BIOECONOMIC MODELING IN FARMING SYSTEMS RESEARCH: A CASE STUDY OF DAIRY IN THREE STATES OF INDIA

S. Vijayalakshmi[1], P. Stonehouse[2], C.B. Singh[3], J.A. Renkema[4] and B.R. Patil[5]

SUMMARY

Optimum production plans for mixed farming systems with mixed crop and dairy enterprise as source of income were developed by using linear programming. The models included physical, financial and biological aspect of the system by analysing average and generalised small farm situations from three different Indian states. One of the cases was studied with a static model for seven technology combinations. All three cases were studied with a multiperiod program on only one technology combination. The possibility to reduce the yield gap between potential and actual performance of cross-bred cows by enhancing the nutritive quality of straw by urea/ammonia treatment was studied. It is clear that the technique of feeding urea treated straw can be complementary to current cross-breeding programs in India only in certain farming systems. The modeling exercise showed a) the importance of the feeding sub-system in the overall system and the effect of the seasonal availability of straw and b) the major limiting factor with the assumptions in the static model seem to be "feed" in the dry farming areas of Baroda, "capital" in the Bangalore system and "labour" in the irrigated area of Karnal. The dynamic model showed that a) initially capital is limiting in the Bangalore case, but that feed becomes limiting over time if no animals are sold, b) in general, availability of working capital increases the resource utilization in all three situations, c) strategic decisions such as investment on animals can be better understood if the optimum plan covers more than one year and/or seasons, d) the limitations of modeling exercises stem from lack of data regarding rainfall distribution, dung management for fuel, crops and marketing, labour utilization, feeding system and farmers' management practices for output and input utilization.

INTRODUCTION

Many agricultural production systems in developing countries are based on mixed farming with a tradition of crop-livestock integration. The density, concentration and combination of various categories of livestock are related to natural factors

[1] MDRI/SRS, Adugodi, Bangalore-560030, Karnataka, India

[2] Ontario Agricultural College, Department of Agricultural Economics and Business, Guelph, Ontario, Canada

[3] MDRI-ESM, Karnal-132001, Haryana, India.

[4] Department of Agricultural Economics, Agicultural University, Hollandseweg 1, Wageningen, the Netherlands

[5] BAIF, Krishigosamvardhana Kendra, Makarpura, Gujarat 390014, Baroda, India

(climate, soil condition), and man-made factors (irrigation, type of farming, cropping pattern and size of holding).

The allocation of resources over time depends on the efficiency of each farm enterprise and overall system performance, based on (biological) interactions of soil, crop and animal components in mixed farming system. Efficiency and system performance depend in turn on level of sophistication and types of production and marketing technologies employed, and in particular on the management skills and abilities of the farmer. That is, the rate at which the resources of the farm are utilized, conserved, revised and reinvigorated depends on biological and ecological as well as on peripheral economic and social constraints.

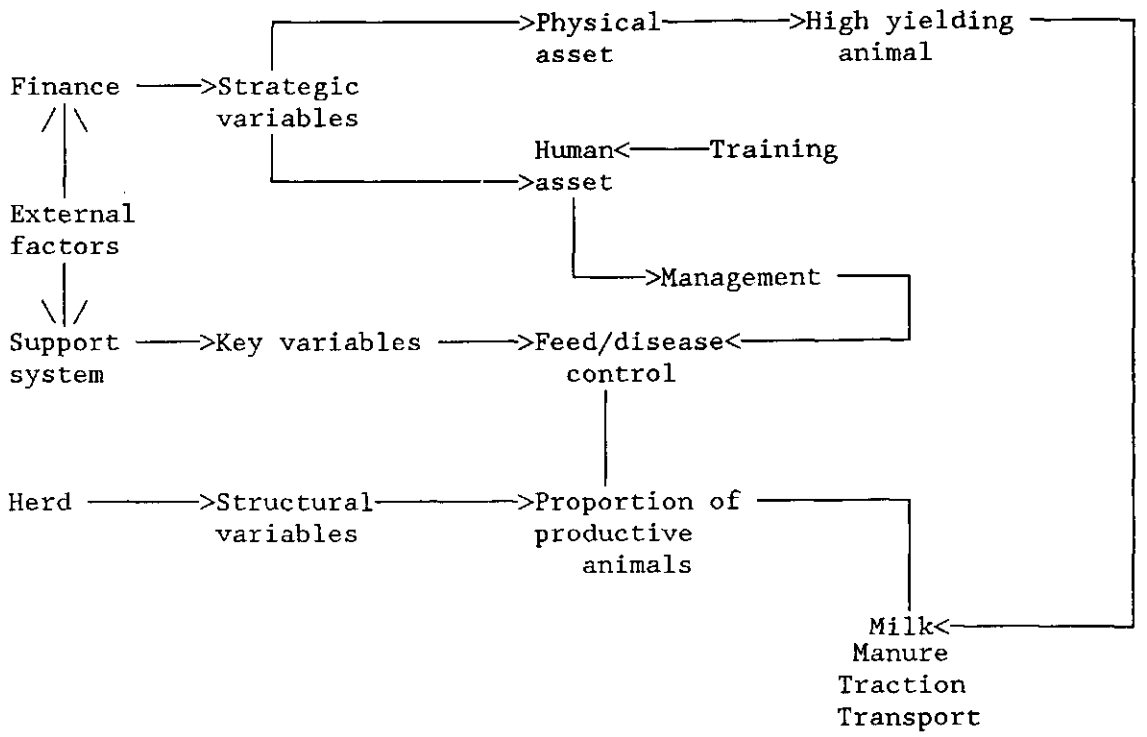
Resource allocation decisions made at one point, affect farm operations for months or even years to come. This is arguably more critical in livestock enterprises. Factors such as the mobility of animals and their long life cycle, non-divisibility and size of units, multiplicity of outputs etc., make the decision making complex (Baker *et al.*, 1988). The animal sub-system in India is undergoing radical changes, primarily by a shift to commercial dairying and decreasing fodder resources (Jodha, 1986 ; Vaidyanathan, 1981). The production efficiency in terms of realization of superior genetic potential of (cross-bred) cows depends on production and management factors and interaction exists between biological characteristics of a cow and optimum management (Van Arendonk, 1988). The social organization of agriculture in developing countries is based on a large number of small family-operated farm units (FAO, 1988). The linkages within the sub-system (Figure 1) shows that the human asset of the farm needs to be supplemented periodically by improved management skills/knowledge infusions for both farm men and women. The cumulative and long term nature of human resource development process is a significant and strategic variable in the system (Gill, 1990).

The majority of farm families in India (with an average of less than two hectares) are often subjected to uncertainties of the monsoon. Such farm families have always sought to wrest a livelihood in remarkably diverse ways, e.g. small farms diversify their enterprise mix, existing resources are put into multiple use and multiple use of a crop or animal is sought. Isolated attempts by each discipline to transfer improved technology to (small) farms are undertaken, but they invariably only touch the fringe of the problem (Haverkort *et al.*, 1988). A superior approach would employ holistic methods of transferring technology incorporating all biological (soil, crop, animal), engineering, and soci-economic aspects, including new or upgraded management skills. This implies the need for a systems approach.

The concept of systems thinking became again popular among agriculturists about two decades ago, and is undertaken on different levels (Dent, 1975; Patel *et al.*, 1993; Fresco and

Westphal, 1988; Conway and Barbier, 1990):
- bio-chemical and physical systems,
- plant and animal systems,
- farm business systems,
- national and international systems.

Figure 1 Farm Production Linkages in a Dairy Sub-system.



The application of systems concept at farm level by model building is difficult when biological data are assessed according to socio-commercial criteria (Dent, 1975). Moreover, dynamics are extremely important in any farming system with biological processes, different resource requirement over seasons, cash flows over years for long term investments and the time lag between input and output. Decision making in agriculture realistically operates in a multi-period environment (Stonehouse, 1981).

Recently, increased focus is put on blending crop-livestock technology, to ensure that farms achieve optimum exploitation of crop biomass for animal production and effective utilization of animal traction and manurial value for crop production. Multi-level farm activities are not yet evaluated sufficiently in an integrated and comprehensive manner while addressing policy

issues involving the provision of physical, financial and social stimulants to the farming community, e.g.:
- new grain varieties are introduced with little attention to straw quantity and quality for animal feeding,
- programs of dairy cattle cross-breeding does not sufficiently consider the availability of feed resources.

The farming system approach is a research imperative to provide appropriate decision support: in strategic, structural or in key/critical variables of production-modeling of whole farm enterprises including linkages (Charlton, 1975). Models need to be built on sound data (Swaminathan, 1981) and theoretical underpinning and include:
- zone-wise typology of soil, water holding capacity of soil, humus content and extent of erosion due to wind, water etc. (Jain and Dhaka, 1993);
- efficient ways to replenish soil nutrients with livestock excreta;
- the breed and the type of animal suited to be raised economically on the forage, crop residues and other by-products that are locally available;
- post harvest technology to utilize other food/fibre available for the use of dairy animals (Sampath, 1983).

OBJECTIVES OF THIS STUDY

Development efforts aimed at integration of crop and dairy enterprises have resulted in general improvements for small farmers, whose potential income gains were often larger than for large farms (Banerjee, 1987). However, the reverse could be true in other areas where adequate infrastructure does not exist. Simultaneous and integrated introduction of technology for crop production by improved seeds, of milk production by improved breeds, sustained by improving feed resources and feeding systems can accelerate the growth of farming communities. This paper describes the (simultaneous) introduction of three technologies:
- new seeds (high-yielding variety),
- use of dairy breeds (cross-breeding),
- improved availability of feed (treated straw).

The introduction of these technologies was simulated for generalized and hypothetical small farm situations of three farming systems in the districts of Bangalore (Karnataka State), Karnal (Haryana state) and Baroda (Gujarat State).

The cases were modelled by using multi-period linear programming (Stonehouse, 1981) to estimate the optimal farm plans. The main objectives of these models were:
- to design optimum farm plans at different levels of technology for the whole mixed farm situation, integrating physical, financial and biological resources of small farm situations,
- to study the stability of the system by adding a dimension of time and risk.

Many alternative empirical modeling techniques were considered for this study, including econometrics, simulation, and mathematical programming models. The last of these appeared to be the most desirable because:

- the problem setting to be analyzed reflects the small farmer's desire to find the most efficient method of allocating scarce resources, given multiple input opportunities, including alternative technologies, and given multiple output choices;
- the range analysis option available with mathematical programming techniques provides useful information about the stability of optimum solutions obtained;
- the duality theorem associated with mathematical programming techniques ensures the derivation of "shadow prices" (or marginal value products) attached to those farmer's resources that are in scarce supply, thus revealing where the most important production or marketing bottlenecks are in any farming system.

In particular, multi-period (as opposed to static) linear programming models were selected in order to embody the all-important time dimension in small farm business studies. The time dimension was incorporated in two important respects. First, intra-year structures allowed for seasonal crop production analysis so important in the multi-cropping setting in India, and also permitted analysis of cash flow and short-term credit needs. Second, inter-year structures allowed for biological production time lags associated with bovine reproduction and herd replacement to be analyzed. Furthermore, the indivisible nature of dairy herd units was felt to be critical, especially for small farms in India where cow numbers may total only from two to six. In order to obtain only integer activity level result for all livestock real variables, these variables were declared integer types in the models. Thus, the modeling technique used was the multi-period, mixed integer programming approach.

THE MODEL: ASSUMPTIONS AND STRUCTURE

Agro-climatological details of the districts and resource levels of the small farms are given in Table 1. Data for Bangalore were updated with 1988-1989 prices along with the technical coefficient details of a past study (Vijayalakshmi, 1985). The information on the Baroda and Karnal situation is simplified and taken from unpublished data of the other authors.

The optimum plans for seven combinations of technology adoption were studied with a static plan. The stability of the final model was further tested with a dynamic model. Both the static and dynamic models were based on the work of Vijayalakshmi *et al.* (1990). They consider an optimum plan over four years, explicitly allowing changes in herd structure, and using calf and heifer mortality of 20%, delayed calving for 50% of milch cows and a 10% inflationary trend for input and output prices. The dynamic model

Table 1 Description of the study area and farm characteristics.

Particulars	Unit	District of		
		Bangalore (Karnataka)	Baroda (Gujarat)	Karnal (Haryana)
Agro-climatological information				
Av. Rainfall	mm	794	750	700-1200
Temperature	°C	12 to 30	10 - 45	2 - 40
Soil type		Red loamy	Black with heavy clay	Loamy
Major food crop		Fingermillet	Sorghum	Wheat and Paddy
Average Small Farm Situation				
Operational land holding	ha	2	2	1.2
Irrigated area	%	20	0	100
Family size	persons	6.28	6.9	6.39
Family labour	persons	3.68	3	2.33
Milch animal/household	animals	3.59	1	2.11
Herd size/household	animals	5.59	6.1	5

connects farm investment decisions for buying of cows on borrowed money over four years with repayment of loan and interest rate. A female calf born in the first year was considered to be a growing animal up to the third year, after which it starts to produce milk. A female calf born in the second year would start lactating in the fifth year if feed would be sufficient.

RESULTS AND DISCUSSIONS

In order to test the structure of the empirical models and validate them in a logical and systematic fashion, model-building proceeded in stages. First, a static (one year) linear programming model was developed. This was extended to a multi-period linear programming, and finally the dairy livestock activities were put in integer from (i.e. fractions of livestock numbers were not allowed).

The static model: Case I - Bangalore

The different levels of techology are shown in the top part of Table 2 for the static LP model.
Resource utilization and income for each plan is shown in Table 2. With INR 10000 for working capital, different levels of

technology introduction gave different combinations of crop and dairy for the total enterprise. In general, unirrigated land was utilized for fingermillet, sorghum and fodder trees, and irrigated land was utilized for paddy, maize and groundnut. The number of dairy animals in each plan varies between 2 to 3 (Vijayalakshimi *et al.*, 1990). The general conclusion from the optimum plans are that:

- an increased level of technology on crop and dairy can increase farm income;
- the requirement for feed purchases are affected by seasonal fluctuations in farm produced by-products;
- treatment of straw can be cost effective, irrespective of level of technology. This can be explained because the model assumes reasonable level of milk production, marketing possibilities and cheap availability of home-grown straw. Therefore, in this case the conditions for successful straw treatment are fulfilled as described by Schiere *et al.* (1988) and Kumar *et al.* (1993). Furthermore, only one technology is considered, and no inference can be drawn over the usefulness of other technologies.

It should be noted that a higher technology adoption in crop/dairy enterprise should require more managerial skill for integration of crop and dairy production. This is not, however, reflected in the farm plan.

The dynamic model for Bangalore, Baroda and Karnal cases

Case 1 - Bangalore

The feasibility of paddy straw treatment over four years under the conditions of plan 7 in Table 2 was further tested in a dynamic model (Table 3). The results of the plan with treated straw shows an impact in the optimal farm plan only in the fourth year when one female calf of year one started to produce milk. However, the plan was infeasible if all the calves in year two start to produce milk in the fifth year because of feed shortages. Calf management will have to be modified to adjust for this. With the starting capital in year one as INR 30000 and 20000 in the subsequent years the plan allows in the first year 3.9 cross-bred cows producing a total of 7100 kg of milk. In the second year, due to the presence of some animals with prolonged dry days, the milk production decreased, to again increase in year 3 and 4 by the advancement of lactation number of milk cows and entry of a heifer as milk producer in the fourth year. The crop production shows a stable income with 100 percent cropping intensity except in year one where the annual crop of fodder trees occupied only 0.5 acre. The entire straw supply was fully utilized in 4th year where the number of animals exceeded six. Up to the fourth year the higher straw requirement was met by increasing the area under fingermillet. However, dry fodder availability becomes limiting in the fifth year, where the number of animals was further increased and if no disposal (sale) of

animals was allowed (Vijayalakshmi *et al.*, 1990). Therefore the model should be expanded by providing marketing options for animals.

Table 2 Resource utilization and income generated by different technology combinations, according to the static model for the Bangalore case.

Details		Plan1	Plan2	Plan3	Plan4	Plan5	Plan6	Plan7
Level of Technology (%)								
Seed		0	50	50	50	50	100	100
Breed		0	0	0	100	100	100	100
Feed		0	0	100	0	100	0	100
Land								
Cropping intensity(%) (*)		46.8	87.1	92.2	94.6	85.5	85.2	85.2
Capital								
Utilized	INR	7252	8427	16234	14428	15155	17151	16982
For feed alone	INR	4643	4303	4199	10624	10829	13898	9794
Income from								
Crop	INR	2499	9217	10733	9922	10007	11735	11977
Dairy	INR	4096	4056	4056	16764	18324	16764	18520
Others (**)	INR	2400	-	-	-	-	-	-
Total	INR	8995	13273	14789	26686	28331	28499	30497

(*) cropping intensity = net cropped area from all crops / level area devoted to crops; (**) others = non farm activities, i.e. wage for outside labour.

Table 3 Credit and cash flow statement for four years-with treated straw**, based on dynamic linear programming model results for Bangalore Case Study.

Details	Year 1	Year 2	Year 3	Year 4	Total
Loan outstanding	9672	8221	5803	2901	
Interest paid	1354	1151	812	406	3723
Repayment of loan	1451	2418	2901	2901	9672
Cash outflow:					
Crop	6855	7555	7654	7784	29848
Dairy	20179	17435	15495	13705	66814
Total *	30950	28559	26862	24796	111167
Cash inflow:					
Crop	15743	20507	20507	20507	77264
Dairy	25632	25422	25181	31625	107860
Total	41375	45929	45688	52132	185115
Cash balance ***	10410	17370	18826	27336	73948

* includes repayment of loans both for capital investment as well as for working capital (short term purposes);
** data for use of untreated straw are available with the principal author;
*** excluding cost of family labour, since that is not limiting (Vijayalaksmi, 1985).

The credit and cash flow over four years based on the linear programming model for Bangalore is now described. With a starting capital of 30,000 in the first year and 20,000 in the each subsequent year the plan shows a cumulative income of INR 102400 for four years. Table 3 shows the details of the cash flow, which was calculated with dynamic model. There is an unequal cash

balance of the farm over four years, but the cash balance becomes more positive at an increasing rate of the total loan amount for purchase of cows allowed as INR 12000, the plan utilized only INRR 9672. This is due to the roughage being sufficient to support an expanded herd size up to year 4. This is also indicated by the model results showing a gradual accumulation of concentrate feed over and above animal requirements (4 kg/day). The multi-period model with untreated straw had shown higher cash expenditure for purchase of feeds compared to the plan with treated straw, relating to the usefulness of straw treatment over years as discussed earlier.

Case 2 - Baroda

This case is an elaboration of the one discussed by Patil *et al.* (1993). More details of the farm situation in Baroda are needed to make the model more realistic. But the available information shows that with a free choice of cropping pattern, with the use of sorghum and cotton crop on rainfed area and INR 5000 as working capital, the model uses a cotton crop on the maximum area, and the sorghum crop was reduced to the requirement for home consumption. This indirectly limited the possibility to include a milch animal to less than one, due to limited availability of sorghum straw. When working capital availability was increased to INR 10000, still little more than one animal could be sustained, mainly using purchased feed. This type of feeding system is uncommon in the case study area, i.e. modifications were included such as the access to fodder from common grazing land and reduced area under cotton. With this modification, with INR 5000 as working capital, buffaloes entered the farm plan and milk sales contributed considerably to farm income. Cross-bred cows entered only at higher working capital availability. The dynamic model suggests use of a lower number of animals, and slower herd expansion, in the second year. Multi-purpose use of cattle and buffalo needs to be accounted for when building the model. The important points that emerge from this simplified and analysis with limited data are that:

- the feeding system of the area pre-supposes good pasture land for grazing at least 5 to 7 months in a year, which would require significant intervention by a wastelands rehabilitation or similar program;
- the multiple use of animals for "outputs" like dung, asset value etc. needs to be better quantified and incorporated in the model.

Case 3 - Karnal

The Karnal district has good irrigation facilities and gives optimum farm plans that differ from the Bangalore and Baroda cases. With INR 5000 as starting working capital and milk sales as an additional source of working capital, most income is derived from cropping. Even when the capital availability was

increased to INR 10000 the optimum plan did not include enough animals to utilize all the straw and green fodder that was available in the plan. The reason can be that labour was the limiting factor during the kharif and rabi seasons where crop cultivation utilized maximum family labour. When the labour constraint was relaxed by hiring labour, the model gave less income. This indicates a combined limiting effect of capital and family labour for the small farm situation of the Karnal case, and also that hired labour is expensive compared with family labour (Singh *et al.*, 1993).

The Karnal case (with very limited data) shows the following points:

- labour should be allocated operation-wise to build a better model;
- more forage cropping can be done on summer fallow land, and vegetables could be a source of additional income for the family and feed for animals;
- feeding of chopped paddy straw and berseem should be considered as per the nutritive value of combined feed;
- labour availability could be a problem with these options but in the actual situation, chopping is indeed practiced (De Wit *et al.*, 1993).

CONCLUSIONS

The usefulness of technological innovations for livestock production cannot be seen in isolation from crop production, in cases where crops and livestock occur integrated on farms. Economic modeling can be useful to study the interrelations of the system, for *ex ante* analysis of effects of innovations and to determine constraints in the system. Especially livestock production is of a long term nature. It is affected by seasonal fluctuations in feed and labour supply as well as market prices. Moreover, a decision in one year is likely to affect the results of the system over years to come. Therefore not only static models, but also models with a time dimension are required for analysis of crop and livestock systems. With limited data available for three cases of distinct farming systems in India, it was tentatively shown that the three systems had also distinct constraints, i.e. capital and straw for Bangalore, concentrate feed for Baroda and labour for Karnal. The models and data used need to be refined, but the results show a need to design different development approaches as per the constraints in the prevailing farming system.

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