0.
      DO 100 I = 1,11
         IF(I.LE.4) THEN
            FEEDUT(NTHYR,12) = FEEDUT(NTHYR,12) + FEEDUT(NTHYR,I)
         ELSE
            FEEDUT(NTHYR,12) = FEEDUT(NTHYR,12) - FEEDUT(NTHYR,I)
         ENDIF
  100 CONTINUE
C COMPUTE ACTUAL HERD AVERAGE MILK PRODUCTION LEVEL
      FEEDUT(NTHYR,13) = TMP/NCOWS
C COMPUTE TOTAL ALFALFA SOLD (- IF PURCHASED)
      FEEDUT(NTHYR,14)=FEEDUT(NTHYR,5)+FEEDUT(NTHYR,6)
  500 CONTINUE
      RETURN
      END
C
C ********************************************************************
      SUBROUTINE FEEDUM(ANIMAL,TYPE,ANIM1,STOR,STOR1,IPR5)
```

```
C ********************************************************************
C
C THIS SUBROUTINE FEEDS A SET OF ANIMALS, MAKES SURE ALL ANIMALS ARE
C FED AND THAT FEED STOCKS ARE ADJUSTED CORRECTLY
C
      INTEGER*4 IPR5
      INTEGER TYPE,HAYUSE,HLGUSE,CRNUSE,LIMF
      REAL STOR(11,5),STOR1(11),FAIF,RATION(11),ANIMAL(3,6,7),ANIM1(6),
     +     ACCMP,XLIMF(7),OTPT(4)
C
C CALL "FEED" TO DETERMINE WHICH FEEDS TO USE IN RATION FORMULATION
C
      ACCMP = 0.0
   10 CALL FEED(ANIMAL,ANIM1,TYPE,STOR,STOR1,FAIF,FHAYIA,HAYUSE,HLGUSE,
     +          CRNUSE)
C
C CALL SINGLE ANIMAL MODEL TO DETERMINE RATION
C
      CALL SINGLE(TYPE,ANIMAL,FAIF,FHAYIA,HAYUSE,HLGUSE,CRNUSE,
     +            STOR,RATION,OTPT)
C
C DETERMINE IF ALL ANIMALS IN SET "TYPE" CAN BE FED WITH CURRENT RATION
C FIRST DETERMINE HOW MANY ANIMALS THE FEED IN STORAGE WILL SATISFY
C NUMBER FED IS MINIMUM OF: (ALL IN SET TYPE), (NUMBER LIMITED FROM
C EACH FEED TYPE)
C
      FED = ANIMAL(3,TYPE,1)
      DO 60 I=1,7
         IF(RATION(I).GT.0.0005) THEN
            XLIMF(I) = STOR(I,1)/(365.0*RATION(I))
            IF (XLIMF(I).LT.FED) THEN
               FED = XLIMF(I)
               LIMF = I
            ENDIF
         ELSE
C           NO FEED OF CATEGORY I WAS USED
         ENDIF
   60 CONTINUE
C
C DECREASE AMOUNT OF FEED IN STORAGE OF THOSE FEEDS STILL IN STOCK
C PURCHASED FEEDS WILL END UP WITH (-) QUANTITIES WHICH INDICATE
C PURCHASES WERE NECESSARY IN THAT AMOUNT
C
      DO 80 I=1,7
         IF(STOR(I,1).GT.0.0)
     +         STOR(I,1) = STOR(I,1) - RATION(I)*365.0*FED
   80 CONTINUE
      DO 90 I=8,11
         STOR(I,1) = STOR(I,1) - RATION(I)*365.0*FED
   90 CONTINUE
C
C IF ANIMAL(3,TYPE,1) > 0.0, THE STOCK OF FEED TYPE "LIMF" IS NOW 0.0 AND
C SOME ANIMALS ARE LEFT TO BE FED
```

```
C
      ANIMAL(3,TYPE,1) = ANIMAL(3,TYPE,1) - FED
      IF (ANIMAL(3,TYPE,1).GT.0.0) STOR(LIMF,1) = 0.0
      ACCMP = FED*ANIMAL(3,TYPE,7) + ACCMP
C
C NOTICE ANIMAL(3,TYPE,1) NOW REFERS TO NUMBER LEFT TO BE FED, NOT THE
C TOTAL NUMBER IN SET "TYPE". ANIMAL(3,A,B) SHOULD BE RESET FOR EACH YEAR
C SIMULATED
C
C ----- DETAILED OUTPUT OF RATION INFORMATION -----
      IF(IPR5.EQ.1) THEN
         WRITE(6,900) TYPE,FED,(RATION(I),I=1,11),(OTPT(I),I=1,4)
  900 FORMAT(1X,I3,F8.1,11F8.1,4F8.3)
      ENDIF
C ----- END OF RATION DETAILED OUTPUT -----
      IF (ANIMAL(3,TYPE,1).GT.0.0) GOTO 10
C
C THIS "GOTO" IS FOR FEEDING THE LEFTOVER ANIMALS WHICH WERE NOT FED
C IF ANIMAL(3,TYPE,1) = 0.0, ALL ANIMALS WERE FED WITH NO SHORTAGE OF FEED
C
      ANIMAL(3,TYPE,7) = ACCMP/ANIM1(TYPE)
      RETURN
      END
C
C ************************************************************************
      SUBROUTINE FEED(ANIMAL,ANIM1,TYPE,STOR,STOR1,FAIF,FHAYIA;HAYUSE,
     +                HLGUSE,CRNUSE)
C ************************************************************************
C SUBROUTINE FEED ASSURES THAT THE ANIMALS ARE FED CORRECT FEEDS
C
      INTEGER HAYUSE,HLGUSE,CRNUSE,TYPE
      REAL STOR(11,5),STOR1(11),FAIF,FHAYIA,ANIMAL(3,6,7),ANIM1(6)
C
C COMPUTE CURRENT STOCKS
C
      HLGNOW = STOR(1,1)+STOR(2,1)
      HAYNOW = STOR(3,1)+STOR(4,1)
C
C GET ROUGH ESTIMATE OF ANNUAL RV RQMT BASED ON MAX FORAGE DIETS FOR
C THE WHOLE HERD
C I.E., FORAGE RQMT = SUM OVER GROUPS OF:
C       0.75(IC)(NUMBER IN GROUP)(365DAYS)
C
C                         FIC FACTOR     WEIGHT        #      INTAKE FACTOR
         ARV1 = 0.75*0.01*ANIMAL(3,2,5)*ANIMAL(3,2,4)*ANIM1(2)*365.*1.
     +          + 0.75*0.01*ANIMAL(3,3,5)*ANIMAL(3,2,4)*ANIM1(3)*365.*1.
     +          + 0.75*0.01*ANIMAL(3,4,5)*ANIMAL(3,2,4)*ANIM1(4)*365.*.7
     +          + 0.75*0.01*ANIMAL(3,5,5)*ANIMAL(3,5,4)*ANIM1(5)*365.*1.
     +          + 0.75*0.01*ANIMAL(3,6,5)*ANIMAL(3,6,4)*ANIM1(6)*365.*1.
         ARV2 = ARV1 +
     +            0.75*0.01*ANIMAL(3,1,5)*ANIMAL(3,1,4)*ANIM1(1)*365.*1.
C
C ROUGH ESTIMATE OF ALFALFA RQMT = FORAGE ARV - CORN SILAGE ARV
```

```
      GR = (STOR(5,4) - 0.67)/(-0.33)
      CSRV = STOR1(5)*(STOR(5,4)-0.12*GR)
      ALFRV = ARV2 - CSRV
C TRY TO GET RID OF ALL CORN SILAGE

      IF((HLGNOW+HAYNOW.EQ.0.).AND.(STOR(5,1).GT.0.)) THEN
C       ONLY CORN SILAGE ON THE FARM
         FAIF = 0.
      ELSEIF(STOR(5,1).GT.0) THEN
C       BOTH CORN SILAGE AND SOME ALFALFA ON THE FARM
         FAIF = AMAX1( 0., (1. - CSRV/ARV1) )
      ELSE
C       NO CORN SILAGE ON THE FARM
         FAIF = 1.
      ENDIF
C BUT FOR FIRST STAGE COWS, DO NOT USE CORN SILAGE UNLESS IT IS THE ONLY
C ON-FARM FORAGE ( I.E., THERE IS NO ALFALFA ON THE FARM)
      IF((TYPE.EQ.1).AND.(FAIF.NE.0.)) FAIF = 1.
C
C CHOOSE PREFERRED ALFALFA QUALITY FOR THE ANIMAL TYPE GIVEN
C
      IF (TYPE.LE.3) THEN
C       FEED HIGH QUAL ALFALFA TO MILKING COWS
         IQUAL = 1
      ELSE
C       FEED LOW QUAL ALFALFA TO YOUNG HEIFERS, OLDER HEIFERS AND DRY COWS
         IQUAL = 2
      ENDIF
C
C SET ALFALFA USE FACTORS
C
      IF(HLGNOW.NE.0.0) THEN
C       THERE IS SOME ALFALFA SILAGE IN STORAGE
C       SET PREFERRED HAYLAGE TO BE USED
         HLGUSE = IQUAL
C       IF HAYLAGE OF PREFERRED QUALITY IS DEPLETED, USE THE ALTERNATIVE
         IF((HLGUSE.EQ.1).AND.(STOR(HLGUSE,1).EQ.0.).AND.
     +      (STOR(2,1).GT.0.)) HLGUSE = 2
         IF((HLGUSE.EQ.2).AND.(STOR(HLGUSE,1).EQ.0.).AND.
     +      (STOR(1,1).GT.0.)) HLGUSE = 1
C TRY TO GET RID OF ALL ALFALFA SILAGE
         HLGRV = (STOR1(1)*STOR(1,4) + STOR1(2)*STOR(2,4))
         FHAYIA = AMAX1( 0. , (1.-HLGRV/ALFRV) )
      ELSE
C       NO HAYLAGE IN STORAGE, USE ONLY HAY
C       SET HLGUSE TO IQUAL TO AVOID ACCESSING STOR(0,?)
         HLGUSE = IQUAL
         FHAYIA = 1.
      ENDIF
C
      IF(HAYNOW.NE.0.0) THEN
C       THERE IS SOME ALFALFA HAY IN STORAGE
C       SET PREFERRED HAY TO BE USED
```

```
         HAYUSE = IQUAL + 2
         IF((HAYUSE.EQ.3).AND.(STOR(HAYUSE,1).EQ.0.).AND.
     +      (STOR(4,1).GT.0.)) HAYUSE = 4
         IF((HAYUSE.EQ.4).AND.(STOR(HAYUSE,1).EQ.0.).AND.
     +      (STOR(3,1).GT.0.)) HAYUSE = 3
      ELSE
C       NO HAY IN STORAGE, USE PURCHASED HAY
         HAYUSE = 10.
      ENDIF
C
C CORN USE PRIORITY: 1) ON FARM PRODUCED CORN GRAIN  2) PURCHASED CORN GRAIN
C
      IF (STOR(7,1).NE.0.0) THEN
         CRNUSE = 7
      ELSE
         CRNUSE = 9
      ENDIF
      RETURN
      END
C
C ********************************************************************
      SUBROUTINE SINGLE(TYPE,ANIMAL,FAIF,FHAYIA,HAYUSE,HLGUSE,
     +                  CRNUSE,STOR,RATION,OTPT)
C ********************************************************************
C THIS SUBROUTINE DETERMINES A FEED RATION FOR AN ANIMAL GROUP
C (D.R. BUCKMASTER, SEPT. 1988)
C
      IMPLICIT REAL (I-N)
      LOGICAL INFEAS
      INTEGER*4 IPR5
      INTEGER I,J,K,N,TYPE,NCOLS,HAYUSE,HLGUSE,CRNUSE,IFEED
      DOUBLE PRECISION DPM,RHS,OBJ,ZC
      INTEGER*2 INACT,ISACOL,IRWTY
      REAL NEL(7),CP(7),ESCP(7),NH3(7),FPD(5),DEGR(7),STOR(11,5)
      REAL NDF(7),OTPT(4),COST(7),RV(7),ADIP(7),ANIMAL(3,6,7),RATION(11)
      COMMON/LPDT/DPM(6,20),RHS(6),OBJ(20),ZC(20),INACT(6),ISACOL(6),
     + IRWTY(40),INFEAS
      COMMON/FDCOW/XLCOWS,AHRDAV,PFCH,BASEWT,XOHEIF,XYHEIF,PMILK,
     +      PSOYM,PDST,PCORN,PALF,SCG,SHMC,SAFA,SCS,IFEED,IPR5,PRCE(11)
C
C CHARACTERISTICS OF AVAILABLE FEEDS WHERE FEEDS ARE:
C           1. ALFALFA SILAGE
C           2. ALFALFA HAY
C           3. CORN SILAGE
C           4. HIGH MOISTURE EAR CORN
C           5. DRY CORN
C           6. SOYBEAN MEAL
C           7. DISTILLERS GRAIN
C
   10 DO 20 I = 1,7
         IF(I.EQ.1) THEN
            J = HLGUSE
         ELSEIF(I.EQ.2) THEN
```

```
            J = HAYUSE
         ELSEIF(I.GT.2.AND.I.LT.7) THEN
            J = I + 2
         ELSEIF(I.EQ.7) THEN
            J = 11
         ENDIF
         NDF(I) = STOR(J,4)
         IF(I.LE.2) THEN
            RV(I) = NDF(I)
         ELSEIF(I.EQ.3) THEN
            RV(I) = 1.249*NDF(I) - 0.154
         ELSE
            RV(I) = 0.
         ENDIF
         NEL(I) = STOR(J,3)
         CP(I) = STOR(J,2)
         IF((I.EQ.1).OR.(I.EQ.3)) DEGR(I) = 0.5 + 0.5*STOR(J,5)
         IF(I.EQ.2) ADIP(I) = STOR(J,5)
   20 CONTINUE
C
C SET "COSTS" TO MAXIMIZE FORAGE USE
C       DATA (COST(I),I=1,7)/0.0,0.0,0.0,0.0,1.0,2.2,1.6/
C       IF(STOR(6,1).GT.0.0) THEN
C          COST(4)=0.
C       ELSE
C          COST(4)=900.
C       ENDIF
C
C SET RELATIVE UNIT COSTS USING INPUTS OF PRCE ARRAY READ IN FARM FILE
C
      COST(1) = PRCE(HAYUSE)
      COST(2) = PRCE(HLGUSE)
      COST(3) = PRCE(5)
      IF(STOR(6,1).GT.0.) THEN
         COST(4) = PRCE(6)
      ELSE
         COST(4)  = 900.
      ENDIF
      IF(STOR(7,1).GT.0.) THEN
         COST(5) = PRCE(7)
      ELSE
         COST(5) = PRCE(9)
      ENDIF
      COST(6) = PRCE(8)
      COST(7) = PRCE(11)
C
C SET DEGRADABILITY OF NON SILAGES AND ADIP OF NON-HAY AS CONSTANTS
      DATA DEGR(2),DEGR(4),DEGR(5),DEGR(6),DEGR(7)/0.70,0.44,0.48,
     +     0.65,0.47/
      DATA ADIP(1),ADIP(3),ADIP(4),ADIP(5),ADIP(6),ADIP(7)
     +     /0.05,0.059,0.09,0.02,0.0062,0.087/
      DO 40 I = 1,7
         NH3(I) = CP(I)*DEGR(I)
```

```
         ESCP(I) = CP(I)-NH3(I)-CP(I)*ADIP(I)
   40 CONTINUE
C
C CALCULATE FORAGE NUTRIENT CONCENTRATION
   45 NDFF = FAIF*FHAYIA*NDF(2) + FAIF*(1.-FHAYIA)*NDF(1) +
     +       (1.0-FAIF)*NDF(3)
      RVF = FAIF*FHAYIA*RV(2) + FAIF*(1.-FHAYIA)*RV(1) +
     +       (1.0-FAIF)*RV(3)
      NELF = FAIF*FHAYIA*NEL(2) + FAIF*(1.-FHAYIA)*NEL(1) +
     +       (1.0-FAIF)*NEL(3)
      ESCPF = FAIF*FHAYIA*ESCP(2) + FAIF*(1.-FHAYIA)*ESCP(1) +
     +        (1.-FAIF)*ESCP(3)
      NH3F = FAIF*FHAYIA*NH3(2) + FAIF*(1.-FHAYIA)*NH3(1) +
     +       (1.0-FAIF)*NH3(3)
      COSTF = FAIF*FHAYIA*COST(2) + FAIF*(1.-FHAYIA)*COST(1) +
     +       (1.0-FAIF)*COST(3)
      CPF = FAIF*FHAYIA*CP(2) + FAIF*(1.-FHAYIA)*CP(1) +
     +      (1.0-FAIF)*CP(3)
C
C DETERMINE REQUIREMENTS FOR RHS OF LP.  FLEAD IS LEAD FACTOR FOR SET-
C TING NUTRIENT CONCENTRATION RICHER THAN NECESSARY FOR THE AVERAGE COW
C
      MILK = ANIMAL(3,TYPE,2)
      IF(TYPE.EQ.1) THEN
         FLEAD = 1.12
      ELSE
         FLEAD = 1.07
      ENDIF
C INGESTIVE CAPACITY
      IF(TYPE.LE.4) THEN
         IC = 0.01*ANIMAL(3,TYPE,5)*ANIMAL(3,2,4)
      ELSE
         IC = 0.01*ANIMAL(3,TYPE,5)*ANIMAL(3,TYPE,4)
      ENDIF
      IF(TYPE.EQ.3) THEN
         DPREG = 130.
      ELSEIF(TYPE.EQ.4) THEN
         DPREG = 250.
      ELSEIF(TYPE.EQ.5) THEN
         DPREG = 180.
      ELSE
         DPREG = 0.
      ENDIF
C ENERGY (NEL FOR LACT COWS, ME FOR GROWING HEIFERS)
   50 IF(TYPE.LE.4) THEN
         NELM = 0.08*ANIMAL(3,TYPE,4)**.75
         IF(DPREG.LT.210.) THEN
            NELP = 0.
         ELSE
            NELP = 0.024*ANIMAL(3,TYPE,4)**.75
         ENDIF
         IF(ANIMAL(3,TYPE,6).GT.0.) THEN
            NELG = 5.12*ANIMAL(3,TYPE,6)
```

```
         ELSE
            NELG = 4.92*ANIMAL(3,TYPE,6)
         ENDIF
         NELL =(0.3512 + 0.0962*ANIMAL(3,TYPE,3))*MILK*FLEAD
         NELR = NELM + NELL + NELP + NELG
         MMNT = NELR/NELM
C RATHER THAN ADJUST FEED ENERGY CONTENT, ADJUST REQUIREMENT FOR MMNT
         NELREQ = NELR * 0.92/(1.-0.04*(MMNT-1.))
C
C ABSORBED PROTEIN REQUIREMENT
C  FECAL NITROGEN CONTRIBUTION
C         BCP = 6.25 * (-.03093 + .01145*NELR)
         BCP = 6.25*0.01*NELR
         RAPREQ = BCP/0.9
         RELMBS = (ANIMAL(3,TYPE,4)**0.75)/(600**0.75)
         XMIN = 10.*RELMBS*0.74/(0.3152+0.0962*ANIMAL(3,TYPE,3))
         NELDD = 1.42 + 0.01*(MILK-XMIN)*RELMBS*0.74/
     +                      (0.3512+0.0962*ANIMAL(3,TYPE,3))
         IF(MILK.EQ.0) THEN
            NELD = 1.25
         ELSE
            NELD = AMIN1(1.72,AMAX1(1.42,NELDD))
         ENDIF
         ATDN = 0.92*(NELD+0.12)/2.45
         PDMI = NELR/NELD
         IDM = PDMI*(1.-ATDN)
      ELSE
         RELLW = ANIMAL(3,TYPE,4)/800.
         MED = AMAX1( (AMIN1(2.67,(2.804-1.072*RELLW))) , 2.0 )
         NEMD = 1.37*MED - 0.138*MED**2 + 0.0105*MED**3 - 1.12
         NEGD = 1.42*MED - 0.174*MED**2 + 0.0122*MED**3 - 1.65
         NEMR = 0.086*ANIMAL(3,TYPE,4)**.75
         NEGR = 0.035*ANIMAL(3,TYPE,4)**.75*ANIMAL(3,TYPE,6)**1.119 +
     +          ANIMAL(3,TYPE,6)
         PDMI = NEMR/NEMD + NEGR/NEGD
         MEREQ = MED*PDMI
         DED = (MED+0.45)/1.01
         ATDN = 0.92*(DED/4.409)
         BTDN = DED/4.409
C         BCP = 6.25 * (-.03186 + .02612*BTDN*PDMI)
         BCP = 6.25*0.0230*BTDN*PDMI
         RAPREQ = BCP/0.9
         IDM = PDMI*(1.-ATDN)
      ENDIF
      FPN = 0.090*IDM
C  MAINTENANCE NITROGEN CONTRIBUTION
      MNTP = 0.0002*ANIMAL(3,TYPE,4)**0.6 +
     +       0.00275*ANIMAL(3,TYPE,4)**0.5
C  CONTRIBUTION FROM CHANGE IN BODY WEIGHT
      IF(TYPE.LE.4) THEN
         RPN = 0.
         DPA = AMAX1(-.1875,.256*ANIMAL(3,TYPE,6))
      ELSE
```

```
         RPN = ANIMAL(3,TYPE,6)*(0.211 - 0.0262*NEGR/ANIMAL(3,TYPE,6))
         DPA = 0.
      ENDIF
C  CONCEPTUS PROTEIN CONTRIBUTION
      IF(DPREG.GE.210.) THEN
         YPN = 0.001136*ANIMAL(3,TYPE,4)**.7
      ELSE
         YPN = 0.
      ENDIF
C  MILK PROTEIN CONTRIBUTION
      LPN = (.019 + 0.004*ANIMAL(3,TYPE,3))*FLEAD*MILK
C
C ABSORBED PROTEIN REQ.
      APREQ = FPN + MNTP/.67 + RPN/.65 + YPN/.5 + LPN/.7 + DPA
C
C SET CONSTRAINT TYPES
      IRWTY(1) = 1
      IRWTY(2) = 3
      IRWTY(3) = 2
      IRWTY(4) = 3
      IRWTY(5) = 3
      IRWTY(6) = 1
C
C ZERO OUT LP VARIABLES
      DO 80 I = 1,6
         RHS(I) = 0.
         DO 60 J=1,20
            DPM(I,J) = 0.
            OBJ(J) = 0.
   60    CONTINUE
   80 CONTINUE
C
C SET OBJECTIVE FUNCTION, LP MATRIX AND RHS
      OBJ(1) = -COSTF
      DPM(1,1) = NDFF
      DPM(2,1) = RVF - 0.75*NDFF
      IF(TYPE.LE.4) THEN
         DPM(3,1) = NELF
C         DPM(4,1) = 0.046*NELF + 0.95*ESCPF
      ELSE
         DPM(3,1) = 1.65*NELF
C         DPM(4,1) = 0.02345*(1.65*NELF+.45) + 0.95*ESCPF
      ENDIF
      DPM(4,1) = NH3F + 0.15*CPF
C      DPM(5,1) = 0.64*0.9*(NH3F+0.15*CPF) + 0.95*ESCPF
      DPM(5,1) = 0.95*ESCPF
      DPM(6,1) = CPF
      DO 100 I = 2,5
         J = I+2
         OBJ(I) = -COST(J)
         DPM(1,I) = NDF(J)
         DPM(2,I) = RV(J) - 0.75*NDF(J)
         IF(TYPE.LE.4) THEN
```

```
            DPM(3,I) = NEL(J)
C             DPM(4,I) = 0.0458*NEL(J) + 0.95*ESCP(J)
         ELSE
            DPM(3,I) = 1.65*NEL(J)
C             DPM(4,I) = 0.02345*(1.65*NEL(J)+.45) + 0.95*ESCP(J)
         ENDIF
         DPM(4,I) = NH3(J) + 0.15*CP(J)
C          DPM(5,I) = 0.64*0.9*(NH3(J)+0.15*CP(J)) + 0.95*ESCP(J)
         DPM(5,I) = 0.95*ESCP(J)
         DPM(6,I) = CP(J)
  100 CONTINUE
      RHS(1) = IC
      RHS(2) = 0.
      IF(TYPE.LE.4) THEN
         RHS(3) = NELREQ
C          RHS(4) = APREQ + 0.1237
      ELSE
         RHS(3) = MEREQ
C          RHS(4) = APREQ + 0.1274
      ENDIF
      RHS(4) = RAPREQ
C      RHS(5) = APREQ
      RHS(5) = APREQ - 0.576*RAPREQ
      RHS(6) = 100.
C
C CALL LP ROUTINES TO COMPUTE RATION
      NCOLS = 5
      DO 120 I = 1,6
         CALL ROWSET(I,NCOLS)
  120 CONTINUE
      CALL LPSOL(6,NCOLS)
C
C IF INFEASIBLE=TRUE, IT COULD NOT BALANCE RATION, THEREFORE,
C   IF LACTATING COW, TAKE CORN SILAGE OUT OF DIET THEN REDUCE
C      MILK PER DAY IF NECESSARY.
C
      IF(INFEAS) THEN
         IF(TYPE.LE.3) THEN
            IF(FAIF.LT.1.) THEN
               FAIF = 1.
            ELSE
               MILK = MILK*0.985
            ENDIF
            GOTO 50
         ELSE
            WRITE(*,*) 'INFEASIBLE RATION FOR GROUP',TYPE
         ENDIF
      ENDIF
      ADMI = 0.
      DO 140 N = 1,5
         FPD(N) = 0.
  140 CONTINUE
      DO 160 N = 1,6
```

```
         IF(INACT(N).LE.5) THEN
            FPD(INACT(N)) = RHS(N)
            ADMI = ADMI + FPD(INACT(N))
         ENDIF
  160 CONTINUE
C
C WITH NUTRIENT DENSITY RICHER THAN NEEDED FOR THE AVERAGE ANIMAL, FOLLOW
C FEED DISAPPEARANCE FOR AVERAGE ANIMAL IN GROUP. I.E., REMOVE LEAD FACTOR
C EFFECT FOR LACTATING ANIMALS TO DETERMINE FEED USE.
C
      IF(TYPE.LE.3) THEN
         NELR2 = NELR - NELL + NELL/FLEAD
         NELRE2 = NELR2 * 0.92/(1.-0.04*(MMNT-1.))
         APREQ2 = APREQ - LPN/.7 + (LPN/FLEAD)/.7
         FACTOR = AMAX1((NELRE2/NELREQ),(APREQ2/APREQ))
         DO 170 I = 1,5
            FPD(I) = FACTOR*FPD(I)
  170    CONTINUE
         ADMI = FACTOR*ADMI
      ELSEIF(TYPE.EQ.4) THEN
         NELRE2 = NELREQ
         APREQ2 = APREQ
      ELSE
         APREQ2 = APREQ
      ENDIF
C
C RATION INFORMATION FOR OUTPUT -- ARRAY "OTPT"
C (1) MILK/DAY
C (2) NEL CONTENT OF DIET
C (3) NDF CONTENT OF DIET
C (4) CP CONTENT OF DIET
C
      DO 200 I = 1,11
         RATION(I) = 0.
  200 CONTINUE
      RATION(HLGUSE) = FPD(1)*FAIF*(1.-FHAYIA)
      RATION(HAYUSE) = FPD(1)*FAIF*FHAYIA
      RATION(5) = FPD(1)*(1.-FAIF)
      NELID = FPD(1)*NELF
      NDFID = FPD(1)*NDFF
      CPID = FPD(1)*CPF
      ESCPID = FPD(1)*ESCPF
      NH3ID = FPD(1)*NH3F
      IF(FPD(2).GT.0)THEN
         RATION(6)=FPD(2)
      ENDIF
      IF(FPD(3).GT.0)THEN
         RATION(MAXO(7,CRNUSE))=FPD(3)
      ENDIF
      RATION(8)=FPD(4)
      RATION(11)=FPD(5)
      DO 220 K = 2,5
         L = K+2
```

```
          NELID = NELID + FPD(K)*NEL(L)
          NDFID = NDFID + FPD(K)*NDF(L)
          CPID = CPID + FPD(K)*CP(L)
          ESCPID = ESCPID + FPD(K)*ESCP(L)
          NH3ID = NH3ID + FPD(K)*NH3(L)
  220 CONTINUE
      OTPT(1) = MILK
      OTPT(2) = NELID/ADMI
      OTPT(3) = NDFID/ADMI
      OTPT(4) = CPID/ADMI
      ANIMAL(3,TYPE,7) = MILK
      RETURN
      END
C
C *******************************************************************
C     LINEAR PROGRAMMING ROUTINES -- Version 4.1
C     AUTHOR: S. B. Harsh, Mich. State Univ.
C     LAST DATE OF REVISION: April 24, 1986
C
C     REVISED TO MEET FORTRAN 5 ABILITIES JANUARY 1987 BY D. BUCKMASTER
C *******************************************************************
C*  C* COMMENT LINES ADDED BY D.R.B. 1/87 FOR CLARITY OF THE PROGRAMS
C*
C*  SUBROUTINE ROWSET SETS UP AUXILIARY MATRIX
C*  SUBROUTINE LPDMP PRINTS THE MATRIX EACH ITERATION IF DESIRED
C*  SUBROUTINE LPSOL SOLVES THE PROBLEM AND PRINTS THE FINAL SOLUTION
C*    IF PROBLEMS OCCUR (I.E., NO FEASIBLE SOLUTION, EXCEEDS MAXIMUM
C*     NUMBER OF ITERATIONS, OR UNBOUNDED PROBLEM) LPSOL WILL POINT THIS OUT.
C*    SOLUTION IS DONE USING SIMPLEX METHOD.
C*
C* PARTIAL GLOSSARY:
C*
C*     DPM(I,J) = DOUBLE PRECISION MATRIX OF COEFFICIENTS (COMMONLY
C*                REFERRED TO AS A(I,J)
C*     INACT(I) = ACTIVITIES IN THE SOLUTION
C*     INFEAS = INDICATES WHEN PROBLEM IS INFEASIBLE (INFEAS=TRUE)
C*     IRWTY(I) = TYPE OF INEQUALITY CORRESPONDING TO ROW I
C*            IRWTY(I) = 1 IMPLIES LESS THAN OR EQUAL TO
C*            IRWTY(I) = 2 IMPLIES EQUAL TO
C*            IRWTY(I) = 3 IMPLIES GREATER THAN OR EQUAL TO
C*     ISACOL(J) = ACTIVITY RECENTLY REMOVED FROM THE SOLUTION
C*     JCOL = NUMBER OF COLUMNS IN ORIGINAL FORMULATION (CHANGES WHEN
C*            AUXILIARY MATRIX IS FORMED
C*     MXITER = MAXIMUM NUMBER OF ITERATIONS TO CONSIDER DOING
C*     NOROW = NUMBER OF ROWS IN THE PROBLEM FORMULATION
C*     NOCOL = NUMBER OF COLUMNS IN THE AUXILIARY FORMULATION
C*     OBJ(J) = COEFFICIENT IN THE OBJECTIVE FUNCTION FOR EACH VARIABLE
C*     OBJV = OBJECTIVE FUNCTION VALUE
C*     RHS(I) = RIGHT HAND SIDE CONSTRAINTS FOR ROW I
C*           IN THE SOLUTION RHS(I) = LEVEL OF ACTIVITY FOR INACT(I)
C*
C *******************************************************************
      SUBROUTINE ROWSET(I,JCOL)
```

```
C *********************************************************************
C     Sets up rows, slacks, and artificials
      COMMON/LPDT/DPM(6,20),RHS(6),OBJ(20),ZC(20),INACT(6),ISACOL(6),
     + IRWTY(40),INFEAS
      DOUBLE PRECISION DPM,RHS,OBJ,ZC
      INTEGER*2 INACT,ISACOL,IRWTY
      LOGICAL INFEAS
C
      JCOL=JCOL+1
      INACT(I)=JCOL
      ISACOL(I)=JCOL
      IF(RHS(I).GE.0.0) THEN
           IF(IRWTY(I).LT.1) THEN
                WRITE(*,890) I
           ELSEIF(IRWTY(I).EQ.1) THEN
                DPM(I,JCOL) = 1.
                OBJ(JCOL) = 0.0
           ELSEIF(IRWTY(I).EQ.2) THEN
                DPM(I,JCOL) = 1.
                OBJ(JCOL) = -9.*10.**9
           ELSEIF(IRWTY(I).EQ.3) THEN
                DPM(I,JCOL) = 1.
                OBJ(JCOL) = -9.*10.**9
                JCOL = JCOL+1
                DPM(I,JCOL) = -1.
                OBJ(JCOL) = 0.0
           ELSE
                WRITE(*,890) I
           ENDIF
      ELSE
           WRITE(*,890) I
      ENDIF
      RETURN
  890 FORMAT(1X,//,1X,'ERROR -- Wrong RHS values for row, ',I4,
     + ', Program stopped in subroutine ROWSET.')
      END
C *********************************************************************
      SUBROUTINE LPSOL(NOROW,NOCOL)
C *********************************************************************
C *** Solves the LP problem
      COMMON/LPDT/DPM(6,20),RHS(6),OBJ(20),ZC(20),INACT(6),ISACOL(6),
     + IRWTY(40),INFEAS
      DOUBLE PRECISION DPM,RHS,OBJ,ZC
      INTEGER*2 INACT,ISACOL,IRWTY
      LOGICAL INFEAS
C
      DOUBLE PRECISION COLKEY(40),X,Z,ZCMX,OBJV,EPISP,RMIN,R,R1,R2
      INFEAS = .TRUE.
C      WRITE(*,980)
C  980 FORMAT(1X,8(/),1X,'START L. P. SOLVE ')
      X=10.**8
      EPISP=1./X
      MXITER=4*NOROW + 1
```

```
      DO 200 NOITER = 1,MXITER
           JZCMX = 0
           ZCMX = 0.0
           DO 50 J=1,NOCOL
                Z = 0.0
                DO 40 I = 1,NOROW
                     Z = Z + DPM(I,J)*OBJ(INACT(I))
   40           CONTINUE
                ZC(J) = Z - OBJ(J)
                IF((ZC(J).LT.0.0) .AND. ((ZC(J)-ZCMX).LT.0.0)) THEN
                     ZCMX = ZC(J)
                     JZCMX = J
                ENDIF
   50      CONTINUE
           IF(JZCMX.LE.0) THEN
                IF(NOITER.LE.1) THEN
C                     WRITE(*,910)
C  910 FORMAT(' BAD MATRIX')
                     RETURN
                ENDIF
                X = -9.*10.**9
                DO 60 I = 1,NOROW
                     J = INACT(I)
                     IF((RHS(I).NE.0.0).AND.(OBJ(J).EQ.X)) THEN
C                          WRITE(*,960)
C  960 FORMAT(' THERE ARE NO FEASIBLE SOLUTIONS')
                          RETURN
                     ENDIF
                     IF(IRWTY(I).NE.1) THEN
                          J = ISACOL(I)
                          ZC(J) = ZC(J) + X
                     ENDIF
   60           CONTINUE
                OBJV = 0.0
                DO 70 I = 1,NOROW
                     OBJV = OBJV + RHS(I)*OBJ(INACT(I))
   70           CONTINUE
C                 WRITE(*,990) NOITER,OBJV
C  990 FORMAT(1X,//,1X,'+',19('--'),'+',/,1X,'|',38X,'|',/,
C     A 1X,'| OPTIMAL SOLUTION (',I3,' Iterations)    |',/,
C     B 1X,'| OBJECTIVE FUNCTION = ',F15.4,' |',/,
C     C 1X,'|',38X,'|',/,1X,'+',19('--'),'+')
                INFEAS = .FALSE.
                RETURN
           ELSE
                RMIN = 99.*10.**8
                NKR = 0
                DO 90 I = 1,NOROW
                     IF(DPM(I,JZCMX).GT.0.0) THEN
                          R = RHS(I)/DPM(I,JZCMX)
                          IF(R.LT.RMIN) THEN
                               RMIN = R
                               NKR = I
```

```
                        ELSEIF(R.EQ.RMIN) THEN
                             DO 80 J = 1,NOCOL
                                  R1 = DPM(NKR,J)/DPM(NKR,JZCMX)
                                  R2 = DPM(I,J)/DPM(I,JZCMX)
                                  IF(R2.LT.R1) THEN
                                       NKR = I
                                       GO TO 90
                                  ELSEIF(R2.GT.R1) THEN
                                       GO TO 90
                                  ENDIF
   80                        CONTINUE
C                             WRITE(*,930) NKR,I
C  930 FORMAT(' CYCLING HAS OCCURED AT',2X,I4,2X,I5)
                             RETURN
                        ENDIF
                   ENDIF
   90         CONTINUE
              IF(NKR.LT.1) THEN
C                   WRITE(*,950) JZCMX
C  950 FORMAT(' UNBOUNDED SOLUTION,ACTIVITY',2X,I5)
                   RETURN
              ENDIF
              INACT(NKR) = JZCMX
              DO 100 I = 1,NOROW
                   COLKEY(I) = DPM(I,JZCMX)
  100         CONTINUE
              DO 110 J = 1,NOCOL
                   DPM(NKR,J) = DPM(NKR,J)/COLKEY(NKR)
  110         CONTINUE
              RHS(NKR) = RHS(NKR)/COLKEY(NKR)
              DO 130 I = 1,NOROW
                   IF(I.NE.NKR) THEN
                        RHS(I) = RHS(I) - RHS(NKR)*COLKEY(I)
                        IF(COLKEY(I).NE.0.0) THEN
                             DO 120 J = 1,NOCOL
                                  IF(DPM(NKR,J).NE.0.0) THEN
                           DPM(I,J) = DPM(I,J) - DPM(NKR,J)*COLKEY(I)
                           IF(ABS(DPM(I,J)).LE.EPISP) DPM(I,J) = 0.0
                                  ENDIF
  120                        CONTINUE
                        ENDIF
                   ENDIF
  130         CONTINUE
         ENDIF
  200 CONTINUE
C      WRITE(*,920)
C  920 FORMAT(' NO. ITERATIONS EQUAL MAXIMUM')
      RETURN
      END
```

APPENDIX C

Formulated rations and feed use data used to determine alfalfa value as presented in Chapter 6.

Table C.1 Formulated rations with varying alfalfa quality, forage type and cow size.

CASE	CP	NDF	STG OF LACT.	MPD	RATION (kg dm/day) AHAY	ASIL	CS	CG	SBM	DST
MIXED FORAGE DIETS (600 kg cow):										
1	0.12	0.51	1	35.2	2.90	2.90	2.89	7.81	1.69	1.18
2	0.12	0.54	1	35.2	2.75	2.75	2.75	8.50	1.85	0.78
3	0.12	0.57	1	34.9	2.64	2.64	2.63	8.97	1.96	0.47
4	0.15	0.45	1	35.2	3.24	3.24	3.24	6.20	0.60	2.73
5	0.15	0.48	1	35.2	3.06	3.06	3.06	7.07	0.85	2.20
6	0.15	0.51	1	35.2	2.90	2.90	2.90	7.84	1.07	1.72
7	0.15	0.54	1	35.2	2.76	2.76	2.75	8.54	1.26	1.29
8	0.15	0.57	1	35.1	2.63	2.63	2.63	9.26	1.68	0.53
9	0.18	0.39	1	35.2	3.68	3.68	3.68	4.64	0.00	3.48
10	0.18	0.42	1	35.2	3.45	3.45	3.45	5.52	0.00	3.32
11	0.18	0.45	1	35.2	3.25	3.25	3.25	6.29	0.00	3.18
12	0.18	0.48	1	35.2	3.07	3.07	3.06	7.10	0.19	2.76
13	0.18	0.51	1	35.2	2.91	2.91	2.90	7.87	0.44	2.26
14	0.18	0.54	1	35.2	2.76	2.76	2.76	8.57	0.67	1.80
15	0.21	0.36	1	35.2	3.96	3.96	3.96	4.17	0.00	3.07
16	0.21	0.39	1	35.2	3.70	3.70	3.69	5.14	0.00	2.93
17	0.21	0.42	1	35.2	3.46	3.46	3.46	6.00	0.00	2.81
18	0.21	0.45	1	35.2	3.26	3.26	3.25	6.75	0.00	2.70
19	0.21	0.48	1	35.2	3.08	3.08	3.07	7.42	0.00	2.60
20	0.24	0.36	1	35.2	3.98	3.98	3.97	4.72	0.00	2.48
21	0.24	0.39	1	35.2	3.71	3.71	3.70	5.66	0.00	2.38
22	0.24	0.42	1	35.2	3.48	3.48	3.47	6.48	0.00	2.29
1	0.12	0.51	2	31.8	3.63	3.63	3.63	6.11	1.12	1.94
2	0.12	0.54	2	31.8	3.45	3.45	3.45	6.98	1.33	1.44
3	0.12	0.57	2	31.5	3.30	3.30	3.30	7.63	1.48	1.04
4	0.15	0.45	2	31.8	4.07	4.07	4.06	4.24	0.00	3.50
5	0.15	0.48	2	31.8	3.84	3.84	3.84	5.18	0.07	3.21
6	0.15	0.51	2	31.8	3.64	3.64	3.64	6.15	0.34	2.61
7	0.15	0.54	2	31.8	3.46	3.46	3.45	7.02	0.59	2.08
8	0.15	0.57	2	31.7	3.30	3.30	3.29	7.76	0.80	1.61
9	0.18	0.39	2	31.8	4.63	4.63	4.62	2.72	0.00	3.27
10	0.18	0.42	2	31.8	4.34	4.34	4.33	3.83	0.00	3.07
11	0.18	0.45	2	31.8	4.08	4.08	4.07	4.80	0.00	2.90
12	0.18	0.48	2	31.8	3.85	3.85	3.85	5.68	0.00	2.74
13	0.18	0.51	2	31.8	3.65	3.65	3.64	6.45	0.00	2.60
14	0.18	0.54	2	31.8	3.47	3.47	3.46	7.15	0.00	2.48
15	0.21	0.36	2	31.8	4.97	4.97	4.97	2.14	0.00	2.76
16	0.21	0.39	2	31.8	4.64	4.64	4.63	3.36	0.00	2.58
17	0.21	0.42	2	31.8	4.35	4.35	4.34	4.43	0.00	2.43
18	0.21	0.45	2	31.8	4.09	4.09	4.09	5.37	0.00	2.29

19	0.21	0.48	2	31.8	3.86	3.86	3.86	6.22	0.00	2.17
20	0.24	0.36	2	31.8	4.99	4.99	4.99	2.83	0.00	2.02
21	0.24	0.39	2	31.8	4.66	4.66	4.65	4.01	0.00	1.89
22	0.24	0.42	2	31.8	4.36	4.36	4.36	5.04	0.00	1.78
1	0.12	0.51	3	19.5	4.47	4.47	4.46	0.95	0.00	3.13
2	0.12	0.54	3	19.5	4.24	4.24	4.24	1.87	0.00	2.91
3	0.12	0.57	3	19.4	4.05	4.05	4.04	2.70	0.09	2.55
4	0.15	0.45	3	19.5	5.01	5.01	5.00	0.00	0.87	1.56
5	0.15	0.48	3	19.5	4.73	4.73	4.72	0.59	0.00	2.67
6	0.15	0.51	3	19.5	4.48	4.48	4.47	1.58	0.00	2.47
7	0.15	0.54	3	19.5	4.25	4.25	4.25	2.46	0.00	2.28
8	0.15	0.57	3	19.5	4.05	4.05	4.05	3.26	0.00	2.10
9	0.18	0.39	3	19.5	5.09	5.09	5.09	0.00	1.64	0.00
10	0.18	0.42	3	19.5	5.29	5.29	5.28	0.00	1.53	0.00
11	0.18	0.45	3	19.5	5.02	5.02	5.01	0.18	0.00	2.17
12	0.18	0.48	3	19.5	4.74	4.74	4.73	1.25	0.00	1.97
13	0.18	0.51	3	19.5	4.49	4.49	4.48	2.21	0.00	1.80
14	0.18	0.54	3	19.5	4.26	4.26	4.26	3.06	0.00	1.65
15	0.21	0.36	3	19.5	5.10	5.10	5.09	0.00	1.27	0.00
16	0.21	0.39	3	19.5	5.30	5.30	5.29	0.00	1.15	0.00
17	0.21	0.42	3	19.5	5.35	5.35	5.34	0.00	0.47	0.85
18	0.21	0.45	3	19.5	5.03	5.03	5.03	0.88	0.00	1.42
19	0.21	0.48	3	19.5	4.75	4.75	4.74	1.92	0.00	1.27
20	0.24	0.36	3	19.5	5.30	5.30	5.29	0.00	0.77	0.00
21	0.24	0.39	3	19.5	5.52	5.52	5.51	0.00	0.62	0.00
22	0.24	0.42	3	19.5	5.37	5.37	5.36	0.46	0.00	0.79
23	0.12	0.51	1	36.5	2.84	2.84	2.84	8.57	1.89	0.89
24	0.12	0.54	1	35.7	2.73	2.73	2.73	8.80	1.94	0.66
25	0.15	0.45	1	38.3	3.10	3.10	3.09	8.11	1.16	1.92
26	0.15	0.48	1	37.6	2.96	2.96	2.95	8.82	1.78	0.80
27	0.15	0.51	1	36.7	2.84	2.84	2.84	8.94	1.67	0.81
28	0.15	0.54	1	35.9	2.73	2.73	2.73	9.31	1.99	0.18
29	0.18	0.39	1	38.3	3.52	3.52	3.51	6.27	0.00	3.54
30	0.18	0.42	1	38.3	3.30	3.30	3.29	7.22	0.19	3.10
31	0.18	0.45	1	38.3	3.10	3.10	3.10	8.15	0.49	2.50
32	0.18	0.48	1	37.8	2.96	2.96	2.95	9.44	1.95	0.10
33	0.18	0.51	1	36.9	2.84	2.84	2.84	9.58	1.91	0.02
34	0.18	0.54	1	36.0	2.73	2.73	2.73	9.27	1.22	0.98
35	0.21	0.36	1	38.3	3.78	3.78	3.78	5.83	0.00	3.16
36	0.21	0.39	1	38.3	3.53	3.53	3.52	6.76	0.00	3.02
37	0.21	0.42	1	38.3	3.31	3.31	3.30	7.57	0.00	2.90
38	0.21	0.45	1	38.3	3.11	3.11	3.11	8.28	0.00	2.80
39	0.21	0.48	1	37.9	2.96	2.96	2.95	9.32	0.98	1.17
40	0.24	0.36	1	38.3	3.79	3.79	3.79	6.35	0.00	2.59
41	0.24	0.39	1	38.3	3.54	3.54	3.53	7.24	0.00	2.50
42	0.24	0.42	1	38.3	3.32	3.32	3.31	8.03	0.00	2.41
23	0.12	0.51	2	32.9	3.59	3.59	3.58	6.74	1.29	1.70
24	0.12	0.54	2	32.2	3.44	3.44	3.43	7.22	1.40	1.34
25	0.15	0.45	2	34.5	3.94	3.94	3.94	5.71	0.24	3.18
26	0.15	0.48	2	33.9	3.75	3.75	3.75	6.40	0.43	2.69

27	0.15	0.51	2	33.1	3.59	3.59	3.58	6.88	0.55	2.32
28	0.15	0.54	2	32.4	3.44	3.44	3.43	7.36	0.69	1.93
29	0.18	0.39	2	34.5	4.48	4.48	4.48	4.10	0.00	3.32
30	0.18	0.42	2	34.5	4.20	4.20	4.20	5.17	0.00	3.13
31	0.18	0.45	2	34.5	3.95	3.95	3.95	6.12	0.00	2.96
32	0.18	0.48	2	34.1	3.75	3.75	3.75	6.76	0.00	2.80
33	0.18	0.51	2	33.3	3.59	3.59	3.58	7.13	0.00	2.66
34	0.18	0.54	2	32.5	3.44	3.44	3.43	7.47	0.00	2.50
35	0.21	0.36	2	34.5	4.82	4.82	4.81	3.54	0.00	2.83
36	0.21	0.39	2	34.5	4.50	4.50	4.49	4.72	0.00	2.66
37	0.21	0.42	2	34.5	4.21	4.21	4.21	5.76	0.00	2.51
38	0.21	0.45	2	34.5	3.97	3.97	3.96	6.67	0.00	2.38
39	0.21	0.48	2	34.2	3.76	3.76	3.75	7.32	0.00	2.25
40	0.24	0.36	2	34.5	4.84	4.84	4.83	4.20	0.00	2.11
41	0.24	0.39	2	34.5	4.51	4.51	4.51	5.34	0.00	1.99
42	0.24	0.42	2	34.5	4.23	4.23	4.22	6.34	0.00	1.88
23	0.12	0.51	3	20.2	4.44	4.44	4.43	1.23	0.00	3.18
24	0.12	0.54	3	19.8	4.23	4.23	4.23	1.98	0.00	2.93
25	0.15	0.45	3	21.2	4.92	4.92	4.92	0.18	0.00	3.03
26	0.15	0.48	3	20.8	4.67	4.67	4.66	1.12	0.00	2.78
27	0.15	0.51	3	20.3	4.44	4.44	4.44	1.89	0.00	2.53
28	0.15	0.54	3	19.9	4.24	4.24	4.23	2.61	0.00	2.31
29	0.18	0.39	3	21.2	5.34	5.34	5.34	0.00	1.75	0.00
30	0.18	0.42	3	21.2	5.25	5.25	5.24	0.00	0.53	1.69
31	0.18	0.45	3	21.2	4.94	4.94	4.93	0.86	0.00	2.30
32	0.18	0.48	3	21.0	4.68	4.68	4.67	1.81	0.00	2.09
33	0.18	0.51	3	20.5	4.45	4.45	4.44	2.56	0.00	1.88
34	0.18	0.54	3	20.0	4.25	4.25	4.24	3.23	0.00	1.69
35	0.21	0.36	3	21.2	5.35	5.35	5.34	0.00	1.37	0.00
36	0.21	0.39	3	21.2	5.56	5.56	5.55	0.00	1.24	0.00
37	0.21	0.42	3	21.2	5.26	5.26	5.26	0.41	0.00	1.74
38	0.21	0.45	3	21.2	4.95	4.95	4.95	1.55	0.00	1.57
39	0.21	0.48	3	21.0	4.69	4.69	4.68	2.48	0.00	1.41
40	0.24	0.36	3	21.2	5.56	5.56	5.56	0.00	0.84	0.00
41	0.24	0.39	3	21.2	5.64	5.64	5.63	0.00	0.17	0.82
42	0.24	0.42	3	21.2	5.28	5.28	5.27	1.14	0.00	0.95
43	0.15	0.45	1	38.6	3.09	3.09	3.08	8.79	2.01	0.59
44	0.18	0.39	1	40.9	3.38	3.38	3.37	8.54	1.65	1.15
45	0.18	0.42	1	39.8	3.22	3.22	3.22	8.83	1.57	0.99
46	0.18	0.45	1	38.7	3.09	3.09	3.08	8.67	1.02	1.69
47	0.21	0.36	1	42.3	3.55	3.55	3.54	8.78	1.70	0.90
48	0.21	0.39	1	41.1	3.38	3.38	3.37	9.12	1.69	0.62
49	0.21	0.42	1	40.0	3.22	3.22	3.22	9.44	1.69	0.35
50	0.21	0.45	1	38.9	3.09	3.09	3.08	9.23	1.06	1.16
51	0.24	0.36	1	42.5	3.55	3.55	3.54	9.32	1.64	0.50
52	0.24	0.39	1	41.3	3.38	3.38	3.37	9.70	1.74	0.08
53	0.24	0.42	1	40.1	3.22	3.22	3.22	9.30	0.66	1.49
43	0.15	0.45	2	34.8	3.93	3.93	3.93	5.86	0.28	3.12
44	0.18	0.39	2	36.9	4.36	4.36	4.35	5.31	0.00	3.33
45	0.18	0.42	2	35.9	4.14	4.14	4.13	5.85	0.00	3.14

46	0.18	0.45	2	34.9	3.94	3.94	3.93	6.29	0.00	2.97
47	0.21	0.36	2	38.2	4.62	4.62	4.61	5.44	0.00	2.85
48	0.21	0.39	2	37.1	4.37	4.37	4.36	6.01	0.00	2.69
49	0.21	0.42	2	36.1	4.14	4.14	4.13	6.51	0.00	2.53
50	0.21	0.45	2	35.1	3.94	3.94	3.93	6.92	0.00	2.39
51	0.24	0.36	2	38.3	4.63	4.63	4.62	6.17	0.00	2.17
52	0.24	0.39	2	37.3	4.37	4.37	4.36	6.70	0.00	2.04
53	0.24	0.42	2	36.2	4.15	4.15	4.14	7.13	0.00	1.92
43	0.15	0.45	3	21.4	4.92	4.92	4.91	0.24	0.00	3.05
44	0.18	0.39	3	22.7	5.53	5.53	5.52	0.00	1.74	0.16
45	0.18	0.42	3	22.1	5.21	5.21	5.20	0.02	0.00	2.58
46	0.18	0.45	3	21.5	4.93	4.93	4.92	0.95	0.00	2.32
47	0.21	0.36	3	23.5	5.68	5.68	5.67	0.00	1.48	0.00
48	0.21	0.39	3	22.8	5.54	5.54	5.53	0.00	0.39	1.45
49	0.21	0.42	3	22.2	5.22	5.22	5.21	0.79	0.00	1.82
50	0.21	0.45	3	21.6	4.94	4.94	4.93	1.68	0.00	1.60
51	0.24	0.36	3	23.6	5.91	5.91	5.91	0.00	0.87	0.08
52	0.24	0.39	3	22.9	5.55	5.55	5.54	0.59	0.00	1.23
53	0.24	0.42	3	22.2	5.23	5.23	5.22	1.55	0.00	1.04

ALFALFA HAY BASED DIETS (600 kg cow):

54	0.12	0.51	1	35.6	8.37	0.00	0.00	9.40	1.83	0.20
55	0.12	0.54	1	34.5	7.91	0.00	0.00	9.63	1.86	0.00
56	0.12	0.57	1	33.4	7.49	0.00	0.00	9.68	1.83	0.00
57	0.15	0.45	1	38.7	9.47	0.00	0.00	9.42	0.97	1.05
58	0.15	0.48	1	37.3	8.88	0.00	0.00	9.74	1.09	0.69
59	0.15	0.51	1	35.9	8.37	0.00	0.00	9.93	1.17	0.40
60	0.15	0.54	1	34.8	7.90	0.00	0.00	10.20	1.27	0.11
61	0.15	0.57	1	33.7	7.49	0.00	0.00	10.29	1.30	0.00
62	0.18	0.39	1	42.5	10.92	0.00	0.00	9.47	0.67	1.30
63	0.18	0.42	1	40.7	10.13	0.00	0.00	9.61	0.18	1.71
64	0.18	0.45	1	39.0	9.47	0.00	0.00	9.92	0.26	1.34
65	0.18	0.48	1	37.6	8.87	0.00	0.00	10.26	0.51	0.84
66	0.18	0.51	1	36.2	8.36	0.00	0.00	10.34	0.49	0.76
67	0.18	0.54	1	35.1	7.90	0.00	0.00	10.59	0.63	0.44
68	0.21	0.36	1	45.1	11.81	0.00	0.00	10.45	1.14	0.03
69	0.21	0.39	1	42.8	10.92	0.00	0.00	10.08	0.00	1.44
70	0.21	0.42	1	41.0	10.13	0.00	0.00	10.45	0.00	1.16
71	0.21	0.45	1	39.3	9.47	0.00	0.00	10.70	0.00	0.92
72	0.21	0.48	1	37.9	8.87	0.00	0.00	10.96	0.23	0.51
73	0.24	0.36	1	45.4	11.81	0.00	0.00	10.87	0.00	0.81
74	0.24	0.39	1	43.2	10.92	0.00	0.00	11.30	0.28	0.12
75	0.24	0.42	1	41.3	10.14	0.00	0.00	11.40	0.00	0.31
54	0.12	0.51	2	32.1	10.52	0.00	0.00	8.01	1.27	0.75
55	0.12	0.54	2	31.1	9.88	0.00	0.00	8.60	1.41	0.32
56	0.12	0.57	2	30.1	9.33	0.00	0.00	9.05	1.51	0.00
57	0.15	0.45	2	34.9	12.09	0.00	0.00	7.29	0.00	2.06
58	0.15	0.48	2	33.7	11.25	0.00	0.00	8.03	0.22	1.52
59	0.15	0.51	2	32.4	10.53	0.00	0.00	8.60	0.42	1.03
60	0.15	0.54	2	31.4	9.89	0.00	0.00	9.17	0.62	0.58

61	0.15	0.57	2	30.4	9.34	0.00	0.00	9.64	0.78	0.19
62	0.18	0.39	2	38.3	14.27	0.00	0.00	7.12	0.00	1.24
63	0.18	0.42	2	36.7	13.09	0.00	0.00	7.86	0.00	1.12
64	0.18	0.45	2	35.2	12.11	0.00	0.00	8.40	0.00	1.01
65	0.18	0.48	2	33.9	11.26	0.00	0.00	8.94	0.00	0.90
66	0.18	0.51	2	32.7	10.54	0.00	0.00	9.32	0.00	0.80
67	0.18	0.54	2	31.7	9.90	0.00	0.00	9.73	0.00	0.70
68	0.21	0.36	2	40.7	15.69	0.00	0.00	7.55	0.00	0.24
69	0.21	0.39	2	38.6	14.31	0.00	0.00	8.42	0.00	0.00
70	0.21	0.42	2	37.0	13.12	0.00	0.00	9.04	0.00	0.00
71	0.21	0.45	2	35.5	12.13	0.00	0.00	9.50	0.00	0.00
72	0.21	0.48	2	34.2	11.28	0.00	0.00	9.91	0.00	0.00
73	0.24	0.36	2	41.0	15.66	0.00	0.00	7.93	0.00	0.00
74	0.24	0.39	2	39.0	14.25	0.00	0.00	8.61	0.00	0.00
75	0.24	0.42	2	37.3	13.08	0.00	0.00	9.18	0.00	0.00
54	0.12	0.51	3	19.7	12.95	0.00	0.00	3.06	0.00	1.96
55	0.12	0.54	3	19.1	12.10	0.00	0.00	4.04	0.06	1.58
56	0.12	0.57	3	18.5	11.37	0.00	0.00	4.98	0.29	0.97
57	0.15	0.45	3	21.5	15.13	0.00	0.00	2.20	0.00	1.18
58	0.15	0.48	3	20.7	13.97	0.00	0.00	3.37	0.00	0.93
59	0.15	0.51	3	19.9	12.99	0.00	0.00	4.34	0.00	0.69
60	0.15	0.54	3	19.3	12.14	0.00	0.00	5.20	0.00	0.49
61	0.15	0.57	3	18.7	11.40	0.00	0.00	5.94	0.00	0.30
62	0.18	0.39	3	23.6	18.22	0.00	0.00	0.70	0.00	0.26
63	0.18	0.42	3	22.6	16.56	0.00	0.00	2.25	0.00	0.06
64	0.18	0.45	3	21.6	15.18	0.00	0.00	3.39	0.00	0.00
65	0.18	0.48	3	20.8	14.00	0.00	0.00	4.32	0.00	0.00
66	0.18	0.51	3	20.1	13.01	0.00	0.00	5.07	0.00	0.00
67	0.18	0.54	3	19.5	12.14	0.00	0.00	5.74	0.00	0.00
68	0.21	0.36	3	25.0	19.45	0.00	0.00	0.00	0.00	0.00
69	0.21	0.39	3	23.7	18.21	0.00	0.00	1.02	0.00	0.00
70	0.21	0.42	3	22.7	16.53	0.00	0.00	2.39	0.00	0.00
71	0.21	0.45	3	21.8	15.15	0.00	0.00	3.47	0.00	0.00
72	0.21	0.48	3	21.0	13.98	0.00	0.00	4.40	0.00	0.00
73	0.24	0.36	3	25.2	19.54	0.00	0.00	0.00	0.00	0.00
74	0.24	0.39	3	24.0	18.18	0.00	0.00	1.13	0.00	0.00
75	0.24	0.42	3	22.9	16.51	0.00	0.00	2.46	0.00	0.00

ALFALFA SILAGE BASED DIETS (600 KG COW):

76	0.12	0.51	1	35.4	0.00	8.37	0.00	8.89	2.28	0.22
77	0.12	0.54	1	34.3	0.00	7.90	0.00	8.92	1.86	0.65
78	0.12	0.57	1	33.2	0.00	7.49	0.00	9.05	1.69	0.69
79	0.15	0.45	1	38.3	0.00	9.47	0.00	8.60	1.77	0.97
80	0.15	0.48	1	36.9	0.00	8.87	0.00	8.71	1.43	1.24
81	0.15	0.51	1	35.6	0.00	8.37	0.00	9.34	2.06	0.06
82	0.15	0.54	1	34.5	0.00	7.90	0.00	9.41	1.75	0.33
83	0.15	0.57	1	33.4	0.00	7.49	0.00	9.58	1.69	0.23
84	0.18	0.39	1	42.0	0.00	10.92	0.00	8.68	2.24	0.41
85	0.18	0.42	1	40.2	0.00	10.13	0.00	8.65	1.26	1.45
86	0.18	0.45	1	38.5	0.00	9.47	0.00	8.94	1.26	1.17
87	0.18	0.48	1	37.1	0.00	8.87	0.00	9.12	1.09	1.23

88	0.18	0.51	1	35.7	0.00	8.36	0.00	9.07	0.71	1.64
89	0.18	0.54	1	34.6	0.00	7.90	0.00	9.19	0.53	1.74
90	0.21	0.36	1	44.4	0.00	11.81	0.00	8.84	2.16	0.39
91	0.21	0.39	1	42.2	0.00	10.92	0.00	8.94	1.47	0.95
92	0.21	0.42	1	40.4	0.00	10.13	0.00	8.98	0.69	1.74
93	0.21	0.45	1	38.7	0.00	9.47	0.00	9.30	0.76	1.37
94	0.21	0.48	1	37.3	0.00	8.87	0.00	9.53	0.74	1.23
95	0.24	0.36	1	44.6	0.00	11.81	0.00	9.02	1.17	1.23
96	0.24	0.39	1	42.4	0.00	10.92	0.00	9.20	0.70	1.50
97	0.24	0.42	1	40.7	0.00	10.13	0.00	10.08	1.36	0.13
76	0.12	0.51	2	31.9	0.00	10.48	0.00	6.39	0.16	3.38
77	0.12	0.54	2	30.9	0.00	9.85	0.00	7.07	0.36	2.81
78	0.12	0.57	2	30.0	0.00	9.30	0.00	7.65	0.53	2.29
79	0.15	0.45	2	34.5	0.00	12.05	0.00	5.72	0.00	3.54
80	0.15	0.48	2	33.3	0.00	11.21	0.00	6.40	0.00	3.26
81	0.15	0.51	2	32.1	0.00	10.49	0.00	6.99	0.00	2.99
82	0.15	0.54	2	31.1	0.00	9.86	0.00	7.52	0.00	2.76
83	0.15	0.57	2	30.1	0.00	9.31	0.00	7.95	0.00	2.54
84	0.18	0.39	2	37.9	0.00	14.19	0.00	4.92	0.00	3.36
85	0.18	0.42	2	36.3	0.00	13.03	0.00	5.81	0.00	3.06
86	0.18	0.45	2	34.7	0.00	12.07	0.00	6.50	0.00	2.80
87	0.18	0.48	2	33.5	0.00	11.23	0.00	7.15	0.00	2.56
88	0.18	0.51	2	32.2	0.00	10.52	0.00	7.65	0.00	2.34
89	0.18	0.54	2	31.2	0.00	9.88	0.00	8.14	0.00	2.15
90	0.21	0.36	2	40.1	0.00	15.59	0.00	4.78	0.00	2.88
91	0.21	0.39	2	38.1	0.00	14.22	0.00	5.84	0.00	2.47
92	0.21	0.42	2	36.5	0.00	13.05	0.00	6.65	0.00	2.26
93	0.21	0.45	2	34.9	0.00	12.09	0.00	7.29	0.00	2.06
94	0.21	0.48	2	33.7	0.00	11.24	0.00	7.89	0.00	1.87
95	0.24	0.36	2	40.2	0.00	15.64	0.00	5.75	0.00	1.93
96	0.24	0.39	2	38.3	0.00	14.26	0.00	6.75	0.00	1.60
97	0.24	0.42	2	36.7	0.00	13.07	0.00	7.55	0.00	1.45
76	0.12	0.51	3	19.6	0.00	12.91	0.00	1.96	0.00	3.07
77	0.12	0.54	3	19.0	0.00	12.06	0.00	2.97	0.00	2.71
78	0.12	0.57	3	18.4	0.00	11.33	0.00	3.84	0.00	2.38
79	0.15	0.45	3	21.2	0.00	15.05	0.00	0.36	0.00	3.02
80	0.15	0.48	3	20.5	0.00	13.91	0.00	1.66	0.00	2.63
81	0.15	0.51	3	19.7	0.00	12.93	0.00	2.75	0.00	2.28
82	0.15	0.54	3	19.1	0.00	12.09	0.00	3.72	0.00	1.97
83	0.15	0.57	3	18.5	0.00	11.35	0.00	4.54	0.00	1.70
84	0.18	0.39	3	23.3	0.00	17.04	0.00	0.00	1.86	0.00
85	0.18	0.42	3	22.3	0.00	16.44	0.00	0.00	0.28	2.06
86	0.18	0.45	3	21.3	0.00	15.09	0.00	1.28	0.00	2.10
87	0.18	0.48	3	20.6	0.00	13.94	0.00	2.52	0.00	1.78
88	0.18	0.51	3	19.8	0.00	12.97	0.00	3.54	0.00	1.48
89	0.18	0.54	3	19.2	0.00	12.12	0.00	4.44	0.00	1.23
90	0.21	0.36	3	24.6	0.00	17.51	0.00	0.00	1.44	0.00
91	0.21	0.39	3	23.4	0.00	17.95	0.00	0.00	1.18	0.00
92	0.21	0.42	3	22.4	0.00	16.49	0.00	0.84	0.00	1.49
93	0.21	0.45	3	21.5	0.00	15.13	0.00	2.20	0.00	1.18
94	0.21	0.48	3	20.7	0.00	13.97	0.00	3.37	0.00	0.93

95	0.24	0.36	3	24.7	0.00	18.46	0.00	0.00	0.71	0.00
96	0.24	0.39	3	23.5	0.00	18.20	0.00	0.24	0.00	0.71
97	0.24	0.42	3	22.6	0.00	16.53	0.00	1.86	0.00	0.47

MIXED FORAGE DIETS (660 KG COW):

98	0.12	0.51	1	40.5	3.13	3.13	3.12	9.94	2.28	0.32
99	0.12	0.54	1	39.6	3.01	3.01	3.00	10.22	2.35	0.00
100	0.12	0.57	1	38.8	2.89	2.89	2.89	10.30	2.32	0.00
101	0.15	0.45	1	42.7	3.39	3.39	3.39	9.88	2.41	0.26
102	0.15	0.48	1	41.6	3.25	3.25	3.25	9.64	1.49	1.39
103	0.15	0.51	1	40.7	3.12	3.12	3.12	10.13	1.75	0.71
104	0.15	0.54	1	39.8	3.00	3.00	3.00	10.42	1.77	0.43
105	0.15	0.57	1	39.0	2.89	2.89	2.89	10.67	1.84	0.16
106	0.18	0.39	1	45.2	3.72	3.72	3.71	9.79	2.53	0.22
107	0.18	0.42	1	44.0	3.55	3.55	3.54	10.11	2.44	0.04
108	0.18	0.45	1	42.8	3.39	3.39	3.39	9.67	1.20	1.65
109	0.18	0.48	1	41.8	3.25	3.25	3.25	10.18	1.50	0.92
110	0.18	0.51	1	40.9	3.12	3.12	3.12	10.75	1.93	0.01
111	0.18	0.54	1	40.0	3.00	3.00	3.00	10.79	1.55	0.34
112	0.21	0.36	1	46.7	3.90	3.90	3.90	9.81	2.18	0.55
113	0.21	0.39	1	45.3	3.72	3.72	3.71	9.51	1.12	1.87
114	0.21	0.42	1	44.1	3.55	3.55	3.54	9.89	1.19	1.47
115	0.21	0.45	1	43.0	3.39	3.39	3.39	10.25	1.26	1.10
116	0.21	0.48	1	42.0	3.25	3.25	3.25	10.76	1.58	0.34
117	0.24	0.36	1	46.9	3.90	3.90	3.90	10.26	1.88	0.47
118	0.24	0.39	1	45.5	3.72	3.72	3.71	10.02	0.99	1.57
119	0.24	0.42	1	44.3	3.55	3.55	3.54	10.42	1.11	1.10
98	0.12	0.51	2	36.5	3.95	3.95	3.94	8.08	1.70	0.98
99	0.12	0.54	2	35.7	3.78	3.78	3.78	8.56	1.79	0.64
100	0.12	0.57	2	35.0	3.63	3.63	3.62	9.03	1.89	0.30
101	0.15	0.45	2	38.5	4.33	4.33	4.32	7.12	0.59	2.49
102	0.15	0.48	2	37.5	4.13	4.13	4.13	7.67	0.74	2.07
103	0.15	0.51	2	36.7	3.95	3.95	3.94	8.24	0.89	1.65
104	0.15	0.54	2	35.9	3.78	3.78	3.78	8.72	1.02	1.28
105	0.15	0.57	2	35.2	3.63	3.63	3.62	9.17	1.15	0.93
106	0.18	0.39	2	40.8	4.80	4.80	4.79	6.12	0.00	3.39
107	0.18	0.42	2	39.7	4.55	4.55	4.55	6.85	0.00	3.04
108	0.18	0.45	2	38.6	4.34	4.34	4.33	7.41	0.00	2.77
109	0.18	0.48	2	37.7	4.13	4.13	4.13	7.89	0.00	2.61
110	0.18	0.51	2	36.9	3.95	3.95	3.94	8.39	0.08	2.34
111	0.18	0.54	2	36.1	3.78	3.78	3.78	8.87	0.25	1.93
112	0.21	0.36	2	42.1	5.08	5.08	5.08	6.08	0.00	3.05
113	0.21	0.39	2	40.9	4.81	4.81	4.80	6.82	0.00	2.70
114	0.21	0.42	2	39.8	4.56	4.56	4.56	7.51	0.00	2.38
115	0.21	0.45	2	38.8	4.34	4.34	4.33	8.11	0.00	2.12
116	0.21	0.48	2	37.9	4.14	4.14	4.13	8.57	0.00	1.99
117	0.24	0.36	2	42.3	5.09	5.09	5.08	6.85	0.00	2.32
118	0.24	0.39	2	41.0	4.82	4.82	4.81	7.56	0.00	2.01
119	0.24	0.42	2	40.0	4.57	4.57	4.56	8.22	0.00	1.73
98	0.12	0.51	3	22.5	4.88	4.88	4.88	1.58	0.00	3.26

99	0.12	0.54	3	22.0	4.66	4.66	4.65	2.38	0.02	2.96
100	0.12	0.57	3	21.5	4.46	4.46	4.45	3.23	0.21	2.41
101	0.15	0.45	3	23.7	5.42	5.42	5.41	0.47	0.00	3.08
102	0.15	0.48	3	23.1	5.14	5.14	5.13	1.42	0.00	2.80
103	0.15	0.51	3	22.6	4.89	4.89	4.89	2.30	0.00	2.53
104	0.15	0.54	3	22.1	4.67	4.67	4.66	3.06	0.00	2.31
105	0.15	0.57	3	21.6	4.46	4.46	4.46	3.77	0.00	2.09
106	0.18	0.39	3	25.1	6.09	6.09	6.08	0.00	1.54	0.46
107	0.18	0.42	3	24.4	5.74	5.74	5.73	0.24	0.00	2.56
108	0.18	0.45	3	23.7	5.43	5.43	5.42	1.24	0.00	2.29
109	0.18	0.48	3	23.2	5.15	5.15	5.14	2.18	0.00	2.04
110	0.18	0.51	3	22.7	4.90	4.90	4.89	3.02	0.00	1.82
111	0.18	0.54	3	22.2	4.68	4.68	4.67	3.76	0.00	1.62
112	0.21	0.36	3	25.9	6.31	6.31	6.30	0.00	1.43	0.00
113	0.21	0.39	3	25.1	6.10	6.10	6.09	0.00	0.11	1.79
114	0.21	0.42	3	24.5	5.75	5.75	5.74	1.08	0.00	1.72
115	0.21	0.45	3	23.8	5.44	5.44	5.43	2.05	0.00	1.48
116	0.21	0.48	3	23.3	5.16	5.16	5.15	2.94	0.00	1.29
117	0.24	0.36	3	26.0	6.52	6.52	6.51	0.00	0.60	0.33
118	0.24	0.39	3	25.2	6.12	6.12	6.11	0.84	0.00	1.05
119	0.24	0.42	3	24.6	5.77	5.77	5.76	1.91	0.00	0.86

Table C.2 Simulated annual milk production (AMP), annual supplemental feed costs (ASFC), annual corn silage use (ACS) and annual alfalfa use (AA) data used to determine alfalfa value.

CASE	CP	NDF	AMP (kg/y)	ASFC ($/y)	ACS (kg/y)	AA (kg/y)
MIXED FORAGE DIETS (600 kg cow):						
1	0.12	0.51	7939.3	274.0	1220.7	2441.4
2	0.12	0.54	7939.3	290.4	1160.0	2319.9
3	0.12	0.57	7872.7	302.1	1107.5	2215.0
4	0.15	0.45	7939.3	223.9	1368.0	2735.9
5	0.15	0.48	7939.3	240.1	1291.3	2582.6
6	0.15	0.51	7939.3	259.1	1223.5	2447.1
7	0.15	0.54	7939.3	276.2	1162.5	2325.0
8	0.15	0.57	7917.7	290.9	1108.1	2216.3
9	0.18	0.39	7939.3	185.0	1454.1	2908.2
10	0.18	0.42	7939.3	191.1	1450.1	2900.2
11	0.18	0.45	7939.3	204.9	1371.2	2742.4
12	0.18	0.48	7939.3	226.2	1294.7	2589.5
13	0.18	0.51	7939.3	245.2	1226.5	2453.0
14	0.18	0.54	7939.3	262.4	1165.1	2330.2
15	0.21	0.36	7939.3	153.4	1499.9	2999.9
16	0.21	0.39	7939.3	161.0	1490.3	2980.7
17	0.21	0.42	7939.3	169.6	1462.0	2924.1
18	0.21	0.45	7939.3	191.4	1375.2	2750.5
19	0.21	0.48	7939.3	213.2	1298.3	2596.5
20	0.24	0.36	7939.3	128.4	1536.5	3073.1
21	0.24	0.39	7939.3	135.5	1529.4	3058.9
22	0.24	0.42	7939.3	152.6	1466.3	2932.6
23	0.12	0.51	8232.2	289.7	1208.7	2417.3
24	0.12	0.54	8052.4	296.3	1155.6	2311.1
25	0.15	0.45	8638.2	257.2	1335.1	2670.2
26	0.15	0.48	8480.1	270.4	1267.9	2535.9
27	0.15	0.51	8277.1	277.9	1209.7	2419.4
28	0.15	0.54	8097.4	285.6	1156.5	2312.9
29	0.18	0.39	8638.2	211.2	1474.9	2949.8
30	0.18	0.42	8638.2	221.8	1423.0	2846.0
31	0.18	0.45	8638.2	242.4	1338.8	2677.6
32	0.18	0.48	8525.0	259.6	1269.4	2538.7
33	0.18	0.51	8323.7	267.5	1210.8	2421.6
34	0.18	0.54	8120.7	272.5	1158.0	2316.1
35	0.21	0.36	8638.2	179.6	1519.2	3038.3
36	0.21	0.39	8638.2	186.5	1512.8	3025.5
37	0.21	0.42	8638.2	204.7	1427.0	2854.0
38	0.21	0.45	8638.2	228.4	1342.6	2685.2
39	0.21	0.48	8548.3	246.8	1271.6	2543.2
40	0.24	0.36	8638.2	153.9	1557.4	3114.8
41	0.24	0.39	8638.2	163.4	1527.9	3055.9
42	0.24	0.42	8638.2	190.5	1431.5	2862.9
43	0.15	0.45	8706.4	262.5	1332.1	2664.3

44	0.18	0.39	9224.8	237.2	1488.2	2976.5
45	0.18	0.42	8976.8	239.6	1406.1	2812.2
46	0.18	0.45	8728.0	248.1	1334.7	2669.4
47	0.21	0.36	9541.0	217.7	1544.9	3089.7
48	0.21	0.39	9269.7	218.0	1489.7	2979.4
49	0.21	0.42	9021.8	228.5	1408.3	2816.5
50	0.21	0.45	8773.0	237.4	1336.5	2673.0
51	0.24	0.36	9585.9	192.7	1584.7	3169.3
52	0.24	0.39	9314.6	203.8	1492.0	2984.0
53	0.24	0.42	9045.1	214.0	1411.2	2822.5
ALFALFA HAY BASED DIETS (600 kg cow)						
54	0.12	0.51	8029.1	282.7	0.0	3536.7
55	0.12	0.54	7782.9	292.9	0.0	3314.0
56	0.12	0.57	7534.1	301.8	0.0	3120.4
57	0.15	0.45	8728.0	232.4	0.0	4096.9
58	0.15	0.48	8413.5	248.4	0.0	3798.1
59	0.15	0.51	8097.4	259.9	0.0	3545.3
60	0.15	0.54	7849.4	271.5	0.0	3321.1
61	0.15	0.57	7600.6	280.3	0.0	3126.2
62	0.18	0.39	9585.9	168.6	0.0	4883.4
63	0.18	0.42	9179.9	192.4	0.0	4458.7
64	0.18	0.45	8796.3	212.6	0.0	4106.9
65	0.18	0.48	8480.1	231.6	0.0	3804.5
66	0.18	0.51	8165.6	245.7	0.0	3548.3
67	0.18	0.54	7917.7	259.4	0.0	3321.9
68	0.21	0.36	10172.5	140.1	0.0	5260.1
69	0.21	0.39	9654.1	157.8	0.0	4885.6
70	0.21	0.42	9248.1	185.5	0.0	4458.1
71	0.21	0.45	8865.4	206.9	0.0	4104.9
72	0.21	0.48	8548.3	226.7	0.0	3802.1
73	0.24	0.36	10240.7	135.2	0.0	5272.2
74	0.24	0.39	9744.0	159.7	0.0	4874.0
75	0.24	0.42	9314.6	185.8	0.0	4450.9
ALFALFA SILAGE BASED DIETS (600 kg cow):						
76	0.12	0.51	7984.2	298.1	0.0	3525.8
77	0.12	0.54	7735.4	305.9	0.0	3304.8
78	0.12	0.57	7487.5	311.7	0.0	3112.6
79	0.15	0.45	8638.2	262.3	0.0	4079.9
80	0.15	0.48	8323.7	274.5	0.0	3783.9
81	0.15	0.51	8029.1	285.4	0.0	3531.2
82	0.15	0.54	7782.9	293.9	0.0	3308.8
83	0.15	0.57	7534.1	300.3	0.0	3115.8
84	0.18	0.39	9472.7	235.7	0.0	4677.0
85	0.18	0.42	9066.7	233.4	0.0	4434.2
86	0.18	0.45	8683.1	247.2	0.0	4088.3
87	0.18	0.48	8368.6	260.8	0.0	3790.8
88	0.18	0.51	8052.4	269.9	0.0	3538.8
89	0.18	0.54	7804.5	279.6	0.0	3315.4
90	0.21	0.36	10014.4	212.4	0.0	4926.0
91	0.21	0.39	9517.6	203.1	0.0	4834.0
92	0.21	0.42	9113.3	215.3	0.0	4443.9

93	0.21	0.45	8728.0	232.0	0.0	4096.8
94	0.21	0.48	8413.5	247.2	0.0	3797.7
95	0.24	0.36	10059.3	176.8	0.0	5088.4
96	0.24	0.39	9562.6	175.5	0.0	4878.5
97	0.24	0.42	9179.9	201.8	0.0	4452.2

MIXED FORAGE DIETS (660 kg cow):

98	0.12	0.51	9143.3	314.3	1330.1	2660.3
99	0.12	0.54	8931.9	321.0	1272.2	2544.5
100	0.12	0.57	8751.4	329.2	1218.6	2437.3
101	0.15	0.45	9630.8	283.3	1467.4	2934.8
102	0.15	0.48	9382.9	290.6	1396.6	2793.1
103	0.15	0.51	9179.9	300.1	1331.7	2663.5
104	0.15	0.54	8976.8	307.6	1273.3	2546.6
105	0.15	0.57	8796.3	315.2	1219.5	2439.1
106	0.18	0.39	10195.8	254.9	1638.9	3277.9
107	0.18	0.42	9924.5	259.0	1548.9	3097.7
108	0.18	0.45	9654.1	266.6	1470.1	2940.2
109	0.18	0.48	9427.8	277.5	1398.2	2796.3
110	0.18	0.51	9224.8	287.8	1333.1	2666.2
111	0.18	0.54	9021.8	295.3	1274.4	2548.8
112	0.21	0.36	10533.6	232.3	1709.5	3418.9
113	0.21	0.39	10217.4	230.2	1641.7	3283.3
114	0.21	0.42	9956.2	243.4	1551.7	3103.5
115	0.21	0.45	9699.1	254.6	1472.3	2944.6
116	0.21	0.48	9472.7	266.4	1400.1	2800.1
117	0.24	0.36	10578.5	205.4	1745.4	3490.8
118	0.24	0.39	10262.3	215.7	1644.6	3289.2
119	0.24	0.42	9992.8	230.1	1554.7	3109.4

APPENDIX D

DAFOSYM farm and machinery input files used in the simulation experiments.

FILE: FARM.ME
BRIEF DESCRIPTION: base medium sized farm (see Chapter 7)

```
ELANWTHR                                        ELANCORN
D:\DENNIS\SIMUL\MACHHMEC.SM2                      26
    3      1      2      2      2      1
    1      1      1      0      1      1      1      1      1      2
    4      2      5      0      2      5      4      4      5
    2      3      3      3
        91        335       1953       1954
         0          1          1          0
    175.00     175.00      70.00       1.00       1.00
         4          1         95
         2          1          1          2
         0          2          2          0
         2          1          1          2
        65         20         20         65
        41         41         41         41
        22         21         21          0
    143.00     183.00     228.00     288.00
         0        140
     15.00      20.00      15.00
  5   1   4
      8.00       8.00       4.00
      0.08       0.08
      8.00       0.31       0.32       0.08
    260.00     130.00     250.00     190.00
     20.00       0.00       1.00
     10.00       0.10      55.00      84.00     100.00
      0.25     220.00     154.00     106.00      69.00
    100.00      85.00      65.00      48.00
 0 0 0
     50.00 0
    20      0      0      0    150    150    170    100      0
  1.00   0.00   1.00   0.00   1.86   1.86   0.25   0.00   0.00
  0.33   0.33   0.33   0.33   0.41  14.00   0.80  14.00   1.00
  0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
  0.00   1.00   0.22   0.00   1.00   1.00   1.00   0.00   0.00
     50.00 0
    20      0     40     40    170    170    170    100      0
  1.00   0.00   1.00   0.00   0.25   0.25   0.25   0.00   0.00
  0.75   0.75   0.30   0.30   0.41  14.00   0.80  14.00   1.00
  0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
  0.00   1.00   0.21   0.00   1.00   1.00   1.00   0.00   0.00
     50.00 0
    20      0     40     40    170    170    170    100      0
  1.00   0.00   1.00   0.00   0.25   0.25   0.25   0.00   0.00
  0.75   0.75   0.30   0.30   0.41  14.00   0.80  14.00   1.00
  0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
  0.00   1.00   0.21   0.00   1.00   1.00   1.00   0.00   0.00
     50.00 0
    20      0      0      0    150    150    170    100      0
```

```
 1.00  0.00  1.00  0.00  1.86  1.86  0.25  0.00  0.00
 0.33  0.33  0.33  0.33  0.41 14.00  0.80 14.00  1.00
 0.00  0.00  0.00  1.00  0.00  0.00  0.00  0.00  0.00
 0.00  1.00  0.00  0.00  1.00  1.00  1.00  0.00  0.00
  4    1    6    1     0.00  17000.00    300.00
0 0 0 1
   100.00  13490.00      26.00     622.00      30.00      36.00
     0.00      0.00       0.00       0.00       0.00       0.00       0.10
0.22       0.10
     0.00      0.16
```

Operation Information:

1	281	4	1.00	4.80	4.60	0.00	0.00
190	290	5	1.00	5.50	1.50	0.00	1.00
190	300	5	0.05	1.00	0.00	0.00	0.00
190	250	2	2.00	15.00	3.00	0.00	0.05
190	250	2	2.00	15.00	3.00	0.00	0.05
190	240	4	1.00	22.00	0.00	0.00	0.00
20	45	4	1.00	8.00	3.70	0.00	0.00
40	70	2	1.00	7.00	2.70	0.00	0.00
170	101	5	1.00	6.00	3.70	30.00	1.00
170	170	5	0.05	1.00	0.00	0.00	0.00
170	180	2	2.00	8.00	3.00	2.00	0.10
170	180	2	2.00	8.00	3.00	2.00	0.10
170	230	20	1.00	0.00	0.00	0.00	0.00
150	131	5	1.00	5.00	3.70	0.00	1.00
150	150	5	0.05	1.00	0.00	0.00	0.00
150	250	2	2.00	15.00	3.00	0.00	0.05
150	250	2	2.00	15.00	3.00	0.00	0.05
150	240	4	1.00	22.00	0.00	0.00	0.00
140	131	5	1.00	4.00	1.50	0.00	0.40
140	141	5	0.05	1.00	0.00	0.00	0.00
140	250	2	2.00	15.00	3.00	0.00	0.05
140	250	2	2.00	15.00	3.00	0.00	0.05
140	240	4	1.00	22.00	0.00	0.00	0.00
100	131	5	1.00	6.00	3.70	0.00	0.00
100	150	5	1.00	6.00	3.70	0.00	0.00

FILE: FARM.LG
BRIEF DESCRIPTION: 70 ha alfalfa, 70 ha corn, 150 cows, larger storage structures and machinery, identical harvest information

```
ELANWTHR                                        ELANCORN
D:\DENNIS\MACHHMEC.SM2                            26
     3      1      2      2      2      1
     1      1      1      0      1      1      1      1      1      2
     4      2      4      0      2      6      4      4      6
     2      3      3      3
        91        335       1953       1978
         0          1          1          0
    175.00     175.00      70.00       1.00       1.00
         4          1         95
         2          1          1          2
         0          2          2          0
         2          1          1          2
        65         20         20         65
        41         41         41         41
        22         21         21          0
    143.00     183.00     228.00     288.00
         0        140
     25.00      25.00      25.00
   7   1   5
      8.00       8.00       4.00
      0.08       0.08
      8.00       0.31       0.32       0.08
    260.00     130.00     250.00     190.00
     20.00       0.00       1.00
     10.00       0.10      55.00      84.00     100.00
      0.25     220.00     154.00     106.00      69.00
    100.00      85.00      65.00      48.00
 0 0 0
    75.00 0
    20      0      0      0    150    150    170    100      0
  1.00   0.00   1.00   0.00   1.86   1.86   0.25   0.00   0.00
  0.33   0.33   0.33   0.33   0.41  14.00   0.80  14.00   1.00
  0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
  0.00   1.00   0.22   0.00   1.00   1.00   1.00   0.00   0.00
    75.00 0
    20      0     40     40    170    170    170    100      0
  1.00   0.00   1.00   0.00   0.25   0.25   0.25   0.00   0.00
  0.75   0.75   0.30   0.30   0.41  14.00   0.80  14.00   1.00
  0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
  0.00   1.00   0.21   0.00   1.00   1.00   1.00   0.00   0.00
    75.00 0
    20      0     40     40    170    170    170    100      0
  1.00   0.00   1.00   0.00   0.25   0.25   0.25   0.00   0.00
  0.75   0.75   0.30   0.30   0.41  14.00   0.80  14.00   1.00
  0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
  0.00   1.00   0.21   0.00   1.00   1.00   1.00   0.00   0.00
    75.00 0
```

FILE: FARM.LG
BRIEF DESCRIPTION: 70 ha alfalfa, 70 ha corn, 150 cows, larger storage structures and machinery, identical harvest information

```
ELANWTHR                                   ELANCORN
D:\DENNIS\MACHHMEC.SM2                       26
    3     1     2     2     2     1
    1     1     1     0     1     1     1     1     1     2
    4     2     4     0     2     6     4     4     6
    2     3     3     3
       91       335      1953      1978
        0         1         1         0
   175.00    175.00     70.00      1.00      1.00
        4         1        95
        2         1         1         2
        0         2         2         0
        2         1         1         2
       65        20        20        65
       41        41        41        41
       22        21        21         0
   143.00    183.00    228.00    288.00
        0       140
    25.00     25.00     25.00
  7   1   5
     8.00      8.00      4.00
     0.08      0.08
     8.00      0.31      0.32      0.08
   260.00    130.00    250.00    190.00
    20.00      0.00      1.00
    10.00      0.10     55.00     84.00    100.00
     0.25    220.00    154.00    106.00     69.00
   100.00     85.00     65.00     48.00
 0 0 0
    75.00 0
   20     0     0     0   150   150   170   100     0
 1.00  0.00  1.00  0.00  1.86  1.86  0.25  0.00  0.00
 0.33  0.33  0.33  0.33  0.41 14.00  0.80 14.00  1.00
 0.00  0.00  0.00  1.00  0.00  0.00  0.00  0.00  0.00
 0.00  1.00  0.22  0.00  1.00  1.00  1.00  0.00  0.00
    75.00 0
   20     0    40    40   170   170   170   100     0
 1.00  0.00  1.00  0.00  0.25  0.25  0.25  0.00  0.00
 0.75  0.75  0.30  0.30  0.41 14.00  0.80 14.00  1.00
 0.00  0.00  0.00  1.00  0.00  0.00  0.00  0.00  0.00
 0.00  1.00  0.21  0.00  1.00  1.00  1.00  0.00  0.00
    75.00 0
   20     0    40    40   170   170   170   100     0
 1.00  0.00  1.00  0.00  0.25  0.25  0.25  0.00  0.00
 0.75  0.75  0.30  0.30  0.41 14.00  0.80 14.00  1.00
 0.00  0.00  0.00  1.00  0.00  0.00  0.00  0.00  0.00
 0.00  1.00  0.21  0.00  1.00  1.00  1.00  0.00  0.00
    75.00 0
```

20	0	0	0	150	150	170	100	0
1.00	0.00	1.00	0.00	1.86	1.86	0.25	0.00	0.00
0.33	0.33	0.33	0.33	0.41	14.00	0.80	14.00	1.00
0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00

6 1 4 4 0.00 22000.00 400.00

0 0 0 0

150.00 13490.00 26.00 622.00 45.00 54.00

0.00 0.00 0.00 0.00 0.00 0.00 0.10

0.22 0.10

0.00 0.16

Operation Information:

1	281	4	1.00	4.80	4.60	0.00	0.00
190	290	6	1.00	5.50	1.50	0.00	1.00
190	300	6	0.05	1.00	0.00	0.00	0.00
190	250	2	2.00	15.00	3.00	0.00	0.05
190	250	2	2.00	15.00	3.00	0.00	0.05
190	240	4	1.00	22.00	0.00	0.00	0.00
20	45	4	1.00	8.00	3.70	0.00	0.00
40	70	2	1.00	7.00	2.70	0.00	0.00
170	101	4	1.00	6.00	3.70	30.00	1.00
170	170	4	0.05	1.00	0.00	0.00	0.00
170	180	2	2.00	8.00	3.00	2.00	0.10
170	180	2	2.00	8.00	3.00	2.00	0.10
170	230	20	1.00	0.00	0.00	0.00	0.00
150	131	6	1.00	5.00	3.70	0.00	1.00
150	150	6	0.05	1.00	0.00	0.00	0.00
150	250	2	2.00	15.00	3.00	0.00	0.05
150	250	2	2.00	15.00	3.00	0.00	0.05
150	240	4	1.00	22.00	0.00	0.00	0.00
140	131	6	1.00	4.00	1.50	0.00	0.40
140	141	6	0.05	1.00	0.00	0.00	0.00
140	250	2	2.00	15.00	3.00	0.00	0.05
140	250	2	2.00	15.00	3.00	0.00	0.05
140	240	4	1.00	22.00	0.00	0.00	0.00
100	131	6	1.00	6.00	3.70	0.00	0.00
100	150	6	1.00	6.00	3.70	0.00	0.00

FILE: FARM.SM
BRIEF DESCRIPTION: 30 ha alfalfa, 30 ha corn, 60 cows, smaller storage structures and machinery, identical harvest information

```
ELANWTHR                                        ELANCORN
D:\DENNIS\MACHHMEC.SM2                            26
     2      1      1      1      1      1
     1      1      1      0      1      1      1      1      1      1
     2      2      3      0      2      4      3      3      4
     1      1      1      1
        91        335        1953       1978
         0          1           1          0
    175.00     175.00       70.00       1.00       1.00
         4          1          95
         2          1           1          2
         0          2           2          0
         2          1           1          2
        65         20          20         65
        41         41          41         41
        22         21          21          0
    143.00     183.00      228.00     288.00
         0        140
     10.00      10.00       10.00
   4   1   2
      8.00       8.00        4.00
      0.08       0.08
      8.00       0.31        0.32       0.08
    260.00     130.00      250.00     190.00
     20.00       0.00        1.00
     10.00       0.10       55.00      84.00     100.00
      0.25     220.00      154.00     106.00      69.00
    100.00      85.00       65.00      48.00
 0 0 0
    30.00 0
   20      0      0      0    150    150    170    100      0
 1.00   0.00   1.00   0.00   1.86   1.86   0.25   0.00   0.00
 0.33   0.33   0.33   0.33   0.41  14.00   0.80  14.00   1.00
 0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
 0.00   1.00   0.22   0.00   1.00   1.00   1.00   0.00   0.00
    30.00 0
   20      0     40     40    170    170    170    100      0
 1.00   0.00   1.00   0.00   0.25   0.25   0.25   0.00   0.00
 0.75   0.75   0.30   0.30   0.41  14.00   0.80  14.00   1.00
 0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
 0.00   1.00   0.21   0.00   1.00   1.00   1.00   0.00   0.00
    30.00 0
   20      0     40     40    170    170    170    100      0
 1.00   0.00   1.00   0.00   0.25   0.25   0.25   0.00   0.00
 0.75   0.75   0.30   0.30   0.41  14.00   0.80  14.00   1.00
 0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
 0.00   1.00   0.21   0.00   1.00   1.00   1.00   0.00   0.00
    30.00 0
```

20	0	0	0	150	150	170	100	0
1.00	0.00	1.00	0.00	1.86	1.86	0.25	0.00	0.00
0.33	0.33	0.33	0.33	0.41	14.00	0.80	14.00	1.00
0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00

```
  5    1    1    1      0.00  11000.00     200.00
 0 0 0 0
      60.00  13490.00     26.00     622.00      18.00      22.00
       0.00      0.00      0.00       0.00       0.00       0.00       0.10
0.22       0.10
       0.00      0.16
```

Operation Information:

1	280	3	1.00	4.80	3.00	0.00	0.00
190	290	4	1.00	5.50	1.50	0.00	1.00
190	300	4	0.05	1.00	0.00	0.00	0.00
190	250	2	1.00	15.00	2.00	0.00	0.05
190	250	2	1.00	15.00	2.00	0.00	0.05
190	240	3	1.00	22.00	0.00	0.00	0.00
20	40	2	1.00	8.00	2.70	0.00	0.00
40	70	2	1.00	7.00	2.70	0.00	0.00
170	100	3	1.00	6.00	2.70	25.00	1.00
170	170	3	0.05	1.00	0.00	0.00	0.00
170	180	2	1.00	8.00	2.00	2.00	0.10
170	180	2	1.00	8.00	2.00	2.00	0.10
170	230	20	1.00	0.00	0.00	0.00	0.00
150	130	4	1.00	5.00	2.70	0.00	1.00
150	150	4	0.05	1.00	0.00	0.00	0.00
150	250	2	1.00	15.00	2.00	0.00	0.05
150	250	2	1.00	15.00	2.00	0.00	0.05
150	240	3	1.00	22.00	0.00	0.00	0.00
140	130	4	1.00	4.00	0.80	0.00	0.40
140	140	4	0.05	1.00	0.00	0.00	0.00
140	250	2	1.00	15.00	2.00	0.00	0.05
140	250	2	1.00	15.00	2.00	0.00	0.05
140	240	3	1.00	22.00	0.00	0.00	0.00
100	130	4	1.00	6.00	2.70	0.00	0.00
100	150	4	1.00	6.00	2.70	0.00	0.00

FILE: FARM.DRY
BRIEF DESCRIPTION: medium sized farm with hay harvest at 15% moisture, silage harvest at 60% moisture (5 points drier than in FARM.ME)

```
ELANWTHR                                        ELANCORN
D:\DENNIS\SIMUL\MACHHMEC.SM2                      26
     3      1      2      2      2      1
     1      1      1      0      1      1      1      1      1      2
     4      2      5      0      2      5      4      4      5
     2      3      3      3
        91        335       1953       1978
         0          1          1          0
    175.00     175.00      70.00       1.00       1.00
         4          1         95
         2          1          1          2
         0          2          2          0
         2          1          1          2
        60         15         15         60
        41         41         41         41
        22         21         21          0
    143.00     183.00     228.00     288.00
         0        140
     15.00      20.00      15.00
   5   1   4
      8.00       8.00       4.00
      0.08       0.08
      8.00       0.31       0.32       0.08
    260.00     130.00     250.00     190.00
     20.00       0.00       1.00
     10.00       0.10      55.00      84.00     100.00
      0.25     220.00     154.00     106.00      69.00
    100.00      85.00      65.00      48.00
 0 0 0
     50.00 0
    20      0      0      0    150    150    170    100      0
  1.00   0.00   1.00   0.00   1.50   1.50   0.25   0.00   0.00
  0.33   0.33   0.33   0.33   0.41  14.00   0.80  14.00   1.00
  0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
  0.00   1.00   0.22   0.00   1.00   1.00   1.00   0.00   0.00
     50.00 0
    20      0     40     40    170    170    170    100      0
  1.00   0.00   1.00   0.00   0.18   0.18   0.25   0.00   0.00
  0.75   0.75   0.30   0.30   0.41  14.00   0.80  14.00   1.00
  0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
  0.00   1.00   0.21   0.00   1.00   1.00   1.00   0.00   0.00
     50.00 0
    20      0     40     40    170    170    170    100      0
  1.00   0.00   1.00   0.00   0.18   0.18   0.25   0.00   0.00
  0.75   0.75   0.30   0.30   0.41  14.00   0.80  14.00   1.00
  0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
  0.00   1.00   0.21   0.00   1.00   1.00   1.00   0.00   0.00
     50.00 0
```

```
  20      0      0      0    150    150    170    100      0
 1.00   0.00   1.00   0.00   1.50   1.50   0.25   0.00   0.00
 0.33   0.33   0.33   0.33   0.41  14.00   0.80  14.00   1.00
 0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
 0.00   1.00   0.00   0.00   1.00   1.00   1.00   0.00   0.00
  4    1    6    1      0.00   17000.00     300.00
0 0 0 0
   100.00  13490.00      26.00     622.00      30.00      36.00
     0.00      0.00       0.00      0.00       0.00       0.00       0.10
0.22      0.10
     0.00      0.16
```

Operation Information:

1	281	4	1.00	4.80	4.60	0.00	0.00
190	290	5	1.00	5.50	1.50	0.00	1.00
190	300	5	0.05	1.00	0.00	0.00	0.00
190	250	2	2.00	15.00	3.00	0.00	0.05
190	250	2	2.00	15.00	3.00	0.00	0.05
190	240	4	1.00	22.00	0.00	0.00	0.00
20	45	4	1.00	8.00	3.70	0.00	0.00
40	70	2	1.00	7.00	2.70	0.00	0.00
170	101	5	1.00	6.00	3.70	30.00	1.00
170	170	5	0.05	1.00	0.00	0.00	0.00
170	180	2	2.00	8.00	3.00	2.00	0.10
170	180	2	2.00	8.00	3.00	2.00	0.10
170	230	20	1.00	0.00	0.00	0.00	0.00
150	131	5	1.00	5.00	3.70	0.00	1.00
150	150	5	0.05	1.00	0.00	0.00	0.00
150	250	2	2.00	15.00	3.00	0.00	0.05
150	250	2	2.00	15.00	3.00	0.00	0.05
150	240	4	1.00	22.00	0.00	0.00	0.00
140	131	5	1.00	4.00	1.50	0.00	0.40
140	141	5	0.05	1.00	0.00	0.00	0.00
140	250	2	2.00	15.00	3.00	0.00	0.05
140	250	2	2.00	15.00	3.00	0.00	0.05
140	240	4	1.00	22.00	0.00	0.00	0.00
100	131	5	1.00	6.00	3.70	0.00	0.00
100	150	5	1.00	6.00	3.70	0.00	0.00

FILE: FARM.RND
BRIEF DESCRIPTION: medium sized farm with round baler in place of rectangular baler. Bales stored inside.

```
ELANWTHR                                ELANCORN
D:\DENNIS\SIMUL\MACHHMEC.SM2              26
     3     1     8     2     2     1
     1     1     1     1     0     1     1     1     1     2
     4     2     5     4     2     5     4     4     5
     4     3     3     3
        91        335       1953       1978
         0          1          1          0
    175.00     175.00      70.00       2.00       1.00
         4          1         95
         2          1          1          2
         0          2          2          0
         2          1          1          2
        65         20         20         65
        41         41         41         41
        22         21         21          0
    143.00     183.00     228.00     288.00
         0        140
     15.00      20.00      15.00
   5   1   4
      8.00       8.00       4.00
      0.08       0.08
      8.00       0.31       0.32       0.08
    260.00     130.00     250.00     190.00
     20.00       0.00       1.00
     10.00       0.10      55.00      84.00     100.00
      0.25     220.00     154.00     106.00      69.00
    100.00      85.00      65.00      48.00
 0 0 0
    50.00 0
    20     0     0     0   150   150    80   100   130
  1.00  0.00  1.00  0.00  1.86  1.86  0.25  0.00  0.00
  0.33  0.33  0.33  0.33  0.41 14.00  0.80 14.00  1.00
  0.00  0.00  0.00  1.00  1.00  1.00  1.00  1.00  0.00
  0.00  1.00  0.22  0.00  2.00  2.00  1.00  0.00  0.00
    50.00 0
    20     0    40    40    80    80    80   100   130
  1.00  0.00  1.00  0.00  0.25  0.25  0.25  0.00  0.00
  0.75  0.75  0.30  0.30  0.41 14.00  0.80 14.00  1.00
  0.00  0.00  0.00  1.00  1.00  1.00  1.00  1.00  0.00
  0.00  1.00  0.21  0.00  2.00  2.00  1.00  0.00  0.00
    50.00 0
    20     0    40    40    80    80    80   100   130
  1.00  0.00  1.00  0.00  0.25  0.25  0.25  0.00  0.00
  0.75  0.75  0.30  0.30  0.41 14.00  0.80 14.00  1.00
  0.00  0.00  0.00  1.00  1.00  1.00  1.00  1.00  0.00
  0.00  1.00  0.21  0.00  2.00  2.00  1.00  0.00  0.00
    50.00 0
```

```
  20      0      0      0    150    150     80    100    130
1.00   0.00   1.00   0.00   1.86   1.86   0.25   0.00   0.00
0.33   0.33   0.33   0.33   0.41  14.00   0.80  14.00   1.00
0.00   0.00   0.00   1.00   1.00   1.00   1.00   1.00   0.00
0.00   1.00   0.00   0.00   2.00   2.00   1.00   0.00   0.00
 4    1    6    1      0.00  17000.00     300.00
0 0 0 0
    100.00  13490.00      26.00     622.00      30.00      36.00
      0.00      0.00       0.00       0.00       0.00       0.00       0.10
0.22      0.10
      0.00      0.16
```

Operation Information:

1	281	4	1.00	4.80	4.60	0.00	0.00
190	290	5	1.00	5.50	1.50	0.00	1.00
190	300	5	0.05	1.00	0.00	0.00	0.00
190	250	2	2.00	15.00	3.00	0.00	0.05
190	250	2	2.00	15.00	3.00	0.00	0.05
190	240	4	1.00	22.00	0.00	0.00	0.00
20	45	4	1.00	8.00	3.70	0.00	0.00
40	70	2	1.00	7.00	2.70	0.00	0.00
80	111	5	1.00	6.00	3.70	600.00	1.00
130	200	4	1.00	6.00	0.00	600.00	1.00
130	210	2	1.00	8.00	0.00	600.00	1.00
150	131	5	1.00	5.00	3.70	0.00	1.00
150	150	5	0.05	1.00	0.00	0.00	0.00
150	250	2	2.00	15.00	3.00	0.00	0.05
150	250	2	2.00	15.00	3.00	0.00	0.05
150	240	4	1.00	22.00	0.00	0.00	0.00
140	131	5	1.00	4.00	1.50	0.00	0.40
140	141	5	0.05	1.00	0.00	0.00	0.00
140	250	2	2.00	15.00	3.00	0.00	0.05
140	250	2	2.00	15.00	3.00	0.00	0.05
140	240	4	1.00	22.00	0.00	0.00	0.00
100	131	5	1.00	6.00	3.70	0.00	0.00
100	150	5	1.00	6.00	3.70	0.00	0.00

FILE: FARM2.RND
BRIEF DESCRIPTION: medium sized farm with round baler in place of rectangular baler. Bales stored outside.

```
ELANWTHR                                ELANCORN
D:\DENNIS\SIMUL\MACHHMEC.SM               26
     3     1     8     2     2     1
     1     1     1     1     0     1     1     1     1     2
     4     2     5     4     2     5     4     4     5
     4     3     3     3
        91       335      1953      1978
         0         1         1         0
    175.00    175.00     70.00      2.00      1.00
         4         1        95
         2         1         1         2
         0         2         2         0
         2         1         1         2
        65        20        20        65
        41        41        41        41
        22        21        21         0
    143.00    183.00    228.00    288.00
         0       140
     15.00     20.00     15.00
   5   1   4
      8.00      8.00      4.00
      0.08      0.08
      8.00      0.31      0.32      0.08
    260.00    130.00    250.00    190.00
     20.00      0.00      1.00
     10.00      0.10     55.00     84.00    100.00
      0.25    220.00    154.00    106.00     69.00
    100.00     85.00     65.00     48.00
 0 0 0
    50.00 0
    20     0     0     0   150   150    80   100   130
  1.00  0.00  1.00  0.00  1.86  1.86  0.25  0.00  0.00
  0.33  0.33  0.33  0.33  0.41 14.00  0.80 14.00  1.00
  0.00  0.00  0.00  1.00  1.00  1.00  1.00  1.00  0.00
  0.00  1.00  0.22  0.00  2.00  2.00  1.00  0.00  0.00
    50.00 0
    20     0    40    40    80    80    80   100   130
  1.00  0.00  1.00  0.00  0.25  0.25  0.25  0.00  0.00
  0.75  0.75  0.30  0.30  0.41 14.00  0.80 14.00  1.00
  0.00  0.00  0.00  1.00  1.00  1.00  1.00  1.00  0.00
  0.00  1.00  0.21  0.00  2.00  2.00  1.00  0.00  0.00
    50.00 0
    20     0    40    40    80    80    80   100   130
  1.00  0.00  1.00  0.00  0.25  0.25  0.25  0.00  0.00
  0.75  0.75  0.30  0.30  0.41 14.00  0.80 14.00  1.00
  0.00  0.00  0.00  1.00  1.00  1.00  1.00  1.00  0.00
  0.00  1.00  0.21  0.00  2.00  2.00  1.00  0.00  0.00
    50.00 0
```

20	0	0	0	150	150	80	100	130
1.00	0.00	1.00	0.00	1.86	1.86	0.25	0.00	0.00
0.33	0.33	0.33	0.33	0.41	14.00	0.80	14.00	1.00
0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00
0.00	1.00	0.00	0.00	2.00	2.00	1.00	0.00	0.00

4 1 6 1 0.00 0.00 0.00
0 0 0 0
100.00 13490.00 26.00 622.00 30.00 36.00
0.00 0.00 0.00 0.00 0.00 0.00 0.10
0.22 0.10
0.00 0.16

Operation Information:

1	281	4	1.00	4.80	4.60	0.00	0.00
190	290	5	1.00	5.50	1.50	0.00	1.00
190	300	5	0.05	1.00	0.00	0.00	0.00
190	250	2	2.00	15.00	3.00	0.00	0.05
190	250	2	2.00	15.00	3.00	0.00	0.05
190	240	4	1.00	22.00	0.00	0.00	0.00
20	45	4	1.00	8.00	3.70	0.00	0.00
40	70	2	1.00	7.00	2.70	0.00	0.00
80	111	5	1.00	6.00	3.70	600.00	1.00
130	200	4	1.00	6.00	0.00	600.00	1.00
130	210	2	1.00	8.00	0.00	600.00	1.00
150	131	5	1.00	5.00	3.70	0.00	1.00
150	150	5	0.05	1.00	0.00	0.00	0.00
150	250	2	2.00	15.00	3.00	0.00	0.05
150	250	2	2.00	15.00	3.00	0.00	0.05
150	240	4	1.00	22.00	0.00	0.00	0.00
140	131	5	1.00	4.00	1.50	0.00	0.40
140	141	5	0.05	1.00	0.00	0.00	0.00
140	250	2	2.00	15.00	3.00	0.00	0.05
140	250	2	2.00	15.00	3.00	0.00	0.05
140	240	4	1.00	22.00	0.00	0.00	0.00
100	131	5	1.00	6.00	3.70	0.00	0.00
100	150	5	1.00	6.00	3.70	0.00	0.00

FILE: FARM.SEA
BRIEF DESCRIPTION: medium sized farm with oxygen limiting alfalfa silos in place of stave silos

```
ELANWTHR                                          ELANCORN
D:\DENNIS\SIMUL\MACHHMEC.SM2                        26
    3       1       2       2       2       1
    1       1       1       0       1       1       1       1       1       2
    4       2       5       0       2       5       4       4       5
    2       3       3       3
         91        335       1953       1978
          0          1          1          0
     175.00     175.00      70.00       1.00       1.00
          4          1         95
          2          1          1          2
          0          2          2          0
          2          1          1          2
         60         20         20         60
         41         41         41         41
         22         21         21          0
     143.00     183.00     228.00     288.00
          0        140
      15.00      20.00      15.00
   5    1    4
       8.00       8.00       4.00
       0.08       0.08
       8.00       0.31       0.32       0.08
     260.00     130.00     250.00     190.00
      20.00       0.00       1.00
      10.00       0.10      55.00      84.00     100.00
       0.25     220.00     154.00     106.00      69.00
     100.00      85.00      65.00      48.00
 0 0 0
    50.00 0
   20      0      0      0    150    150    170    100      0
 1.00   0.00   1.00   0.00   1.50   1.50   0.25   0.00   0.00
 0.33   0.33   0.33   0.33   0.41  14.00   0.80  14.00   1.00
 0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
 0.00   1.00   0.22   0.00   1.00   1.00   1.00   0.00   0.00
    50.00 0
   20      0     40     40    170    170    170    100      0
 1.00   0.00   1.00   0.00   0.25   0.25   0.25   0.00   0.00
 0.75   0.75   0.30   0.30   0.41  14.00   0.80  14.00   1.00
 0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
 0.00   1.00   0.21   0.00   1.00   1.00   1.00   0.00   0.00
    50.00 0
   20      0     40     40    170    170    170    100      0
 1.00   0.00   1.00   0.00   0.25   0.25   0.25   0.00   0.00
 0.75   0.75   0.30   0.30   0.41  14.00   0.80  14.00   1.00
 0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
 0.00   1.00   0.21   0.00   1.00   1.00   1.00   0.00   0.00
    50.00 0
```

```
   20      0      0      0    150    150    170    100      0
 1.00   0.00   1.00   0.00   1.50   1.50   0.25   0.00   0.00
 0.33   0.33   0.33   0.33   0.41  14.00   0.80  14.00   1.00
 0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
 0.00   1.00   0.00   0.00   1.00   1.00   1.00   0.00   0.00
 16    1   18    1       0.00  17000.00     300.00
0 0 0 0
   100.00  13490.00      26.00     622.00      30.00      36.00
     0.00      0.00       0.00       0.00       0.00       0.00      0.10
0.22      0.10
     0.00      0.16
```

Operation Information:

1	281	4	1.00	4.80	4.60	0.00	0.00
190	290	5	1.00	5.50	1.50	0.00	1.00
190	300	5	0.05	1.00	0.00	0.00	0.00
190	250	2	2.00	15.00	3.00	0.00	0.05
190	250	2	2.00	15.00	3.00	0.00	0.05
190	240	4	1.00	22.00	0.00	0.00	0.00
20	45	4	1.00	8.00	3.70	0.00	0.00
40	70	2	1.00	7.00	2.70	0.00	0.00
170	101	5	1.00	6.00	3.70	30.00	1.00
170	170	5	0.05	1.00	0.00	0.00	0.00
170	180	2	2.00	8.00	3.00	2.00	0.10
170	180	2	2.00	8.00	3.00	2.00	0.10
170	230	20	1.00	0.00	0.00	0.00	0.00
150	131	5	1.00	5.00	3.70	0.00	1.00
150	150	5	0.05	1.00	0.00	0.00	0.00
150	250	2	2.00	15.00	3.00	0.00	0.05
150	250	2	2.00	15.00	3.00	0.00	0.05
150	240	4	1.00	22.00	0.00	0.00	0.00
140	131	5	1.00	4.00	1.50	0.00	0.40
140	141	5	0.05	1.00	0.00	0.00	0.00
140	250	2	2.00	15.00	3.00	0.00	0.05
140	250	2	2.00	15.00	3.00	0.00	0.05
140	240	4	1.00	22.00	0.00	0.00	0.00
100	131	5	1.00	6.00	3.70	0.00	0.00
100	150	5	1.00	6.00	3.70	0.00	0.00

FILE: FARM.BUN
BRIEF DESCRIPTION: medium sized farm with bunker silos in place of stave silos.

```
ELANWTHR                                        ELANCORN
D:\DENNIS\SIMUL\MACHHMEC.SM2                      26
     3     1     2     2     2     1
     1     1     1     0     1     1     1     1     1     2
     4     2     5     0     2     5     4     4     5
     2     4     3     3
        91       335      1953      1978
         0         1         1         0
    175.00    175.00     70.00      1.00      1.00
         4         1        95
         2         1         1         2
         0         2         2         0
         2         1         1         2
        70        20        20        70
        41        41        41        41
        22        21        21         0
    143.00    183.00    228.00    288.00
         0       140
     15.00     20.00     15.00
   5   1   4
      8.00      8.00      4.00
      0.08      0.08
      8.00      0.31      0.32      0.08
    260.00    130.00    250.00    190.00
     20.00      0.00      1.00
     10.00      0.10     55.00     84.00    100.00
      0.25    220.00    154.00    106.00     69.00
    100.00     85.00     65.00     48.00
 0 0 0
    50.00 0
   20     0     0     0   150   150   170   100     0
 1.00  0.00  1.00  0.00  2.33  2.33  0.25  0.00  0.00
 0.33  0.33  0.33  0.33  0.41 14.00  0.80 14.00  1.00
 0.00  0.00  0.00  1.00  0.00  0.00  0.00  0.00  0.00
 0.00  1.00  0.22  0.00  1.00  1.00  1.00  0.00  0.00
    50.00 0
   20     0    40    40   170   170   170   100     0
 1.00  0.00  1.00  0.00  0.25  0.25  0.25  0.00  0.00
 0.75  0.75  0.30  0.30  0.41 14.00  0.80 14.00  1.00
 0.00  0.00  0.00  1.00  0.00  0.00  0.00  0.00  0.00
 0.00  1.00  0.21  0.00  1.00  1.00  1.00  0.00  0.00
    50.00 0
   20     0    40    40   170   170   170   100     0
 1.00  0.00  1.00  0.00  0.25  0.25  0.25  0.00  0.00
 0.75  0.75  0.30  0.30  0.41 14.00  0.80 14.00  1.00
 0.00  0.00  0.00  1.00  0.00  0.00  0.00  0.00  0.00
 0.00  1.00  0.21  0.00  1.00  1.00  1.00  0.00  0.00
    50.00 0
```

20	0	0	0	150	150	170	100	0
1.00	0.00	1.00	0.00	2.33	2.33	0.25	0.00	0.00
0.33	0.33	0.33	0.33	0.41	14.00	0.80	14.00	1.00
0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00

26 1 28 1 0.00 17000.00 300.00

0 0 0 0

100.00 13490.00 26.00 622.00 30.00 36.00

0.00 0.00 0.00 0.00 0.00 0.00 0.10

0.22 0.10

0.00 0.16

Operation Information:

1	281	4	1.00	4.80	4.60	0.00	0.00
190	290	5	1.00	5.50	1.50	0.00	1.00
190	300	5	0.05	1.00	0.00	0.00	0.00
190	250	2	2.00	15.00	3.00	0.00	0.05
190	250	2	2.00	15.00	3.00	0.00	0.05
190	240	4	1.00	22.00	0.00	0.00	0.00
20	45	4	1.00	8.00	3.70	0.00	0.00
40	70	2	1.00	7.00	2.70	0.00	0.00
170	101	5	1.00	6.00	3.70	30.00	1.00
170	170	5	0.05	1.00	0.00	0.00	0.00
170	180	2	2.00	8.00	3.00	2.00	0.10
170	180	2	2.00	8.00	3.00	2.00	0.10
170	230	20	1.00	0.00	0.00	0.00	0.00
150	131	5	1.00	5.00	3.70	0.00	1.00
150	150	5	0.05	1.00	0.00	0.00	0.00
150	250	2	2.00	15.00	3.00	0.00	0.05
150	250	2	2.00	15.00	3.00	0.00	0.05
150	270	0	1.00	0.00	0.00	0.00	0.00
140	131	5	1.00	4.00	1.50	0.00	0.40
140	141	5	0.05	1.00	0.00	0.00	0.00
140	250	2	2.00	15.00	3.00	0.00	0.05
140	250	2	2.00	15.00	3.00	0.00	0.05
140	240	4	1.00	22.00	0.00	0.00	0.00
100	131	5	1.00	6.00	3.70	0.00	0.00
100	150	5	1.00	6.00	3.70	0.00	0.00

FILE: FARM.HAY
BRIEF DESCRIPTION: medium sized farm with 3 cuttings of hay (no alfalfa silage harvest)

```
ELANWTHR                                  ELANCORN
D:\DENNIS\SIMUL\MACHHMEC.SM2                26
    3     1     2     1     2     1
    1     1     1     0     1     1     1     1     1     2
    4     2     5     0     2     5     4     4     5
    2     3     3     3
       91        335       1953       1978
        0          1          1          0
   175.00     175.00      70.00       1.00       1.00
        3          1         95
        1          1          1          1
        2          2          2          2
        1          1          1          1
       20         20         20         20
       41         41         41         41
       22         21         21          0
   143.00     183.00     228.00     288.00
        0        140
    15.00      20.00      15.00
  5   1   4
     8.00       8.00       4.00
      .08        .08
     8.00        .31        .32        .08
   260.00     130.00     250.00     190.00
    20.00        .00       1.00
    10.00        .10      55.00      84.00     100.00
      .25     220.00     154.00     106.00      69.00
   100.00      85.00      65.00      48.00
 0 0 0
   50.00 0
   20      0     40     40    170    170    170    100      0
 1.00    .00   1.00    .00    .25    .25    .25    .00    .00
  .75    .75    .30    .30    .41  14.00    .80  14.00   1.00
  .00    .00    .00   1.00    .00    .00    .00    .00    .00
  .00   1.00    .22    .00   1.00   1.00   1.00    .00    .00
   50.00 0
   20      0     40     40    170    170    170    100      0
 1.00    .00   1.00    .00    .25    .25    .25    .00    .00
  .75    .75    .30    .30    .41  14.00    .80  14.00   1.00
  .00    .00    .00   1.00    .00    .00    .00    .00    .00
  .00   1.00    .21    .00   1.00   1.00   1.00    .00    .00
   50.00 0
   20      0     40     40    170    170    170    100      0
 1.00    .00   1.00    .00    .25    .25    .25    .00    .00
  .75    .75    .30    .30    .41  14.00    .80  14.00   1.00
  .00    .00    .00   1.00    .00    .00    .00    .00    .00
  .00   1.00    .21    .00   1.00   1.00   1.00    .00    .00
   50.00 0
```

20	0	40	40	170	170	170	100	0
1.00	.00	1.00	.00	.25	.25	.25	.00	.00
.75	.75	.30	.30	.41	14.00	.80	14.00	1.00
.00	.00	.00	1.00	.00	.00	.00	.00	.00
.00	1.00	.00	.00	1.00	1.00	1.00	.00	.00

1 1 1 1 .00 26000.00 500.00
0 0 0 0

100.00	13490.00	26.00	622.00	30.00	36.00	
.00	.00	.00	.00	.00	.00	.10
.00	.16					

Operation Information:

1	281	4	1.00	4.80	4.60	.00	.00
190	290	5	1.00	5.50	1.50	.00	1.00
190	300	5	.05	1.00	.00	.00	.00
190	250	2	2.00	15.00	3.00	.00	.05
190	250	2	2.00	15.00	3.00	.00	.05
190	240	4	1.00	22.00	.00	.00	.00
20	45	4	1.00	8.00	3.70	.00	.00
40	70	2	1.00	7.00	2.70	.00	.00
170	101	5	1.00	6.00	3.70	30.00	1.00
170	170	5	.05	1.00	.00	.00	.00
170	180	2	2.00	8.00	3.00	2.00	.10
170	180	2	2.00	8.00	3.00	2.00	.10
170	230	20	1.00	.00	.00	.00	.00
150	130	5	1.00	5.00	3.70	.00	1.00
150	150	5	.05	1.00	.00	.00	.00
150	250	2	2.00	15.00	3.00	.00	.05
150	250	2	2.00	15.00	3.00	.00	.05
150	240	4	1.00	22.00	.00	.00	.00
140	130	5	1.00	4.00	.80	.00	.40
140	140	5	.05	1.00	.00	.00	.00
140	250	2	2.00	15.00	3.00	.00	.05
140	250	2	2.00	15.00	3.00	.00	.05
140	240	4	1.00	22.00	.00	.00	.00
100	130	5	1.00	6.00	3.70	.00	.00
100	150	5	1.00	6.00	3.70	.00	.00

FILE: FARM.SLG
BRIEF DESCRIPTION: medium sized farm with 4 cuttings of alfalfa silage (no hay harvest)

```
ELANWTHR                                         ELANCORN
D:\DENNIS\SIMUL\MACHHMEC.SM2                        26
      3       0       0       2       2       1
      1       0       0       0       0       1       1       1       1       2
      1       0       0       0       2       5       4       4       5
      2       3       3       3
         91         335        1953        1978
          0           1           1           0
     175.00      175.00       70.00        1.00        1.00
          4           1          95
          2           2           2           2
          0           0           0           0
          2           2           2           2
         65          65          65          65
         41          41          41          41
         22          21          21           0
     143.00      183.00      228.00      288.00
          0         140
      15.00       20.00       15.00
   5    1    4
       8.00        8.00        4.00
       0.08        0.08
       8.00        0.31        0.32        0.08
     260.00      130.00      250.00      190.00
      20.00        0.00        1.00
      10.00        0.10       55.00       84.00      100.00
       0.25      220.00      154.00      106.00       69.00
     100.00       85.00       65.00       48.00
 0 0 0
     50.00 0
    20      0      0      0    150    150    150    100      0
  1.00   0.00   1.00   0.00   1.86   1.86   0.25   0.00   0.00
  0.33   0.33   0.33   0.33   0.41  14.00   0.80  14.00   1.00
  0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
  0.00   1.00   0.22   0.00   1.00   1.00   1.00   0.00   0.00
     50.00 0
    20      0      0      0    150    150    150    100      0
  1.00   0.00   1.00   0.00   1.86   1.86   0.25   0.00   0.00
  0.33   0.33   0.33   0.33   0.41  14.00   0.80  14.00   1.00
  0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
  0.00   1.00   0.21   0.00   1.00   1.00   1.00   0.00   0.00
     50.00 0
    20      0      0      0    150    150    150    100      0
  1.00   0.00   1.00   0.00   1.86   1.86   0.25   0.00   0.00
  0.33   0.33   0.33   0.33   0.41  14.00   0.80  14.00   1.00
  0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00
  0.00   1.00   0.21   0.00   1.00   1.00   1.00   0.00   0.00
     50.00 0
```

20	0	0	0	150	150	150	100	0
1.00	0.00	1.00	0.00	1.86	1.86	0.25	0.00	0.00
0.33	0.33	0.33	0.33	0.41	14.00	0.80	14.00	1.00
0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00

5 1 7 5 0.00 0.00 0.00
0 0 0 0
100.00 13490.00 26.00 622.00 30.00 36.00
0.00 0.00 0.00 0.00 0.00 0.00 0.10
0.22 0.10
0.00 0.16

Operation Information:

1	281	4	1.00	4.80	4.60	0.00	0.00
190	290	5	1.00	5.50	1.50	0.00	1.00
190	300	5	0.05	1.00	0.00	0.00	0.00
190	250	2	2.00	15.00	3.00	0.00	0.05
190	250	2	2.00	15.00	3.00	0.00	0.05
190	240	4	1.00	22.00	0.00	0.00	0.00
20	45	1	1.00	8.00	3.70	0.00	0.00
150	131	5	1.00	5.00	3.70	0.00	1.00
150	150	5	0.05	1.00	0.00	0.00	0.00
150	250	2	2.00	15.00	3.00	0.00	0.05
150	250	2	2.00	15.00	3.00	0.00	0.05
150	240	4	1.00	22.00	0.00	0.00	0.00
140	131	5	1.00	4.00	1.50	0.00	0.40
140	141	5	0.05	1.00	0.00	0.00	0.00
140	250	2	2.00	15.00	3.00	0.00	0.05
140	250	2	2.00	15.00	3.00	0.00	0.05
140	240	4	1.00	22.00	0.00	0.00	0.00
100	131	5	1.00	6.00	3.70	0.00	0.00
100	150	5	1.00	6.00	3.70	0.00	0.00

FILE: MACHHMEC.SM2
BRIEF DESCRIPTION: machine information file with HMEC harvested with the forage chopper and a small (2 row) snapper head

```
       1.4       30.        0.         1.        6.       7.5       20.
      3.0       10.
tractor                     1  1200. 10000.  9000.     0.   100.  0.0  0.0
0.0  0.0  2.0 20.0  0.0  0.0  0.0  0.0  0.0  .01  2.0
                            2  2100. 17500.  2000.  6000.   100.  0.0  0.0
0.0  0.0  2.0 35.0  0.0  0.0  0.0  0.0  0.0  .01  2.0
                            3  3000. 25000. 22500.     0.   200.  0.0  0.0
0.0  0.0  2.0 50.0  0.0  0.0  0.0  0.0  0.0  .01  2.0
                            4  3900. 32500. 29250.     0.   200.  0.0  0.0
0.0  0.0  2.0 65.0  0.0  0.0  0.0  0.0  0.0  .01  2.0
                            5  4800. 40000. 36000.     0.   250.  0.0  0.0
0.0  0.0  2.0 80.0  0.0  0.0  0.0  0.0  0.0  .01  2.0
                            6  6000. 50000. 45000.     0.   250.  0.0  0.0
0.0  0.0  2.0 100.  0.0  0.0  0.0  0.0  0.0  .01  2.0
                            7  7200. 60000. 54000.     0.   250.  0.0  0.0
0.0  0.0  2.0 120.  0.0  0.0  0.0  0.0  0.0  .01  2.0
motor                      20   100.   500.   450.     0.    0.0  0.0  0.0
0.0  0.0  3.0  2.0  0.0  0.0  0.0  0.0  0.0  .01  2.0
mower                      31   360.  3000.  2700.     0.    0.0  2.7 12.0
0.0  0.0  0.0  0.0  0.0  0.0  7.0  0.0  0.0  .46  1.7
mower-conditioner          40  1360. 10500.  9500.     0.    0.0  2.7 12.0
0.0  0.0  0.0  0.0  0.0  0.0  8.0  0.0  0.0  .26  1.6
                           45  1930. 14700. 13200.     0.    0.0  3.7 15.0
0.0  0.0  0.0  0.0  0.0  0.0  8.0  0.0  0.0  .26  1.6
SP mow-conditioner         46  4500. 33000. 29700.     0.    0.0  3.7 15.0
0.0  1.0  2.0 57.0  0.0  0.0  8.0  0.0  0.0  .06  2.0
mat processor              50  3000. 28000. 25200.     0.    0.0  2.7  7.5
0.0  0.0  0.0  0.0  0.0  0.0  6.4  0.0  0.0  .26  1.6
single rake                70   400.  3500.  3150.     0.    0.0  2.7  0.0
0.0  0.0  0.0  0.0  0.0  0.0  7.0  0.0  0.0  .38  1.4
double rake                71   800.  7900.  7100.     0.    0.0  5.4  0.0
0.0  0.0  0.0  0.0  0.0  0.0  7.0  0.0  0.0  .38  1.4
square baler              100  1200.  8300.  7470.     0.    0.0  0.0  6.0
0.0  0.0  0.0  0.0  0.0  0.0  6.0 25.0  1.0  .23  1.8
                          101  1450. 10500.  9500.     0.    0.0  0.0  8.0
0.0  0.0  0.0  0.0  0.0  0.0  6.0 30.0  1.0  .23  1.8
                          102  1650. 12500. 11250.     0.    0.0  0.0 11.0
0.0  0.0  0.0  0.0  0.0  0.0  6.0 30.0  1.0  .23  1.8
round baler               110  1250.  9300.  8400.     0.    0.0  0.0  6.0
0.0  0.0  0.0  0.0  0.0  0.0  6.0 300.  1.0  .23  1.8
                          111  2000. 14100. 12700.     0.    0.0  0.0  8.5
0.0  0.0  0.0  0.0  0.0  0.0  6.0 600.  1.0  .23  1.8
                          112  2400. 16400. 14700.     0.    0.0  0.0 12.0
0.0  0.0  0.0  0.0  0.0  0.0  6.0 800.  1.0  .23  1.8
forage harvester          130  1000.  8500.  7600.     0.    0.0  0.0 11.0
0.0  0.0  0.0  0.0  0.0  0.0  6.0  0.0  1.0  .26  1.6
                          131  1400. 12600. 11300.     0.    0.0  0.0 14.0
0.0  0.0  0.0  0.0  0.0  0.0  6.0  0.0  1.0  .26  1.6
```

```
                         132  1900. 17000. 15300.      0.      0.0  0.0 18.0
0.0  0.0  0.0  0.0   0.0  0.0  6.0  0.0   1.0  .26  1.6
SP forage harvester  133  7000. 80000. 72000.      0.      0.0  0.0 22.0
0.0  1.0  2.0 186.   0.0  0.0  6.0  0.0   1.0  .06  2.0
row-crop attachment  140   200.  2600.  2340.      0.      0.0  0.8  0.0
0.0  0.0  0.0  0.0   0.0  0.0  4.0 0.05   0.4  .26  1.6
                     141   400.  3800.  3420.      0.      0.0  1.5  0.0
0.0  0.0  0.0  0.0   0.0  0.0  4.0 0.05   0.4  .26  1.6
                     142   900.  7400.  6600.      0.      0.0  2.3  0.0
0.0  0.0  0.0  0.0   0.0  0.0  4.0 0.05   0.4  .26  1.6
                     143  1200. 15000. 13500.      0.      0.0  3.0  0.0
0.0  0.0  0.0  0.0   0.0  0.0  4.0 0.05   0.4  .26  1.6
windrow pickup       150   300.  2200.  1980.      0.      0.0  1.7  0.0
0.0  0.0  0.0  0.0   0.0  0.0  5.0 0.05   1.0  .26  1.6
                     151   500.  3800.  3400.      0.      0.0  2.1  0.0
0.0  0.0  0.0  0.0   0.0  0.0  5.0 0.05   1.0  .26  1.6
bale ejector         170   250.  3000.  2700.      0.      0.0  0.0  0.0
0.0  0.0  0.0  0.0   0.0  0.0  0.0 0.05   1.0  .23  1.8
square bale wagon    180   320.  2100.  1900.      0.      0.0  0.0  0.0
4.5  0.0  0.0  0.0   0.0  0.5  8.0  2.0   0.1  .19  1.3
round bale mover     200   110.   650.   600.      0.      0.0  0.0  0.0
0.8  0.0  0.0  0.0   .03  0.2  6.0  0.0   1.0  .19  1.3
round bale wagon     210   700.  7000.  6300.      0.      0.0  0.0  0.0
3.2  0.0  0.0  0.0   0.0  0.0  8.0  0.0   1.0  .19  1.3
bale elevator        230   600.  4000.  3600.      0.      0.0  0.0  6.8
0.0  0.0  0.0  0.0   0.0  0.0 22.0  0.0   0.0  .19  1.3
forage blower        240   500.  3500.  3150.      0.      0.0  0.0 30.0
0.0  0.0  0.0  0.0   0.0  0.0 22.0  0.0   0.0  .14  1.8
forage box           250  1500.  8000.  7200.      0.      0.0  0.0  0.0
9.0  0.0  0.0  0.0   0.0  0.0 15.0  0.0   .05  .14  1.8
bunker compactor     270  6000.    30.     0.      0.      0.0  0.0  0.0
0.0  1.0  2.0 100.   0.0  0.0  0.0  0.0   0.0  .01  2.0
corn planter         280  1700. 10000.  9000.      0.      0.0  3.0  0.0
0.0  0.0  0.0  0.0   0.0  0.0  4.8  1.0   0.0  .54  2.1
                     281  2500. 14000. 12600.      0.      0.0  4.6  0.0
0.0  0.0  0.0  0.0   0.0  0.0  4.8  1.0   0.0  .54  2.1
                     282  3300. 20000. 18000.      0.      0.0  6.1  0.0
0.0  0.0  0.0  0.0   0.0  0.0  4.8  1.0   0.0  .54  2.1
                     283  5000. 35000. 31500.      0.      0.0  9.1  0.0
0.0  0.0  0.0  0.0   0.0  0.0  4.8  1.0   0.0  .54  2.1
corn combine         290  1000.  8500.     0.      0.      0.0  1.5 11.0
0.0  0.0  0.0  0.0   0.0  0.0  5.5  0.0   1.0  .26  2.1
                     291  1400. 12600.     0.      0.      0.0  2.3 14.0
0.0  0.0  0.0  0.0   0.0  0.0  5.5  0.0   1.0  .26  1.6
                     292  1900. 17000.     0.      0.      0.0  3.0 18.0
0.0  0.0  0.0  0.0   0.0  0.0  5.5  0.0   1.0  .26  1.6
corn attachment      300   200.  2600.  2340.      0.      0.0  1.5  0.0
0.0  0.0  0.0  0.0   0.0  0.0  5.5  .05   1.0  .26  1.6
special                0     0.     0.     0.      0.      0.0  0.0  0.0
0.0  0.0  0.0  0.0   0.0  0.0  0.0 0.05   1.0  0.0  1.0
CORN PLANTING        0.70  4.5  0.0  0.0  0.0
CUTTERBAR MOWING     0.80  1.2  0.0  .01  .75
CUTTERBAR MOW-COND   0.80  3.0  2.0  .02  .75
```

```
MAT MAKER              0.80  4.0 33.0 .012  .80
SINGLE RAKING          0.80  1.0  0.0 .042  .00
DOUBLE RAKING          0.80  1.0  0.0 .042  .00
TEDDING                0.80  2.0  0.0 .023 1.00
RECT BALING (DROP)     0.80  0.0  5.0  .04  .00
ROUND BALING           0.75  0.0  7.5 .048  .00
LARGE STACK BALING     0.70  0.0  7.5 .136  .00
CHOP TO THE GROUND     0.80  0.0 15.0  .00  .00
AUTO BALE WAGON        0.80  0.0  6.0  .00  .00
LARGE STACK MOVER      0.80  0.0  0.0  .00  .00
ROUND BALE MOVER       0.80  0.0  0.0  .00  .00
CHOP (CS)              0.80  0.0 15.0  .05  .00
CHOP (ALF HAYLAGE)     0.80  0.0 15.0 .037  .75
CHOP (ALF-DC)          0.80  0.0 18.0 .037  .75
RECT BALING (EJECT)    0.80  0.0  5.0 .052  .00
HANDPICK BALES         0.80  0.0  0.0  .00  .00
H.M. CORN HARVEST      0.80  0.0 13.0 .035  .00
  31  40  45  46  50                                       -MOWER(4)
  70  71                                                   -JRAKE(2)
 100 101 102 110 111 112                                   -JBALER(6)
 130 131 132 133                                           -JFHRV(4)
 280 281 282 283                                           -JCRNPL(4)
 290 291 292                                               -JHMCHV(3)
   1   2   3   4   5   6   7                               -JTRAC(7)
  0.   0.    0.         0.  4.
 4.88 12.2  63.   15000.  4.
 4.88 15.2  88.   17000.  4.
 4.88 18.3 106.   19000.  4.
 5.49 18.3 142.   23000.  4.
 6.10 18.3 175.   26000.  4.
 6.10 21.3 218.   30000.  4.
 6.10 24.4 265.   33500.  4.
 7.32 21.3 312.   38000.  4.
 7.32 24.4 375.   44000.  4.
 9.14 21.3 485.   55000.  4.
 9.14 24.4 582.   67000.  4.
 9.14 27.4 680.   79000.  4.
 4.88 12.2  63.   40800.  2.
 4.88 15.2  88.   44500.  2.
 4.88 18.3 112.   48300.  2.
 5.49 18.3 142.   53400.  2.
 6.10 18.3 175.   58700.  2.
 6.10 21.3 218.   63500.  2.
 6.10 24.4 265.   68200.  2.
 7.32 21.3 312.   73700.  2.
 7.32 24.4 375.   79400.  2.
 9.14 21.3 485.   89700.  2.
 9.14 24.4 582.   97000.  2.
 9.14 27.4 680.  104000.  2.
 6.10 3.05 112.   20100.  6.
 6.10 3.05 142.   25500.  6.
 9.14 3.66 175.   21000.  6.
 9.14 5.49 318.   39300.  6.
```

15.2	5.49	530.	60900.	6.
15.2	5.49	688.	69000.	6.
15.2	5.49	949.	76000.	6.

APPENDIX E

DAFOSYM output used to determine the value of alfalfa losses.

Eliminated losses in Table E.1 correspond to:

1 Respiration
2 Rain
3 Mower
4 Rake
5 Baler
6 Chopper
7 Hay storage
8 Silo storage
9 Feeding

Table E.1 Description of simulated cases.

Case	Milk Prod.	Farm File	Loss(es) eliminated	Notes
1	13490	FARM.ME	none	base run
2	13490	FARM.ME	1	
3	13490	FARM.ME	2	
4	13490	FARM.ME	3	
5	13490	FARM.ME	4	
6	13490	FARM.ME	5	
7	13490	FARM.ME	6	
8	13490	FARM.ME	3 4 5 6	all machine losses
9	13490	FARM.ME	1 2 3 4 5 6	all harvest losses
10	13490	FARM.ME	7	
11	13490	FARM.ME	8	preseal only
12	13490	FARM.ME	8	fermentation only
13	13490	FARM.ME	8	infiltration only
14	13490	FARM.ME	8	feedout only
15	13490	FARM.ME	8	
16	13490	FARM.ME	7 8	all storage losses
17	13490	FARM.ME	9	
18	13490	FARM.ME	1 2 3 4 5 6 7 8 9	all losses
19	13490	FARM.ME	none	optimal allocation
20	8990	FARM.ME	none	base run
21	8990	FARM.ME	1	
22	8990	FARM.ME	2	
23	8990	FARM.ME	3	
24	8990	FARM.ME	4	
25	8990	FARM.ME	5	
26	8990	FARM.ME	6	
27	8990	FARM.ME	3 4 5 6	all machine losses
28	8990	FARM.ME	1 2 3 4 5 6	all harvest losses
29	8990	FARM.ME	7	
30	8990	FARM.ME	8	preseal only
31	8990	FARM.ME	8	fermentation only
32	8990	FARM.ME	8	infiltration only
33	8990	FARM.ME	8	feedout only
34	8990	FARM.ME	8	
35	8990	FARM.ME	7 8	all storage losses
36	8990	FARM.ME	9	
37	8990	FARM.ME	1 2 3 4 5 6 7 8 9	all losses
38	8990	FARM.ME	none	optimal allocation
39	13490	FARM.LG	none	
40	13490	FARM.LG	1	
41	13490	FARM.LG	2	
42	13490	FARM.LG	3	
43	13490	FARM.LG	4	
44	13490	FARM.LG	5	
45	13490	FARM.LG	6	
46	13490	FARM.LG	7	

47	13490	FARM.LG	8	
48	13490	FARM.LG	9	
49	13490	FARM.LG	none	optimal allocation
50	13490	FARM.LG	1 2 3 4 5 6	
51	13490	FARM.LG	7 8	
52	13490	FARM.LG	1 2 3 4 5 6 7 8 9	
53	8990	FARM.LG	none	
54	8990	FARM.LG	1	
55	8990	FARM.LG	2	
56	8990	FARM.LG	3	
57	8990	FARM.LG	4	
58	8990	FARM.LG	5	
59	8990	FARM.LG	6	
60	8990	FARM.LG	7	
61	8990	FARM.LG	8	
62	8990	FARM.LG	9	
63	8990	FARM.LG	none	optimal allocation
64	8990	FARM.LG	1 2 3 4 5 6	
65	8990	FARM.LG	7 8	
66	8990	FARM.LG	1 2 3 4 5 6 7 8 9	
67	13490	FARM.SM	none	
68	13490	FARM.SM	1	
69	13490	FARM.SM	2	
70	13490	FARM.SM	3	
71	13490	FARM.SM	4	
72	13490	FARM.SM	5	
73	13490	FARM.SM	6	
74	13490	FARM.SM	7	
75	13490	FARM.SM	8	
76	13490	FARM.SM	9	
77	13490	FARM.SM	none	optimal allocation
78	13490	FARM.SM	1 2 3 4 5 6	
79	13490	FARM.SM	7 8	
80	13490	FARM.SM	1 2 3 4 5 6 7 8 9	
81	8990	FARM.SM	none	
82	8990	FARM.SM	1	
83	8990	FARM.SM	2	
84	8990	FARM.SM	3	
85	8990	FARM.SM	4	
86	8990	FARM.SM	5	
87	8990	FARM.SM	6	
88	8990	FARM.SM	7	
89	8990	FARM.SM	8	
90	8990	FARM.SM	9	
91	8990	FARM.SM	none	optimal allocation
92	8990	FARM.SM	1 2 3 4 5 6	
93	8990	FARM.SM	7 8	
94	8990	FARM.SM	1 2 3 4 5 6 7 8 9	
95	13490	FARM.DRY	none	hay at 15%, silage at 60%
96	13490	FARM.DRY	1 2 3 4 5 6	hay at 15%, silage at 60%
97	13490	FARM.DRY	7 8	hay at 15%, silage at 60%
98	13490	FARM.DRY	1 2 3 4 5 6 7 8 9	hay at 15%, silage at 60%
99	8990	FARM.DRY	none	hay at 15%, silage at 60%

100	8990	FARM.DRY	1 2 3 4 5 6	hay at 15%, silage at 60%
101	8990	FARM.DRY	7 8	hay at 15%, silage at 60%
102	8990	FARM.DRY	1 2 3 4 5 6 7 8 9	hay at 15%, silage at 60%
103	13490	FARM.RND	none	round hay bales stored inside
104	13490	FARM.RND	5	round hay bales stored inside
105	13490	FARM.RND	7	round hay bales stored inside
106	13490	FARM.RND	9	round hay bales stored inside
107	8990	FARM.RND	none	round hay bales stored inside
108	8990	FARM.RND	5	round hay bales stored inside
109	8990	FARM.RND	7	round hay bales stored inside
110	8990	FARM.RND	9	round hay bales stored inside
111	13490	FARM2.RND	none	round hay bales stored outside
112	13490	FARM2.RND	7	round hay bales stored outside
113	13490	FARM2.RND	9	round hay bales stored outside
114	8990	FARM2.RND	none	round hay bales stored outside
115	8990	FARM2.RND	7	round hay bales stored outside
116	8990	FARM2.RND	9	round hay bales stored outside
117	13490	FARM.SEA	none	sealed alfalfa silos
118	13490	FARM.SEA	8	'' preseal only
119	13490	FARM.SEA	8	'' fermentation only
120	13490	FARM.SEA	8	'' infiltration only
121	13490	FARM.SEA	8	'' feedout only
122	13490	FARM.SEA	8	sealed alfalfa silos
123	8990	FARM.SEA	none	sealed alfalfa silos
124	8990	FARM.SEA	8	'' preseal only
125	8990	FARM.SEA	8	'' fermentation only
126	8990	FARM.SEA	8	'' infiltration only
127	8990	FARM.SEA	8	'' feedout only
128	8990	FARM.SEA	8	sealed alfalfa silos
129	13490	FARM.BUN	none	bunker alfalfa silos
130	13490	FARM.BUN	8	'' preseal only
131	13490	FARM.BUN	8	'' fermentation only
132	13490	FARM.BUN	8	'' infiltration only
133	13490	FARM.BUN	8	'' feedout only
134	13490	FARM.BUN	8	bunker alfalfa silos
135	8990	FARM.BUN	none	bunker alfalfa silos
136	8990	FARM.BUN	8	'' preseal only
137	8990	FARM.BUN	8	'' fermentation only
138	8990	FARM.BUN	8	'' infiltration only
139	8990	FARM.BUN	8	'' feedout only
140	8990	FARM.BUN	8	bunker alfalfa silos
141	13490	FARM.HAY	none	all hay system
142	13490	FARM.HAY	1	all hay system
143	13490	FARM.HAY	2	all hay system
144	13490	FARM.HAY	3	all hay system
145	13490	FARM.HAY	4	all hay system
146	13490	FARM.HAY	5	all hay system
147	13490	FARM.HAY	7	all hay system
148	13490	FARM.HAY	9	all hay system
149	13490	FARM.HAY	1 2 3 4 5	all hay system
150	13490	FARM.HAY	1 2 3 4 5 7 9	all hay system
151	8990	FARM.HAY	none	all hay system
152	8990	FARM.HAY	1	all hay system

153	8990	FARM.HAY		2								all hay system
154	8990	FARM.HAY			3							all hay system
155	8990	FARM.HAY				4						all hay system
156	8990	FARM.HAY					5					all hay system
157	8990	FARM.HAY							7			all hay system
158	8990	FARM.HAY									9	all hay system
159	8990	FARM.HAY	1	2	3	4	5					all hay system
160	8990	FARM.HAY	1	2	3	4	5		7		9	all hay system
161	13490	FARM.SLG	none									all silage system
162	13490	FARM.SLG	1									all silage system
163	13490	FARM.SLG		2								all silage system
164	13490	FARM.SLG			3							all silage system
165	13490	FARM.SLG						6				all silage system
166	13490	FARM.SLG								8		all silage system
167	13490	FARM.SLG									9	all silage system
168	13490	FARM.SLG	1	2	3			6				all silage system
169	13490	FARM.SLG	1	2	3			6		8	9	all silage system
170	8990	FARM.SLG	none									all silage system
171	8990	FARM.SLG	1									all silage system
172	8990	FARM.SLG		2								all silage system
173	8990	FARM.SLG			3							all silage system
174	8990	FARM.SLG						6				all silage system
175	8990	FARM.SLG								8		all silage system
176	8990	FARM.SLG									9	all silage system
177	8990	FARM.SLG	1	2	3			6				all silage system
178	8990	FARM.SLG	1	2	3			6	7		9	all silage system
179	13490	FARM.ME	none									10% higher animal weights
180	13490	FARM.ME	1	2	3	4	5	6	7	8	9	10% higher animal weights
181	13490	FARM.ME	none									10% higher animal weights
182	8990	FARM.ME	1	2	3	4	5	6	7	8	9	10% higher animal weights
183	13490	FARM.ME	none									10% higher ingestive capacity
184	13490	FARM.ME	1	2	3	4	5	6	7	8	9	10% higher ingestive capacity
185	8990	FARM.ME	none									10% higher ingestive capacity
186	8990	FARM.ME	1	2	3	4	5	6	7	8	9	10% higher ingestive capacity
187	13490	FARM.ME	none									10% higher protein suppl price
188	13490	FARM.ME	1	2	3	4	5	6	7	8	9	10% higher protein suppl price
189	8990	FARM.ME	none									10% higher protein suppl price
190	8990	FARM.ME	1	2	3	4	5	6	7	8	9	10% higher protein suppl price
191	13490	FARM.ME	none									distillers unavailable
192	13490	FARM.ME	1	2	3	4	5	6	7	8	9	distillers unavailable
193	8990	FARM.ME	none									distillers unavailable
194	8990	FARM.ME	1	2	3	4	5	6	7	8	9	distillers unavailable
195	13490	FARM.ME	none									optimal alloc. w/ max forage
196	8990	FARM.ME	none									optimal alloc. w/ max forage
197	13490	FARM.ME								8		hemicellulose breakdown only
198	8990	FARM.ME								8		hemicellulose breakdown only
199	13490	FARM.ME								8		proteolysis only
200	8990	FARM.ME								8		proteolysis only

Table E.2 Feed production and feeds sold (all units T DM/y -- negative values indicate feed purchases).

	Feed production							Feeds sold			
Case	HQH	LQH	HQAS	LQAS	CS	HMEC	CG	ALF	CG	SBM	DST
1	72	150	104	154	123	98	137	-10	44	-18	-34
2	105	122	105	157	123	98	137	0	47	-19	-37
3	91	141	106	157	123	98	137	-2	49	-18	-34
4	84	144	106	157	123	98	137	-5	47	-17	-34
5	100	146	104	154	123	98	137	6	48	-18	-33
6	92	142	104	154	123	98	137	-4	46	-18	-33
7	72	150	107	161	123	98	137	-5	48	-17	-35
8	125	140	108	166	123	98	137	30	51	-18	-32
9	195	92	112	173	123	98	137	51	56	-22	-34
10	74	154	104	154	123	98	137	-11	35	-12	-26
11	72	150	104	154	123	98	137	-10	45	-18	-34
12	72	150	105	155	123	98	137	-9	47	-17	-36
13	72	150	112	163	123	98	137	6	51	-18	-43
14	72	150	106	157	123	98	137	-8	49	-17	-37
15	72	150	115	167	123	98	137	16	53	-18	-47
16	74	154	115	167	135	98	137	3	59	-19	-34
17	76	158	110	162	123	98	137	12	46	-19	-33
18	211	99	129	197	123	98	137	84	55	-19	-34
19	72	150	104	154	123	98	137	-24	-4	0	-11
20	72	150	104	154	123	98	137	-29	105	-15	-31
21	105	122	105	157	123	98	137	-24	115	-21	-26
22	91	141	106	157	123	98	137	-22	115	-18	-26
23	84	144	106	157	123	98	137	-22	108	-16	-29
24	100	146	104	154	123	98	137	-10	110	-16	-29
25	92	142	104	154	123	98	137	-20	108	-15	-29
26	72	150	107	161	123	98	137	-22	108	-16	-29
27	125	140	108	166	123	98	137	17	118	-19	-24
28	195	92	112	173	123	98	137	45	132	-31	-12
29	74	154	104	154	123	98	137	-29	98	-10	-21
30	72	150	104	154	123	98	137	-29	105	-15	-31
31	72	150	105	155	123	98	137	-29	107	-16	-30
32	72	150	112	163	123	98	137	-22	121	-24	-24
33	72	150	106	157	123	98	137	-28	110	-17	-29
34	72	150	115	167	123	98	137	-15	125	-30	-18
35	74	154	115	167	123	98	137	-22	124	-22	-12
36	76	158	110	162	123	98	137	-6	108	-15	-31
37	211	99	129	197	123	98	137	97	137	-34	0
38	72	150	104	154	123	98	137	1	42	0	-2
39	95	225	193	190	191	131	216	-21	65	-24	-62
40	125	204	194	195	191	131	216	-6	75	-24	-71
41	116	219	194	197	191	131	216	-7	77	-24	-62
42	102	228	194	194	191	131	216	-10	69	-24	-61
43	127	229	193	190	191	131	216	4	71	-26	-59
44	112	225	193	190	191	131	216	-10	70	-24	-61

45	95	228	194	200	191	131	216	-11	68	-24	-62
46	98	231	193	190	191	131	216	-29	52	-18	-45
47	95	225	208	209	191	131	216	19	78	-26	-77
48	100	236	203	200	191	131	216	12	69	-26	-61
49	95	225	193	190	191	131	216	-39	-29	0	-4
50	257	175	194	208	191	131	216	62	97	-31	-58
51	98	231	208	209	191	131	216	-19	76	-27	-48
52	278	190	219	241	191	131	216	104	92	-28	-50
53	95	225	193	190	191	131	216	-57	161	-21	-54
54	125	204	194	195	191	131	216	-49	176	-31	-47
55	116	219	194	197	191	131	216	-44	176	-26	-47
56	102	228	194	194	191	131	216	-45	166	-23	-50
57	127	229	193	190	191	131	216	-30	169	-25	-48
58	112	225	193	190	191	131	216	-44	165	-23	-50
59	95	228	194	200	191	131	216	-47	166	-23	-51
60	98	231	193	190	191	131	216	-58	149	-15	-36
61	95	225	208	209	191	131	216	-33	186	-42	-36
62	100	236	203	200	191	131	216	-24	166	-24	-52
63	95	225	193	190	191	131	216	39	27	0	0
64	257	175	194	208	191	131	216	47	201	-48	-17
65	98	231	208	209	191	131	216	-46	184	-30	-25
66	278	190	219	241	191	131	216	121	214	-49	-1
67	48	88	152	0	90	58	74	11	18	-12	-20
68	68	74	152	0	90	58	74	19	19	-12	-24
69	62	81	153	0	90	58	74	15	19	-12	-20
70	55	86	152	0	90	58	74	14	19	-11	-21
71	66	86	152	0	90	58	74	22	20	-12	-21
72	60	84	152	0	90	58	74	16	19	-12	-20
73	50	90	153	0	90	58	74	14	19	-11	-21
74	50	90	152	0	90	58	74	11	15	-8	-17
75	48	88	165	0	90	58	74	34	19	-13	-27
76	51	93	160	0	90	58	74	24	19	-12	-21
77	48	88	152	0	90	58	74	19	-22	0	-1
78	138	48	154	0	90	58	74	45	22	-12	-22
79	50	90	165	0	90	58	74	13	18	-10	-20
80	149	52	175	0	90	58	74	68	18	-12	-20
81	48	88	152	0	90	58	74	2	56	-8	-22
82	68	74	152	0	90	58	74	4	61	-13	-18
83	62	81	153	0	90	58	74	5	60	-11	-18
84	55	86	152	0	90	58	74	5	57	-9	-21
85	66	86	152	0	90	58	74	14	58	-9	-21
86	60	84	152	0	90	58	74	7	57	-9	-21
87	50	90	153	0	90	58	74	4	57	-9	-21
88	50	90	152	0	90	58	74	1	52	-6	-16
89	48	88	165	0	90	58	74	11	65	-17	-14
90	51	93	160	0	90	58	74	16	57	-9	-22
91	48	88	152	0	90	58	74	27	9	0	0
92	138	48	154	0	90	58	74	44	69	-17	-10
93	50	90	165	0	90	58	74	7	64	-13	-10
94	149	52	175	0	90	58	74	73	73	-20	-1
95	50	153	107	142	123	98	137	-35	29	-11	-27
96	182	95	114	165	123	98	137	26	49	-12	-28
97	51	155	118	156	123	98	137	-28	43	-16	-30

98	194	101	132	190	123	98	137	64	54	-17	-33
99	50	153	107	142	123	98	137	-52	86	-8	-25
100	182	95	114	165	123	98	137	18	128	-18	-10
101	51	155	118	156	123	98	137	-46	115	-18	-17
102	194	101	132	190	123	98	137	74	137	-32	0
103	70	131	104	153	123	98	137	-31	42	-17	-33
104	81	130	104	153	123	98	137	-24	44	-17	-33
105	72	135	104	153	123	98	137	-32	34	-11	-26
106	81	152	109	161	123	98	137	10	45	-18	-33
107	54	101	104	153	123	98	137	-67	23	-8	-27
108	63	117	104	153	123	98	137	-55	31	-11	-26
109	72	135	109	161	123	98	137	-4	24	-9	-27
110	70	131	104	153	123	98	137	-50	103	-14	-30
111	81	130	104	153	123	98	137	-43	105	-15	-29
112	72	135	104	153	123	98	137	-50	96	-10	-20
113	81	152	109	161	123	98	137	-8	109	-16	-30
114	54	101	104	153	123	98	137	-80	69	-6	-24
115	63	117	104	153	123	98	137	-73	93	-10	-21
116	72	135	109	161	123	98	137	-17	71	-7	-24
117	73	149	108	148	123	98	137	-14	44	-16	-35
118	73	149	108	148	123	98	137	-14	44	-16	-35
119	73	149	109	149	123	98	137	-13	46	-17	-35
120	73	149	115	157	123	98	137	3	49	-17	-42
121	73	149	110	150	123	98	137	-11	47	-18	-35
122	73	149	117	161	123	98	137	11	50	-18	-44
123	73	149	108	148	123	98	137	-31	103	-15	-30
124	73	149	108	148	123	98	137	-31	103	-15	-30
125	73	149	109	149	123	98	137	-31	105	-15	-29
126	73	149	115	157	123	98	137	-24	120	-22	-25
127	73	149	110	150	123	98	137	-30	108	-16	-29
128	73	149	117	161	123	98	137	-19	124	-27	-20
129	70	153	94	149	123	98	137	-22	45	-16	-36
130	70	153	94	150	123	98	137	-22	45	-16	-36
131	70	153	95	151	123	98	137	-22	46	-17	-36
132	70	153	100	158	123	98	137	-4	48	-18	-42
133	70	153	96	153	123	98	137	-19	47	-18	-36
134	70	153	103	164	123	98	137	5	51	-18	-46
135	70	153	94	149	123	98	137	-41	104	-14	-32
136	70	153	94	150	123	98	137	-41	104	-14	-32
137	70	153	95	151	123	98	137	-40	107	-16	-31
138	70	153	100	158	123	98	137	-35	120	-22	-26
139	70	153	96	153	123	98	137	-40	110	-17	-30
140	70	153	103	164	123	98	137	-28	125	-29	-19
141	142	256	0	0	123	98	137	-75	6	-17	-29
142	180	229	0	0	123	98	137	-66	20	-13	-41
143	180	240	0	0	123	98	137	-66	24	-14	-31
144	155	253	0	0	123	98	137	-69	12	-14	-33
145	174	257	0	0	123	98	137	-52	17	-14	-32
146	167	252	0	0	123	98	137	-63	15	-13	-33
147	146	263	0	0	123	98	137	-77	-14	-9	-12
148	149	269	0	0	123	98	137	-56	9	-16	-31
149	331	178	0	0	123	98	137	-13	50	-17	-31
150	358	193	0	0	123	98	137	10	33	-4	-15

151	142	256	0	0	123	98	137	-100	80	-11	-29
152	180	229	0	0	123	98	137	-92	90	-15	-28
153	180	240	0	0	123	98	137	-91	95	-13	-24
154	155	253	0	0	123	98	137	-92	82	-11	-27
155	174	257	0	0	123	98	137	-74	87	-11	-27
156	167	252	0	0	123	98	137	-85	85	-12	-26
157	146	263	0	0	123	98	137	-101	68	-5	-8
158	149	269	0	0	123	98	137	-81	82	-10	-30
159	331	178	0	0	123	98	137	-20	122	-22	-14
160	358	193	0	0	123	98	137	3	119	-6	-4
161	0	0	154	352	123	98	137	38	51	-15	-61
162	0	0	155	358	123	98	137	48	55	-17	-62
163	0	0	155	356	123	98	137	44	54	-16	-61
164	0	0	155	359	123	98	137	46	51	-16	-60
165	0	0	155	364	123	98	137	52	53	-17	-59
166	0	0	166	376	123	98	137	71	63	-28	-62
167	0	0	162	370	123	98	137	65	51	-16	-62
168	0	0	155	379	123	98	137	38	127	-41	-16
169	0	0	177	426	123	98	137	133	68	-37	-51
170	0	0	154	352	123	98	137	0	122	-31	-26
171	0	0	155	358	123	98	137	13	124	-36	-22
172	0	0	155	356	123	98	137	5	124	-34	-22
173	0	0	155	359	123	98	137	7	123	-32	-24
174	0	0	155	364	123	98	137	12	124	-34	-22
175	0	0	166	376	123	98	137	52	132	-54	-9
176	0	0	162	370	123	98	137	27	123	-32	-26
177	0	0	155	379	123	98	137	38	127	-41	-16
178	0	0	177	426	123	98	137	125	134	-58	-5
179	72	150	104	154	123	98	137	-72	21	-11	-37
180	211	99	129	197	123	98	137	16	48	-16	-34
181	72	150	104	154	123	98	137	-101	109	-17	-13
182	211	99	129	197	123	98	137	23	137	-23	0
183	72	150	104	154	123	98	137	-57	41	-16	-37
184	211	99	129	197	123	98	137	39	58	-19	-37
185	72	150	104	154	123	98	137	-85	128	-25	-9
186	211	99	129	197	123	98	137	53	137	-30	0
187	72	150	104	154	123	98	137	-11	35	-36	-4
188	211	99	129	197	123	98	137	84	48	-41	0
189	72	150	104	154	123	98	137	-29	101	-23	-18
190	211	99	129	197	123	98	137	97	137	-34	0
191	72	150	104	154	123	98	137	-11	34	-39	0
192	211	99	129	197	123	98	137	84	48	-41	0
193	72	150	104	154	123	98	137	-30	94	-34	0
194	211	99	129	197	123	98	137	97	137	-34	0
195	72	150	104	154	123	98	137	-95	12	0	-11
196	72	150	104	154	123	98	137	-121	86	0	-3
197	72	150	104	154	123	98	137	-2	41	-15	-35
198	72	150	104	154	123	98	137	-16	91	-10	-37
199	72	150	104	154	123	98	137	-13	11	-3	-15
200	72	150	104	154	123	98	137	-32	76	-4	-9

Table E.3 Economic information (all units $/y).

Case	Machine Cost	Storage Cost	Labor Cost	Seed Cost	Milk Income	Net Return
1	23710	10853	13305	20150	232505	143115
2	23710	10853	13402	20150	235224	146102
3	23710	10853	13449	20150	234826	146507
4	23710	10853	13397	20150	232927	144295
5	23710	10853	13563	20150	233295	145337
6	23710	10853	13433	20150	233071	144432
7	23710	10853	13371	20150	232995	144354
8	23710	10853	13871	20150	235411	149637
9	23710	10853	14196	20150	239162	155288
10	23710	10853	13305	20150	235384	147461
11	23710	10853	13305	20150	232505	143130
12	23710	10853	13305	20150	232775	143548
13	23710	10853	13305	20150	237164	148351
14	23710	10853	13305	20150	233298	144242
15	23710	10853	13305	20150	239087	150550
16	23710	10853	13386	20150	242259	155970
17	23710	10853	13305	20150	232930	145168
18	23710	10853	14196	20150	249664	170196
19	23710	10853	13305	20150	242380	154174
20	23710	10853	13305	20150	200001	116338
21	23710	10853	13402	20150	200001	116968
22	23710	10853	13449	20150	200001	117747
23	23710	10853	13397	20150	200001	117132
24	23710	10853	13563	20150	200001	117895
25	23710	10853	13433	20150	200001	117180
26	23710	10853	13371	20150	200001	117108
27	23710	10853	13871	20150	200001	120419
28	23710	10853	14196	20150	200001	122764
29	23710	10853	13305	20150	200001	118316
30	23710	10853	13305	20150	200001	116350
31	23710	10853	13305	20150	200001	116495
32	23710	10853	13305	20150	200001	117505
33	23710	10853	13305	20150	200001	116708
34	23710	10853	13305	20150	200001	117986
35	23710	10853	13305	20150	200001	120106
36	23710	10853	13305	20150	200001	118053
37	23710	10853	14196	20150	200001	128786
38	23710	10853	13305	20150	200001	119609
39	25012	14505	19229	30375	351562	227001
40	25012	14505	19381	30375	355569	231515
41	25012	14505	19450	30375	353918	231194
42	25012	14505	19396	30375	352921	229324
43	25012	14505	19606	30375	353929	231237
44	25012	14505	19412	30375	352376	228857
45	25012	14505	19349	30375	353247	229556
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47	25012	14505	19229	30375	359701	236515
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50	25012	14505	20615	30375	362071	245519
51	25012	14505	19229	30375	364266	242958
52	25012	14505	20615	30375	375790	266236
53	25012	14505	19229	30375	300001	184447
54	25012	14505	19381	30375	300001	185380
55	25012	14505	19450	30375	299911	186518
56	25012	14505	19396	30375	300001	185594
57	25012	14505	19606	30375	300001	186691
58	25012	14505	19412	30375	300001	185579
59	25012	14505	19349	30375	300001	185553
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62	25012	14505	19229	30375	300001	186914
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64	25012	14505	20615	30375	300001	193782
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66	25012	14505	20615	30375	300001	203135
67	18112	7096	8365	12150	138670	81107
68	18112	7096	8429	12150	140191	82780
69	18112	7096	8445	12150	140287	83197
70	18112	7096	8426	12150	138829	81699
71	18112	7096	8521	12150	138746	82151
72	18112	7096	8444	12150	138854	81802
73	18112	7096	8424	12150	139128	81911
74	18112	7096	8365	12150	139982	83389
75	18112	7096	8365	12150	142351	85121
76	18112	7096	8365	12150	138538	82052
77	18112	7096	8365	12150	142789	86882
78	18112	7096	8924	12150	142576	88024
79	18112	7096	8365	12150	143777	87509
80	18112	7096	8924	12150	148666	96533
81	18112	7096	8365	12150	120000	65829
82	18112	7096	8429	12150	120000	66117
83	18112	7096	8445	12150	120000	66526
84	18112	7096	8426	12150	120000	66232
85	18112	7096	8521	12150	120000	66777
86	18112	7096	8444	12150	120000	66348
87	18112	7096	8424	12150	120000	66200
88	18112	7096	8365	12150	120000	66966
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92	18112	7096	8924	12150	120000	69311
93	18112	7096	8365	12150	120000	67868
94	18112	7096	8924	12150	120000	72698
95	23710	10853	12688	20150	232074	142398
96	23710	10853	13625	20150	241810	158715
97	23710	10853	12688	20150	240114	151381
98	23710	10853	13625	20150	250393	170166
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100	23710	10853	13625	20150	200001	124102
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102	23710	10853	13625	20150	200001	128215
103	23370	10853	11165	20150	233089	144155
104	23370	10853	11194	20150	233258	145044
105	23370	10853	11165	20150	235510	148004
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107	23370	9079	11165	20150	225947	137295
108	23370	9079	11165	20150	235133	147572
109	23370	9079	11165	20150	226995	142603
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111	23370	10853	11194	20150	200001	117610
112	23370	10853	11165	20150	200001	118706
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117	23710	17322	13384	20150	232645	136616
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143	22732	7096	14096	20150	239223	150251
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145	22732	7096	14217	20150	239624	150669
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148	22732	7096	13858	20150	239484	149542
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153	22732	7096	14096	20150	200001	117899
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156	22732	7096	14082	20150	200001	117257
157	22732	7096	13858	20150	200001	118958
158	22732	7096	13858	20150	200001	117163
159	22732	7096	15060	20150	200001	123982
160	22732	7096	15060	20150	200001	130264
161	21382	12314	13171	20150	239329	147357
162	21382	12314	13224	20150	240000	148500
163	21382	12314	13197	20150	239188	147853
164	21382	12314	13221	20150	239469	148123
165	21382	12314	13234	20150	239475	148631
166	21382	12314	13171	20150	250568	158951
167	21382	12314	13171	20150	239907	149578
168	21382	12314	13167	20150	200001	117336
169	21382	12314	13167	20150	250811	163989
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176	21382	12314	13171	20150	200001	116218
177	21382	12314	13167	20150	200001	117336
178	21382	12314	13167	20150	200001	121538
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180	23710	10853	14196	20150	274958	189514
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182	23710	10853	14196	20150	200001	127661
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