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A Simulation Model for Assessing Alternate Strategies for Beef Production with Land, Energy and Economic Constraints

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ABSTRACT

A computer model has been developed to analyze alternate management strategies and energy and economic constraints. Daily production of beef animals and growing crops is simulated in response to prevailing conditions and system interactions using the GASP IV simulation language. Complete inventories of plant dry matter, animal status, production resources and economic net worth are maintained over the simulation period.

INTRODUCTION

The Kentucky BEEF model is an interdisciplinary effort that allows users to effectively evaluate the consequences of various management strategies on plant and animal production, energy consumption and economic return. The farm manager is influenced by many factors when determining a management strategy. These include land, money, animals, fertilizer, fuel, labor, market conditions and other similar types of resources. The manager develops a mental image or "model" of how these resources will interact over his planning period. He then selects a set of management strategies that will best satisfy his management objectives as he envisions the system to function. During his career, he may make 50 sets of management strategies. With each year of experience, he refines his mental model. However, he may complete his career without ever having an accurate picture of how the various system components function together. Agricultural researchers and extension specialists are faced with a similar situation. They must make decisions based on the best information available, even though their "model" may be incomplete. With this situation in mind, the computer simulation BEEF (Beef, Energy and Economic evaluation for Farms) was developed.

BEEF is the result of an interdisciplinary effort by a team of researchers from the Departments of Agricultural Engineering, Animal Science, Agricultural Economics and Agronomy. The project was funded in part by the National Science Foundation (Walker et al., 1977a, b, c). The objective of the research team was to provide a management, planning and teaching tool for researchers, extension specialists and farmers, capable of determining the consequences of various management and research strategies on production. The objective of this paper is to describe the functions and capabilities of the Kentucky BEEF model.

MODELING TECHNIQUE

The BEEF model is a combination continuous-discrete simulation that utilizes FORTRAN IV with the GASP IV simulation language (Pritsker, 1974). The BEEF model contains more than 4,000 source statements and has a total length of approximately 8,000 cards. BEEF requires more than 600 K bytes of computer memory storage and costs approximately one cent per field per simulated day, depending on the number of output options. Presently, BEEF is submitted in batch form. However, some of the subsystems are also used as separate interactive models. The Systems Dynamics approach is used for the continuous portions of the model such as plant and animal growth (Forrester, 1968; Walker et al., 1977b). This approach defines daily rates of growth and utilization of a system component. The growth rate is added to the existing level of the component, while the utilization rate is subtracted. For example, the daily growth rate of a particular forage is influenced by soil fertility, soil pH, cultural practices, etc., while the utilization rate is a function of cattle size, number, and similar factors (Fig. 1). The net effect of these rates, when added to the existing dry matter level on a particular day, gives the dry matter level on the following day.

Discrete activities include scheduling of cultural practices, such as planting or harvesting, and the purchase or sale of resources. A discrete activity occurs instantaneously. That is, at one point in time a purchase is made or the planting of a crop begins. However, the activity may continue over several days after initiation of the activity as is the case with planting a crop.

The BEEF model utilizes a "field" as the area where management activities are directed. A field is defined as a homogeneous land area where any specified management activity occurs over the entire area. For example, if the planting of a crop is scheduled, it must occur over the entire field. There is no limit as to field size.
Because BEEF can be used for planning future activities (e.g., a planning model) it utilizes average weather data in determining crop and animal performance, and has no stochastic processes. However, a period of stress conditions, such as drought, may be imposed by the model user to evaluate the performance of the system under adverse conditions.

BEEF is a “consequences of action” type model; that is, the user may specify almost any set of management decisions and BEEF will determine the consequences of these actions with regard to physical and economic happenings. No judgement is made concerning the desirability of the management decisions; rather the philosophy of BEEF is that “desirability” will be reflected in physical performance and economic return.

The model user specifications take two forms: resources and management (Fig. 2). The resource specifications describe the “capital” available for management at the beginning of the simulation. The management specifications indicate how the existing resources will be used and modified through future production, purchases and sales. Each management specification includes the year, month and day on which the action will occur, and the work rate, field location and other parameters that further describe the management decision. BEEF, through the GASP IV simulation language, carries out the management decisions in sequential order utilizing the resources available at that point in simulated time.

BEEF is divided into four major subsystems: crop growth, animal growth and reproduction, economic activities, and energy. These subsystems are described in great detail by Walker et al. (1977a, b, c), including all the references cited and the numeric relationships used in evaluating alternative management strategies. These relationships were entered into BEEF as “analyst input” data meaning that numeric values of the various input coefficients can be updated as better and more complete information is obtained from other research projects. The analyst input sector also allows the model user to determine the sensitivity of the model to an individual input.

CROP GROWTH

The model, as it is presently constructed, can simulate the growth of 28 different crops and crop mixes that are produced in the cool-season grass regions. The number and kinds of crops can easily be changed to adapt the model to any geographical region. A set of equations is used to describe the normal growth rate during the normal growing season for each crop planted in each field in the best soil in the geographical region supplemented with recommended production practices. During the simulation, these growth rates are modified according to each of the various operations previously specified by the model user.

The operation that result in modification of the normal growth rates of crops are as follows:

1. **Tillage operations:** The simulator monitors the management input specifications for each field and records if the field has been tilled and the timing and method of tillage. This information is used to determine the appropriate growth rate modifier at the time when a crop is planted.

2. **Planting operations:** The analyst input sector stores the normal length of growing season, the time delay for emergence, and the planting date, planting method, and row spacing growth rate modifiers for each crop. When a planting operation is scheduled, the simulator selects the time when the crop will start grow-
ing and appropriate growth rate modifiers for date of
planting, method of planting, and row spacing. This
analyst input information would vary with geographical
area.

3 Fertilizer application operations: Growth rate is
also affected by the available nitrogen, phosphorus, and
potassium. The use rate of each element by each crop per
unit of dry matter produced, and the quantity of each
element that is adequate for normal growth are stored in
the analyst input data. Equations are used to calculate
the loss of nitrogen due to leaching as a function of the
time of the year. The simulator maintains an accounting
of the quantity of each element in the soil according to
amount applied, amount used by the growing crop, and
amount lost. As long as the quantity in the soil is ade­
quate, the growth rate modifier maintains a value of 1.0,
but when the quantity is below the adequate level the
simulator selects an appropriate growth rate modifier.

4 Lime application operations: Growth rate
modifiers for each crop for different values of soil pH are
stored in the analyst input data as are the changes in soil
pH per ton of lime added to different types of soil. The
simulator maintains as accounting of the soil pH in each
field according to the amount of lime applied and deter­
mines the appropriate growth rate modifier as a crop is
growing.

5 Chemical application operations: Growth rate
modifiers for weeds and insects vary according to the
time during the growing season when these pests affect
the growth rate of each crop. The simulator records
the kind of chemical specified by the model user and when it
is applied on each field. If the time arrives when a certain
pest will begin to affect the growth rate of the growing
crop and a chemical has not been applied that will con­
trol the pest, the simulator will select the appropriate
growth rate modifier and use it during the time interval
when the pest affects crop growth.

6 Row crop cultivation operations: Weeds can be
controlled by cultivation and/or herbicides. Before the
simulator selects a growth rate modifier for the effect of
weeds, it will check whether row crop cultivation has
been performed on the field.

7 Pasture maintenance operations: Cool-season
grass pastures may be clipped once or twice each year to
maintain the grass in the vegetative growth stage, control
weeds, and reduce competition when legumes are in­
terseeded into the pastures. The simulator adjusts the
growth rate to the vegetative stage and adjusts accord­
ingly the nutrient content of the growing crop for beef
animals each time a pasture clipping operation is
scheduled on a field.

8 Harvesting operations: Harvesting operations on
cool-season grasses and legumes cause the growth rate
and nutrient content of the growing crop for beef animals
to revert to the vegetative growth stage. On the other
hand, harvesting operations on grain crops cause the
growth rate to become zero and the crop disappears from
the field, leaving crop residue which has a negative
growth rate, i.e., a loss rate. The simulator adjusts the
growth rate and nutrient content of the growing crop and
crop residue each time a harvesting operation is schedul­
ed to harvest a crop. The simulator also maintains an ac­
counting of the crop that is harvested as it is placed in
storage to be fed or sold. Losses of dry matter and
nutrients during harvesting and storage are also ac­
counted for by the simulator.

9 Animal moving operations: Beef animals may be
moved by the model user from field to field during the
year to utilize growing crops by grazing. Grazing beef
animals are constantly harvesting the growing crop and
consequently have an effect on the crop growth rate and
nutrient content. When the quantity of growing dry mat­
ter reaches a certain minimum level, the growth rate of
the crop is reduced because of the reduction in leaf area
to intercept solar energy. The simulator determines
the rate of consumption of growing dry matter by the grazing
animals and maintains an accounting of the quantity of
growing dry matter for each crop on each field. When the
grazing animals reduce the quantity of growing dry mat­
ter below a certain minimum level, the simulator reduces
the growth rate linearly as the quantity of dry matter is
reduced. The simulator maintains an accounting of the
nutrient content for beef animals of the growing crop.
When the quantity of growing dry matter is reduced to a
fixed minimum level by grazing animals, the nutrient
content reverts to the vegetative growth stage of the grow­
ing crop. When the end of the growing season for each
crop is reached, the simulator imposes a linear natural
loss rate, i.e., a negative growth rate, which diminishes
the dry matter left on each field from a previous growing
season. The simulator also maintains an accounting of
the number, age, sex, reproductive status, and weight of
the animals which are grazing the growing crop on each
field (Smith et al., 1977a, b).

ANIMAL GROWTH AND REPRODUCTION

Beef animals have been identified by 12 different
categories for the purpose of simulating their growth and
reproduction. These categories serve to group the
animals according to age, sex, and reproductive status.
The simulator maintains for each field an accounting of
each category for the number of animals, their weighted
average age and average weight per animal. The number
of animals in each category on each field can change
because of age, breeding, animal moving, birth, death
and castration. For example, calves reach 12 months of
age and become yearlings, non-pregnant cows are bred
and become pregnant cows, animals are moved onto or
away from a field, calves are born, death occurs, and
castration of male animals is scheduled.

The simulator changes animals from one category to
another based upon its accounting of the age of each
category and the instructions given in the input specifica­
tions concerning breeding, animals moving, and
castration. The number of animals in each category are
adjusted each time a change is made.

The simulator maintains an accounting of the average
age of the animals in each category on each field by
chronologically updating the age each day. The average
age of the animals in each category on each field can also
be changed, owing to animals being moved into
categories, by birth of calves, breeding, moving animals
from one field to another, castrating male animals, and
reaching an age that transfers animals to another
category. When animals are moved into each category on
each field the simulator computes a new weighted
average age for each category on each field and continues
the chronological updating of age.

Breeding is initiated when yearling and/or mature
bulls are scheduled by the input information to be moved
onto a field with heifers and/or non-pregnant cows, and when artificial insemination is scheduled. Each category of bulls and method of artificial insemination has a characteristic breeding rate, i.e., number of females covered per day, and the simulator computes a breeding rate based upon the number of bulls and cows of each category on each field. The simulator maintains an accounting of the number of heifers and non-pregnant cows that are available for breeding, taking into account a time delay after calving before lactating cows are available for breeding and that yearling heifers have to reach a certain age and weight before they are available for breeding. The simulator also computes the daily rate of gain or loss of weight per animal for each category of female animals that is available for breeding on each field. If the female animals are losing weight, their rate of conception is reduced in proportion to the rate of weight loss. The simulator uses the bull breeding rate, the number of females in each category that are available for breeding, and the rate of gain or loss of weight per female animals in each available category to compute a conception rate for each female category that is available on each field for breeding. Females that conceive are moved into either the pregnant, non-lactating category and/or the pregnant, lactating category. At the time when the conceived females are moved into the pregnant categories, the simulator creates an unborn calf category, and maintains an accounting of the weighted average age of this category. When the average of the unborn calf category is equal to the gestation period, the calves are born and moved into one of the calf categories.

Animal growth is represented by live weight per animal, and growth rate by the rate of change in live weight as a function of time, i.e., gain or loss of weight per animal per day. The model uses input specifications describing feeding and grazing schedules and castration and health care options. Equations and analyst input data describe dry matter demand, dry matter intake, nutrient content of consumed dry matter, and the utilization of consumed dry matter for body maintenance, lactation, and gain (NRCCAN, 1969). These factors are used to simulate the change in live weight of each category of animals on each field as a function of time. The live weight per animal for each category on each field is updated each day of the simulation.

Dry matter demand is based upon the average age of the animals in each category and the potential weight per animal for animals of this age. The potential weight-age relationship for each category of animals are stored in the program. The simulator maintains an accounting of the average age of the animals in each category on each field and selects the weight per animal from the potential weight-age relationship for each category. This weight is used to compute the dry matter demand for each category of animals on each field each day.

Dry matter intake by each category of animals on each field is based upon the dry matter demand, the quantity of dry matter available, the metabolizable energy content of the available dry matter, the incidence of diseases and parasites among the animals, and the mean daily temperature and relative humidity. The simulator maintains an accounting of the dry matter demand for each category of animals on each field. Analyst inputs provide the metabolizable energy content of stored dry matter that is fed, and the simulator maintains an accounting of the dry matter intake by each category of animals on each field using the following procedure:

1. If the amount of dry matter available is equal to or greater than the dry matter demand, the dry matter intake is equal to the demand or the amount which satisfies the need of each category for metabolizable energy, whichever is smaller. When several different kinds of dry matter are available, the amount of intake of each kind is based upon its quantity and metabolizable energy content.

2. If the amount of dry matter available is less than the dry matter demand, the dry matter intake is equal to the amount available or the amount which satisfies the need of each category for metabolizable energy, whichever is smaller.

3. The dry matter intake, according to 1 or 2 above, is reduced by modifiers for the incidence of diseases and parasites and for high levels of temperature and relative humidity.

The dry matter that is consumed by each animal category on each field is utilized by the animals for maintenance of body functions and weight, lactation, and gain in body weight. The simulator determines each day the quantity of dry matter needed by each category of animals for each of these physiological processes, and compares the need with the amount consumed. The dry matter needs are based upon metabolizable energy, digestible protein, and the metabolic body weight of the animals (Lofgreen and Garrett, 1968). If the needs for the body maintenance and lactation are satisfied, then any excess available dry matter is utilized to provide gain in body weight. Conversely, failure to satisfy the needs for body maintenance and lactation results in loss of body weight. Analyst input data provide inflation factors that may be used to increase the dry matter needs for maintenance of body functions and weight due to the incidence of diseases and parasites for each animal category, and at the times during the year when each disease and parasite affects utilization of dry matter. Input specifications describe whether health care operations are scheduled at the proper times to prevent diseases and control parasites. Analyst input data provide the annual distribution of mean daily temperatures and relative humidities, and the simulator uses an equation to compute a reduction factor to reduce the dry matter intake when the temperature and relative humidity are above certain levels.

The model simulates dry matter intake by each category of animals on each field using the following procedure:

1. If the amount of dry matter available is equal to or greater than the dry matter demand, the dry matter intake is equal to the demand or the amount which satisfies the need of each category for metabolizable energy, whichever is smaller. When several different kinds of dry matter are available, the amount of intake of each kind is based upon its quantity and metabolizable energy content.

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ECONOMIC ACTIVITIES

The BEEF model allows the user to make economic decisions in much the same way as he would do under actual conditions. The model user may alter the cash flow of the farm by scheduling of notes (payable or receivable)
and miscellaneous income and expenses. He may purchase or sell his resources, and an income and net worth statement are prepared for him. Expected prices for resources that are either purchased or sold are set by the model user.

**Money Accounts**

BEEF contains three types of money accounts: checking, savings and loans (Fig. 3). Each account contains a quantity of money specified by the user. The checking account has no interest rate associated with it. The interest rates for the savings and loan accounts are specified by the user. However, only one savings account is allowed while the user may borrow from up to seven separate loan accounts. In addition, the user may automatically control the flow of money among accounts by specifying the high and low limits of checking and savings accounts. For example, one of the options is to set limits on his accounts so that if the checking account is overdrawn, money is automatically transferred from savings to checking. When the savings account is overdrawn, money flows to it from the loan accounts.

When a purchase is made, the user must designate the account that will be used for payment. If a loan account is used, interest will accumulate on the unpaid balances. Likewise, the account that will receive money from a sale must be specified. If a loan account receives money, the interest is paid first followed by the principle. Any additional money from the sale flows into the checking account.

**Miscellaneous Income and Expenses**

The user may specify a schedule for miscellaneous income and expense over the simulation period. For example, if the model user wishes to consider income from a part-time job as part of the cash flow in his analysis, he would specify the quantity of money involved and the time that the money would be added to the user specified account.

**Notes Payable and Receivable**

The user may specify notes, either payable or receivable. A schedule of payments is established by the user including the money account to which the note will go. The payments are computed internally as is the present value of the note. The notes payable and receivable section (Fig. 4) allows the user to account for debts incurred before the simulation period begins.
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| ASSETS | MACHINERY | EACH | 3 | 1.00 | 5378.11 | 5378.11 | 5378.11 |
| ASSETS | MACHINERY | EACH | 4 | 1.00 | 5378.11 | 5378.11 | 5378.11 |
| ASSETS | MACHINERY | EACH | 5 | 1.00 | 5378.11 | 5378.11 | 5378.11 |
| ASSETS | MACHINERY | EACH | 6 | 1.00 | 5378.11 | 5378.11 | 5378.11 |
| ASSETS | MACHINERY | EACH | 7 | 1.00 | 5378.11 | 5378.11 | 5378.11 |
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| ASSETS | MACHINERY | EACH | 11 | 1.00 | 5378.11 | 5378.11 | 5378.11 |
| ASSETS | MACHINERY | EACH | 12 | 1.00 | 5378.11 | 5378.11 | 5378.11 |

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| ASSETS | MINERALS | LBS | 1 | 467.52 | 51.43 | 467.52 | 467.52 |

| ASSETS | HAY | TONS | 2 | 22.84 | 513.60 | 22.84 | 513.60 |

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| ASSETS | GRAIN | BUSHELs | 2 | 1235.10 | 522.57 | 1235.10 | 1235.10 |
| ASSETS | GRAIN | BUSHELs | 3 | 9539.29 | 522.57 | 9539.29 | 9539.29 |
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| LIABIL. | NOTES PAYABLE | DOLIARS | 1 | 27895.14 | 27895.14 | 27895.14 |
| LIABIL. | NOTES PAYABLE | DOLIARS | 2 | 27895.14 | 27895.14 | 27895.14 |
| LIABIL. | NOTES PAYABLE | DOLIARS | 3 | 27895.14 | 27895.14 | 27895.14 |
| LIABIL. | NOTES PAYABLE | DOLIARS | 4 | 27895.14 | 27895.14 | 27895.14 |
| LIABIL. | NOTES PAYABLE | DOLIARS | 5 | 27895.14 | 27895.14 | 27895.14 |
| LIABIL. | BANK ACCOUNTS | DOLIARS | 1 | 277.78 | 277.78 | 277.78 |
| LIABIL. | BANK ACCOUNTS | DOLIARS | 2 | 277.78 | 277.78 | 277.78 |
| LIABIL. | BANK ACCOUNTS | DOLIARS | 3 | 277.78 | 277.78 | 277.78 |
| LIABIL. | BANK ACCOUNTS | DOLIARS | 4 | 277.78 | 277.78 | 277.78 |
| LIABIL. | BANK ACCOUNTS | DOLIARS | 5 | 277.78 | 277.78 | 277.78 |

TOTAL ASSETS, DOLIARS | 125014.50 |
TOTAL LIABILITIES, DOLIARS | 34597.64 |
TOTAL NET WORTH, DOLIARS | 90416.86 |

FIG. 6 Net worth.
net worth being another. An inventory of all resource items and their value per unit are maintained internally. The net worth statement (Fig. 6) reflects the values of the expendable items in inventory, the market value of machinery, the market value of land, the present value of notes and loans, and cash on hand. The change in net worth from the beginning of the simulation is also maintained.

ENERGY

The BEEF model maintains an accounting of the energy use incurred on a daily basis for owning and maintaining buildings, fences, and roads, and the energy use for each production operation as it occurs during the simulation. The energy use for production operations is identified according to the amount (Kcal) used for fuel; labor; manufacture, transport, and repair of machines; seed; fertilizer; lime; chemicals; protein supplement; and mineral supplement (Fig. 7). Analyst input data provide energy values for different methods of performing production operations and materials used in these operations; and input specifications describe when and how each operation will be performed. A complete description of the techniques used in BEEF is given by Bridges and Smith, 1979.

OUTPUT

The BEEF model has several forms of output that may be selected by the model user. These include tables, event monitoring and plots with optional tables.

- **Tables**
  BEEF has a standard output set of tables which reflect the initial conditions of the system. If other output information is desired, it must be specified by the user. Additional tables in any combination may be printed with any frequency. The types of table information include land, machinery, money accounts, notes payable, notes receivable, cattle, fertilizer, lime, chemicals, fuel, seed, protein, minerals, silage, haylage, hay, grain, cubes and wafers, growing crops, present worth, and energy factors (Fig. 8).

- **Event Monitoring**
  The BEEF model allows the user to monitor the management decisions (events) that occur over the simulation period. Field operations and herd management operations may be traced over any time period for any number of fields or categories of beef animals. Financial transactions, such as purchases or sales, may also be monitored.

- **Plots with Associated Tables**
  FORTRAN plots with or without associated tables may be selected for energy utilization, cash flow, pasture performance, and animal performance.

The plot for energy utilization shows the components of the energy used in addition to the total quantity used over time. This allows the user to monitor any category of energy consumption, such as for fuel, over the simulation period. For example, the energy input associated with fertilizer application is highlighted in Fig. 9.
The cash flow plot monitors the checking, savings and loan accounts, and the total cash available. Interest on the loan account is also tabulated. A typical transaction is highlighted in Fig. 10.

Pasture performance may be monitored for up to four fields. The dry matter level and rate of growth are presented in addition to other factors. However, no animal performance information is presented in these plots. The effects of hay harvesting on dry matter availability is highlighted in Fig. 11.

Up to four animal performance plots may be obtained. Each category of animals is monitored on a user specified field rather than added together for the cumulative effect over the total farm. Fig. 12 highlights a reduction in gain for steer calves (category 12) because of insufficient dry matter on field no. 2.

**USER INPUTS**

An input booklet was prepared for the BEEF user to assist him in using the model. The book contains a complete set of input forms with detailed instructions for data entry. Each input sheet utilizes a standard FORTRAN input form so that cards may be punched directly. The complete book will require approximately 8 h to complete depending on farm size and the complexity of management strategies. However, changes in resources
FIG. 11 Plotted output of variables related to pasture performance.

Fig. 12 Plotted output of variables related to animal performance.

September 1
Dry matter level

due to insufficient

Dry matter level due to insufficient

May 25
Hay Harvest

Trans. ASAE
1981
or management strategies will require only minutes to input once the basic farm data is available to be used by the computer.

ANALYST INPUT

The BEEF model was developed so that it might be modified by the analyst to reflect differences in geographical areas or to test the sensitivity of the system to certain input parameters. The analyst inputs reflect our best estimates of the effects of management decisions on the production process. These estimates were obtained directly and indirectly from the literature and other researchers using both inductive and deductive reasoning to obtain the best values possible.

SUMMARY

The Kentucky BEEF model is the result of an interdisciplinary effort that incorporates the interactions of growing crops, grazing beef animals, energy utilization, and economics in a farm production system. It is a dynamic computer simulation that utilizes mathematical expressions in determining the physical cause-effect relationships among system components.

BEEF may be used by farmers to plan future management decisions or resource allocations. It may be used by extension specialists and teachers to demonstrate the benefits of sound management practices. And, it may be used by researchers to evaluate the sensitivity of the total system to subsystem interactions and components.

The BEEF model may be used as a cropping model only. Presently, beef animals are the only livestock category that may be considered by the model user. However, swine, dairy, and sheep are currently being added.

The agricultural system is a complex aggregate of subsystems, each somewhat dependent on the other. Maximizing the effect of one particular sector may reduce the functional capability of the total system. What appears to be a sound management practice may result in reduced production for reasons not readily apparent until the system component interactions are evaluated. When this "counter-intuitive" behavior (Forrester, 1971) is analyzed, it leads to greater understanding of the system by the farmer, extension specialist and researcher. The BEEF model was developed to aid in this understanding.

References