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1977

WORKING PAPERS

DOCUMENTS DE TRAVAIL

Dept of Agriculture Canada

Economics Branch | Direction de L'Economie

A BIO-ECONOMIC MODEL OF BEEF, FORAGE AND GRAIN PRODUCTION FOR WESTERN CANADA*

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Unedited Working Paper
For Discussion Purposes Only

* Presented to AAEA-WAEA Annual Meeting, San Diego, California, July 31 - August 3, 1977.

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Abstract

Multidisciplinary research can provide a better understanding of agricultural production problems. A bio-economic model of beef, forage and grain production is described in terms of its biological and economic components. Special applicabilities for this type of model are noted.

Introduction

A broader understanding of agricultural production and agricultural problems can be gained by synthesizing the viewpoints of several disciplines, including economics. Johnson (1971) suggested that many problems faced by decision (or policy) makers are "so complex that the demands they place upon our disciplinary concepts, information, and quantitative techniques exceed the present capabilities of our discipline". Dillon has argued that multidisciplinary research involving economists, biologists, chemists, etc. facilitates a "synthesizing, integrative, team oriented outlook". Teams formed on a problem basis can better attack many of the practical problems facing agricultural decision makers than can the traditional "analytical compartmentalizing and disciplinary" approach.

Johnson (1974) further argued for increased emphasis on simulation modelling of agricultural systems. Simulation models permit decision makers to explore the consequences of particular actions. The multidisciplinary nature of practical problems of decision makers generally precludes optimizing models based upon invalid assumptions (i.e., where the preconditions necessary for maximizing behaviour are not met).

A simulation model is indeed the most appropriate vehicle for modelling a firm from the systems perspective. A simulation model can more easily accommodate the complex biological, physical, chemical, and economic interrelationships involved in production than can models which must fit within the often restrictive confines of particular algorithms.

Dent and Anderson emphasized the importance of a flexible model structure for the representation of agricultural systems. By not relying upon a formal algorithm for solution the model can be "as complex and as realistic as desired within the confines of available data and detailed structure of the real system being modelled". More important than obtaining optimal solutions is tracing the "detailed workings of the system" and being able to simulate the effects of input for decision changes on the outcome of the firm.

The model described herein is a bio-economic simulation model. The firm is viewed as a system that produces several products. Important biological, physical and economic interrelationships have been incorporated. The time dependent processes involved in production are made explicit.

The model can simulate a wide array of management strategies among the beef, forage, and grain production enterprises over a 10 year planning horizon. The inclusion of financial items of a personal and a non-farm nature permits even more diversity in terms of the firm level analyses which may be undertaken.

Overview of the Model

The simulation model described herein was structured in a hierarchical framework. End products are obtained from intermediate products. Intermediate products require resource services. Many of the resource services are composed of elemental inputs.

The chronological nature of biological processes can be made explicit in a hierarchical structure. Intermediate products represent a virtual continuum of the transformation of elemental inputs into end products.

A vector of production alternatives represents the controllable inputs in the model's operation. A production alternative is defined as a specific way of producing either an end product or some clearly defined intermediate product. It is (usually) composed of a series of steps or activities which can be displayed in a decision tree format.

Each of the production alternatives is associated with prespecified input requirements during the various stages of the biological transformation process. These inputs are organized into particular types of jobs, e.g., calving, baling, planting. The model is divided into 26 bi-weekly time periods for each year of operation. The jobs are, therefore, specified by time period.

The user of the model communicates with it through an input form. A completed input form contains the following information:

1. Inventories of buildings, livestock, land, machines, products and financial items with detail on type, capacity or amount and age.
2. Permanent and seasonal labor supplies on a bi-weekly basis.
3. Prices for products and inputs.
4. Technical transformation rates - conception rates, rates of gain, crop yield, etc.
5. Production systems to be evaluated.
6. Consumption requirements.
7. Values for certain parameters to control operation of the model.

The output from the model is a set of tables that contain the following information:

1. Physical activity levels - number of cows, product sales volume, crop acreages, etc.
2. Inventories - capacity, type and remaining value of assets and debts.
3. Financial situation - assets, debts, net worth, cash balance.
4. Resource flows - cash receipts and expenses, labor use, crop production and use, product sales, etc. by two week periods.

The Production Alternatives

The production alternatives included in the model are illustrated in Figure 1. There are six principal methods of producing beef. They are:

1. cow-calf - sell weaned calves,
2. cow-yearling - sell feeder yearlings,
3. cow-calf-feedlot - where weaned calves go directly to the feedlot and are sold as slaughter cattle,
4. cow-yearling-feedlot - where weaned calves are placed in a stocker program for about five months and are then shifted to a feedlot finishing program,
5. cow-yearling-pasture - where weaned calves are placed in a stocker program for the winter, on pasture the following summer, and are sold off-pasture as short-keep feeders,
6. cow-long yearling-feedlot - which is the same as (5) except that short-keep feeders are placed in the feedlot and finished to slaughter weight.

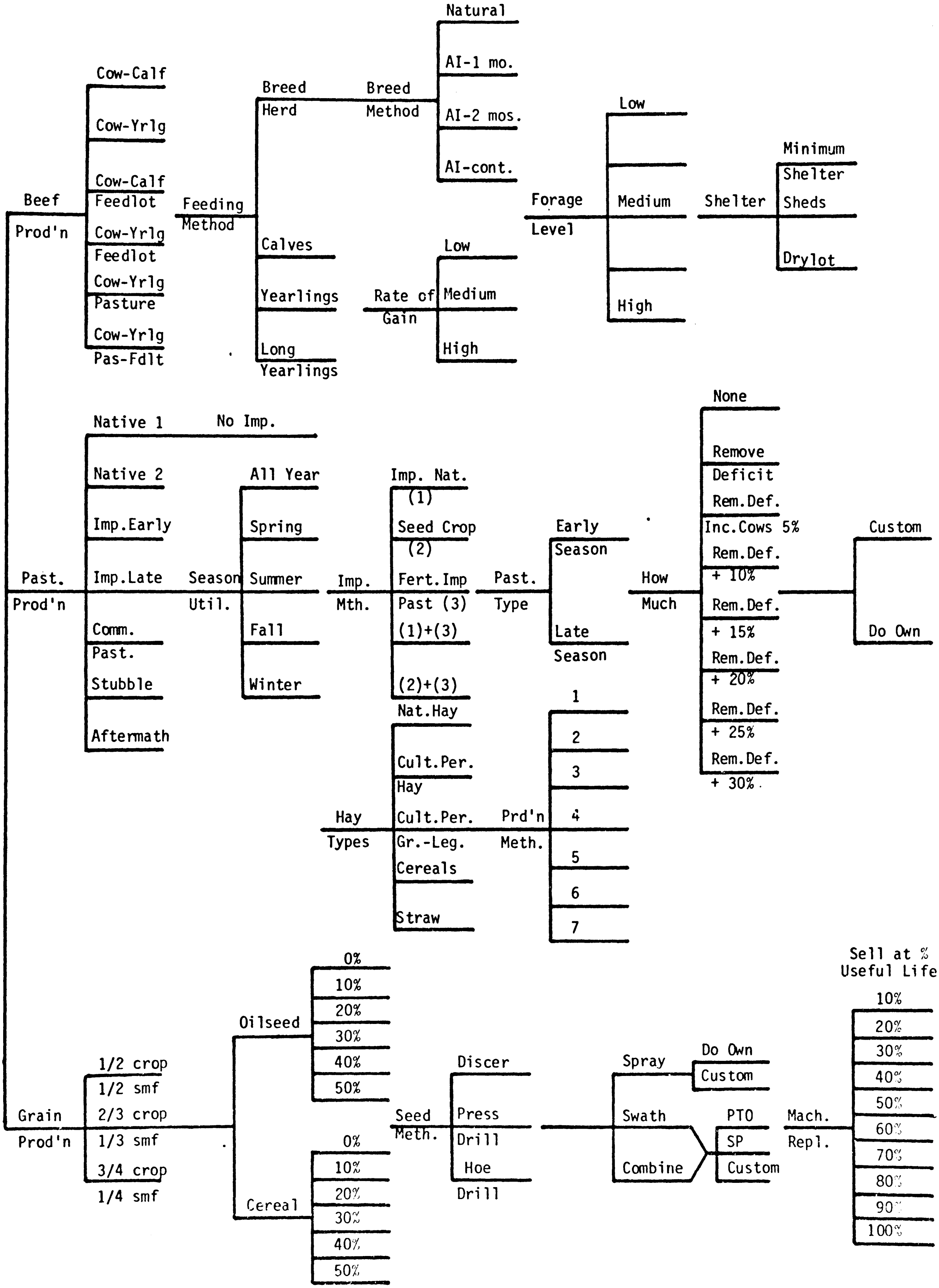

FIGURE 1. SCHEMATIC OF BEEF, FORAGE AND GRAIN PRODUCTION ALTERNATIVES

Other options available include the purchase of feeders or calves, four methods of breeding, optional pregnancy testing, three categories of shelter for each of three classes of cattle, seven lengths of winter feeding period, three rates of gain for feeder calves and feeder yearlings, two rates of gain for long yearlings, five diets each for the breeding herd (during two seasons), stockers, replacement heifers, yearlings, and all low gain animals in the feedlot, four diets for all medium gain feedlot animals, and three diets for all high gain feedlot animals.

There are seven types of pasture in several grazing seasons, five methods of pasture improvement, eight levels of pasture improvement (based on projected increases in the cow herd), two types of improved pasture, and two seasons for improvement of pasture included in the model. In addition, five types of hay and seven methods of harvesting hay are included in the model.

The grain enterprise contains three crops - barley, rapeseed, and cereal forage. Rapeseed and cereal forage are limited to a maximum of 50 percent of the seeded acreage. There are three rotations, three methods of planting, two methods of spraying, two methods of swathing, three methods of combining, ten machine replacement policies, and two grain marketing alternatives available in the model.

Biological Considerations

There are ten classes of livestock in the model ranging from male and female calves, through replacements, stockers, feedlot animals, and breeding herd. The maintenance requirements of each of these classes of cattle are computed for each bi-weekly time period during the year.

Energy and protein requirements are calculated separately for each of the classes of cattle. Salt, calcium, phosphorus, vitamin A, and trace nutrients are aggregated into a cash costs category.

The general form of the energy requirements equation is given in (1):

$$DE_{ik} = (a_i W_{ik}^{.75} + b_i W_{ik}^{.75} G_i) E_i \qquad (1)$$

where: DE_{ik} = digestible energy requirement (kcal) per day for animals of class i (i = 1, 2,···, 10) in biweekly time period k,

a,b = constants which are specific to each class of cattle,

W_{ik} = weight (lbs.) of animals of class i in time period k,

G_i = daily rate of gain (lbs.) of animals of class i,

E_i = feed efficiency index of animals of class i.

Weights and, hence, DE requirements change each period for animals that are gaining or losing weight.

Crude protein (CP) requirements depend on weight, rate of gain, and biological function of the animals. CP requirements are calculated as follows:

i) bulls: $CPR_i = .08F_i$

ii) dry, pregnant cows: $CPR_i = .065F_i$

iii) growing animals: $CPR_i = .4566 + .00081W_i + .276R_i$ (2)

where: CPR_i = crude protein requirements (lbs./day) for animals of class i,

F_i = air dry weight (lbs.) of all feedstuffs consumed by animals of class i,

W_i = weight (lbs.) of animals in class i, and

R_i = rate of gain (lbs./day) of animals in class i.

CP consumption depends on diet composition and protein content of the component feeds. The CP content of a specific diet is calculated from the proportions of perennial hay, cereal hay, straw, and grain in that diet. CP consumption (CPC) from these sources is estimated and compared with CPR. If CPR is greater than CPC a protein supplement is purchased.

Bulls and cows are maintained at their specified weights. Mature cows are assumed to lose twice the birth weight of the calf when giving birth. This weight is regained during the pasture season. Bred heifers gain at a rate such that their weight at first calving is 90 percent of the mature cow weight. Weight loss at calving is twice the calf birth weight. This loss is regained by the time the calf is weaned. Replacements reach mature weight by the time they have their second calf.

The birth weight of calves is exogenous to the model. Weaning weights depend on birth weight, sex, time of calving, and growth rate. Weights for stockers, yearling feeders and slaughter animals at any given time depend on weaning weight, sex and rate of gain. Relative rates of gain of steers and heifers change as they get older. They range from .92 of the daily gain for males for nursing calves to .75 for long yearling feedlot animals.

The number of bulls required for breeding purposes is dependent on the breeding method selected.

The amount of forage that enters the pasture supply in each bi-weekly period depends on the acreage of each type of pasture, the use rate and the yield.

To maintain pastures in a productive state only a fraction of the total growth can be harvested. The proportion that can be harvested while maintaining such a state depends on the species, the utilization method, precipitation, pasture condition and other factors. Use rates are lowest when grazing begins near the start of the growing season. When grazing is delayed into the summer season or later the use rates can be increased.

Pasture yields vary widely from year to year, hence a constant level of carryover is impractical. Use rates can be increased in dry years without damage to the range if it is compensated by reduced use rates and higher carryovers in wet years. The use rates are adjusted in the model as follows:

$$U_{ij} = \bar{U}_{ij} + (1 - \bar{U}_{ij}) * (1 - Y_t) \qquad (3)$$

where: U_{ij} = utilization rate of pasture type i for use method j,

$\bar{U}_{ij}$ = utilization rate for Y_t = 1.0, i.e., average rainfall,

Y_t = pasture yield index in year t (1.0 = average).

When yields (rainfall) are below average ($Y_t < 1.0$), use rates are increased and vice versa.

Pasture yields are highly variable. They depend on species, seasonal precipitation levels, soil fertility, range condition, site (soil type and topography), utilization method and other factors. The pasture yield index in the model is selected each year from a distribution within a range of .75 to 1.34 of average. Yield variability due to precipitation variability is higher when the range condition is low than when it is high.

A pasture deterioration factor is also incorporated into the forage component of the model to reflect the dry matter losses due to factors other than consumption by cattle. In periods outside of the growing season pasture balance is reduced to account for this.

The DE requirements for each type of animal for each bi-weekly time period are converted to quantities of hay, grain and pasture on the basis of the diet selected and average DE values for these three feed categories (1000 kcal. per lb. of air dry feed for hay and pasture and 1550 kcal. per lb. for barley). Equations (4), (5), and (6) describe how pasture production and consumption are reconciled in the model.

$$P_k = P_{k-1} + (PP_k - PR_k) / 2000. \quad (4)$$

$$PP_k = \sum_{j=1}^{5} PA_j * Y * R_t * U_{ij} * YD_{ij} * (1.0 - PD) \quad (5)$$

$$PR_k = \sum_{m=1}^{10} AN_{km} * DE_{km} * PPH_m / 1000. \quad (6)$$

where: P_k = pasture balance in period k (T. DM) ($k \geq 10$),

PP_k = pasture production in period k (lbs. DM),

PR_k = pasture requirements in period k (lbs. DM),

PA_j = acres of pasture type j,

Y = average yield (lbs. of DM per acre),

R_t = rainfall index in year t ($.75 \leq R \leq 1.35$),

U_{ij} = use rate for pasture type j and utilization method i,

YD_{ij} = yield index for pasture type j and utilization method i,

PD = pasture deterioration rate,

AN_{km} = number of animals of type m in period k,

DE_{km} = digestible energy requirement of animal type m in period k (kcal),

PPH_m = proportion of DE from pasture for animal type m,

In addition:

AN_k = f(enterprise size, breeding system, production system, calving rate, mortality rate),

DE_k = f(weight, rate of gain, feed efficiency),

PPH_m = f(diet, feed supply).

If P_k becomes zero, PPH is set to zero and hay or grain is substituted for pasture in the diet.

Dietary considerations place limits on the amount of straw that can be used for feed. The proportion of the forage component of the diet that can be satisfied by straw depends on the class of animal, the forage/grain ratio in the diet, and the source (perennial or cereal hay) of the non-straw forage part of the diet.

Economic Considerations

The objective criterion most commonly used in the model is maximum terminal net worth. However, very minor modifications will permit additional objective criteria such as maximum average net farm income or lexicographic criteria such as maximum terminal net worth subject to minimum income on growth constraints during each year.

All accounting is done on a bi-weekly basis. The cash inflows and outflows (including consumption expenditures[1]) are computed during each two

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[1] Consumption expenditures are withdrawn bi-weekly on the basis of the following annual consumption function:

$$C = Ca + cN$$

where: C = total consumption withdrawal ($),

N = annual net income ($),

Ca = minimum living expenses ($), specified, and

c = proportion of net income withdrawn for consumption ($), specified.

week period. Tax withdrawals, loan payments, and other injections and withdrawals are made at specified time periods during the year. A bi-weekly cash balance is computed.

The production and use of other resources and intermediate products are also calculated on a bi-weekly basis. The various items include grain, hay, and pasture production and use, and labor use by enterprise.

The labor requirement for cows and replacements is a function of the herd size. The proportion of annual labor requirements varies during the year.

Scale economies can also result from the use of larger machines. The operating costs of the tillage, planting, and harvesting machines are dependent upon the draft per foot of width, operating speed, and field efficiency. The model includes from four to ten sizes of each machine. Tractor operating costs are based upon the above factors plus their horsepower related fuel consumption.

The depreciation of each machine is related to its remaining value for future use on the farm. The remaining farm value functions are calculated as:

$$RFV_i = (a)\ REPT\ (b)^{AGE} \qquad (7)$$

where: RFV_i, i = 1, 2, 3, 4 = remaining farm value ($) of each machine in the inventory having depreciation code i,

REPT = replacement cost of machine ($),

AGE = age of machine in years, and

a, b = constants which are specific to each type of machine.

Machine repair costs are based on annual hours of use, age and replacement costs of each machine. The repair and maintenance costs are calculated as:

$$REP_i = a\ H^{b_1}\ Y^{b_2}$$

where: REP_i = repair costs ($/hr/$1000 replacement cost) for machines of class i (i = 1, 2, ···, 10)

H = annual hours of use of the machine,

a, b_1, b_2 are constants specific to each type of machine.

<u>Application of the Model</u>

The simulation model described herein can be employed in various ways. The model provides many opportunities for classroom teaching of farm management principles. On an extension basis, the model can be used to analyze a wide variety of management and investment strategies. As a research tool, the model can be used in several ways. Examples of its adaptability in this regard are:

1) to assist in the planning and direction of applied research,

2) to assist in the evaluation of applied research results,

3) to examine firm level effects of various policy alternatives,

4) to compute prebudgets for aggregate programming models.

The flexibility of the model is probably its greatest attribute. A wide range of data collected from various areas of expertise have been incorporated into the model. However, the model is really no more than a skeleton. Farmer specific data can supplant the "expert data" in most areas of concern by appropriate insertions in the input form.

The present model has evolved over a 4-5 year period. Many alterations (conceptual and empirical) have been made over this time period. The model will undoubtedly continue to evolve as new data become available or as new research or extension problems are presented.

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