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MODELLING OF INTEGRATED ENERGY SYSTEMS FOR FOOD PRODUCTION IN BANGLADESH

B. K. Bala[1] M. A. Satter[2]

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ABSTRACT

Previous efforts in energy modelling have been reviewed and critically examined. A model based on system dynamics approach has been formulated for integrated energy use for food production. The model considers the integrated energy use in the form of draft power from cattle, manually operated irrigation water lifting devices and organic manure from cowdung. The model effectively takes into account of feedback loops, non-linearity and time-lag characteristics inherent in the real world system. The model structure of the system consists of basically two components, levels and rates. The model will provide greater insights and better understanding of the system and can be used to investigate the alternative policy actions and trade offs in developing countries.

INTRODUCTION

Food production systems in Bangladesh are still traditional and are mainly based on biomass, animal and human energy and commercial fertilizer. The biomass energy is being used at an extremely high rate and is running out rapidly due to high population growth and declining per household animal population. The animal draught power is in a state of short supply creating thrust for gradual introduction of mechanical devices in the agricultural sector which affect employment and income distribution. Again there exists an acute shortage of food from the domestic supply sources. A rational approach striving for self reliance in food and energy should consider an integrated approach i.e. systems approach to the food production through sagacious use of available energy. This is the background for energy planners where the computer models have great potentiality to help understand better decision making processes.

The purpose of this paper is (i) to provide a general overview of modelling in the energy field and (ii) to present a system dynamics model of integrated energy systems for Bangladesh for policy analysis and trade offs.

Baughman and Hnyilicza (1975) presented an overview of modelling in the energy field and have examined the various methodological approaches available and discussed the alternative ways in which model can be used, through simulation and optimization. Jordanides and Meditch (1977) critically reviewed the previous efforts in modelling petroleum utilization in the United States and formulated a system dynamics model for policy analysis on both the short and long term utilization of petroleum.

Walker (1984) presented a state space method for designing and evaluating integrated energy systems into agricultural production system. Stout and Myers (1978) designed a comprehensive manual for energy use in world-wide agriculture.

[1] Professor [2] Associate Professor
Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh

This manual presents energy flow in the food production system and energy requirements for each operation of production, processing and delivery.

Pellizi (1984) simulated an integrated energy system for a Kenyan village and indicated that the system can cover the villagers' energy requirements with minimum cost associated with food self sufficiency and raised standard of living. Adams *et al.* (1982) developed an analytical model of the production and distribution of biomass liquid fuel and their economic relationship with the production and distribution of other agricultural products, by maximization of non-linear objective functions, subjected to linear restrictions and recommended the implementation of the national alcohol plan for its beneficial effects on agricultural sector.

Lewis *et al.* (1982) developed a system dynamics model for a South Indian village to demonstrate how biogas plants could develop within such a village purely under economic forces with the rate of introduction controlled by the mechanism of price. The adoption of the system has been shown to increase food production potentiality by 200%, indigenous energy production by 85% and overall solar energy capture by over 150%, within a simulated period of 12 years.

Kennes *et al.* (1984) presented a detailed quantitative picture of biomass production in Bangladesh and revealed the picture of skewed energy use among nine categories of socio-economic classes. The authors are of the opinion that simulation is the best available rational means to study the effects of policy measures for such a complex system. Huq (1975) proposed a more complete and realistic model for integrated rural energy utilization in Bangladesh. Bala and Satter (1986) proposed a system dynamics model of rural energy systems to provide greater insights and better understanding of the complex rural energy systems and a rational basis for policy analysis.

Nail (1992) reported an integrated model of U.S energy supply and demand, which is used to prepare projections for energy policy analysis in the U.S. Department of Energy's Office of Policy, Planning and Analysis. This model was implemented at the Department of Energy in 1978 as an in-home analytical tool and has been used regularly for national energy policy analysis since that time.

Alam *et al.* (1991) developed a system dynamics model for integrated rural energy system. The potentiality of the model was illustrated at the micro level by using the data of a village in Bangladesh. The model was also applied in agriculture for macro-level policy analysis.

Luhanga *et al.* (1993) reported the LEAP Model for Tanzania energy planning through the optimization models in combination with a forecasting program for sustainable development planning.

Bala (1997) presented projection of rural energy supply and demand and assessed the contributions to global warming for Bangladesh. The output of a dynamic system model was used in the LEAP model and overall energy balance were then compiled using a bottom-up approach.

Satter (1995) developed a system dynamics model of agricultural mechanization in Bangladesh and successfully showed how social, economic and technological elements can be combined for their impacts on rice production.

MODELLING OF THE SYSTEM

Bangladesh is a densely populated rural based food deficit country associated with rapidly diminishing bio-energy resources. Self reliant development of Bangladesh should not only consider population control measures and increased production policies but also need to take into account of integrated use of energy for improving quality of life and self sufficiency in energy. On recognizing the above facts the study of simulation models of integrated energy systems has been initiated by Huq (1975), Bala and Satter (1986) and Bala (1997). This paper reports the modelling and simulation of integrated energy systems for food production. Integrated energy system is a complex combination of social, economic and technological elements containing inherent time-lag characteristics and non-linearity. The system dynamics methodology developed by Forrester (1968) is probably the most appropriate available technique to study the dynamic behaviour of such a complex system.

The model consists of four sub-models as shown in Fig. 1 to Fig. 4. The model has been adopted for Bangladesh to determine the level of food production influenced by irrigation practices, draft energy availability from animal sources and the amount of fertilizer applied. The cattle supplies the entire draft energy for land preparation in Bangladesh. The cattle population is determined by birth and importation rates, and consumption rates. Price links cattle population non-linearly through deficit in draft power, production and consumption. Cattle raisers adjust their current expected price by exponentially smoothing actual price received in the past, and accordingly their expectation to raise cattle is being continuously adjusted by the mechanism of price. The cattle production rate is either increased or decreased continuously to adjust the gap between actual and desired capacity over a period of 2 years. The cattle production rate is also highly influenced by straw availability which is the principal source of staple food supply for Bangladesh cattle.

Fig. 3 shows the management policy of cowdung manure for crop production. Cowdung contains nitrogen, phosphorus and potassium which are highly required to be supplemented in the crop field if desired cropping intensity and yield rate are to be maintained. This model considers the balancing of nitrogen by applying required amount of cowdung with removal rates per crop. Phosphorous and potassium are supplemented by commercial fertilizer if there exists any deficit in the manure applied areas. This model shows quantitatively the fraction of crop area being covered by cowdung manure.

Irrigation expansion has been incorporated in this model in the way that all the irrigated areas will be covered by high yielding varieties of rice and has the cropping intensity of 200%. The potential coverage by indigenous and manual irrigation methods have been considered first and then the remaining irrigable areas will be covered by mechanical methods.

SIMULATED RESULTS

The model developed in this study was written in BASIC and simulated on a micro-computer. The results for some important variables are shown in Fig. 5 to Fig. 8. The population and total food production are shown to rise to 1.29715×10^8 and 1.4785×10^{10} kg by the year 2000, but the per capita food available is found to vary within the range of 170.2 kg to 116.38 kg and is below subsistence level (Fig. 5). Cattle population and draft power levels are shown to change with time (Fig. 6). The simulated run also projects organic manure available as a fertilizer to supplement the nitrogen, phosphorus and potassium requirements and the numbers of traditional and modern irrigation units to be used to increase food production and employment in irrigated agriculture.

DISCUSSION AND CONCLUSION

The model predicts the commonly observed phenomenon of increased food production with increased irrigated area coverage by exogenous policy input of irrigation. The pulsating behaviour of the simulated food production has been contributed by the possible limit cycle oscillation of the cattle production system which is mainly due to the inherent non-linearity of the system. As the cattle population supplies the draft power for tillage operation, this phenomenon is obvious as long as there is any deficit of draft power in any form. Again the cattle population is influenced by the availability of food in the form of straw and fodder which in turn supplies draft power and dung as fertilizer. Thus food production is closely related to animal production in Bangladesh and the pulsating behaviour of the food production can be ironed out possibly by the removal of the deficit.

The simulated cattle population is not far removed from the prediction of Dickey and Hoque (1986), but shows limit cycle oscillation as explained above and has been subjected to ramp input of cattle importation.

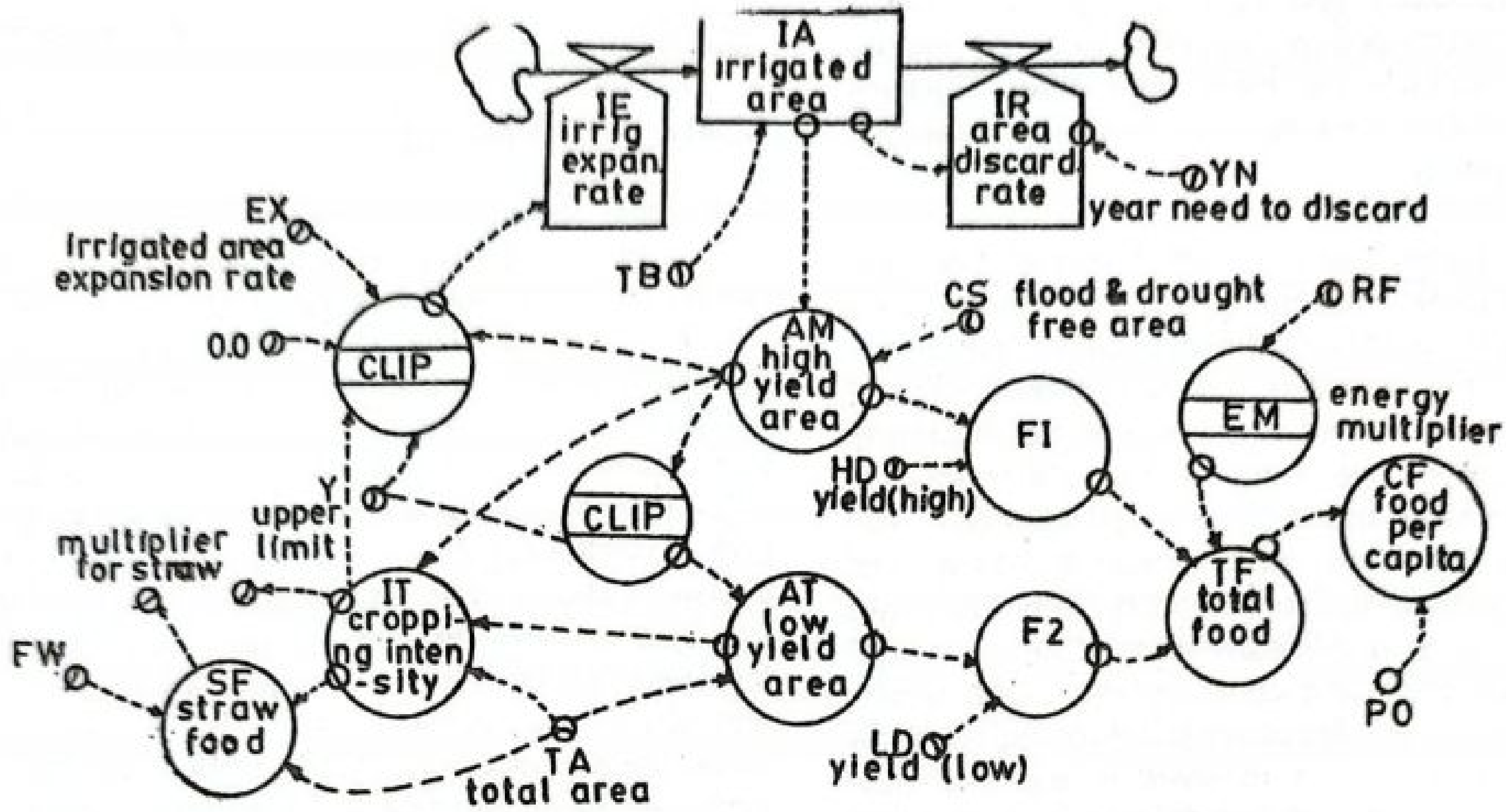

Fig. 1 Block diagram of the food production submodel

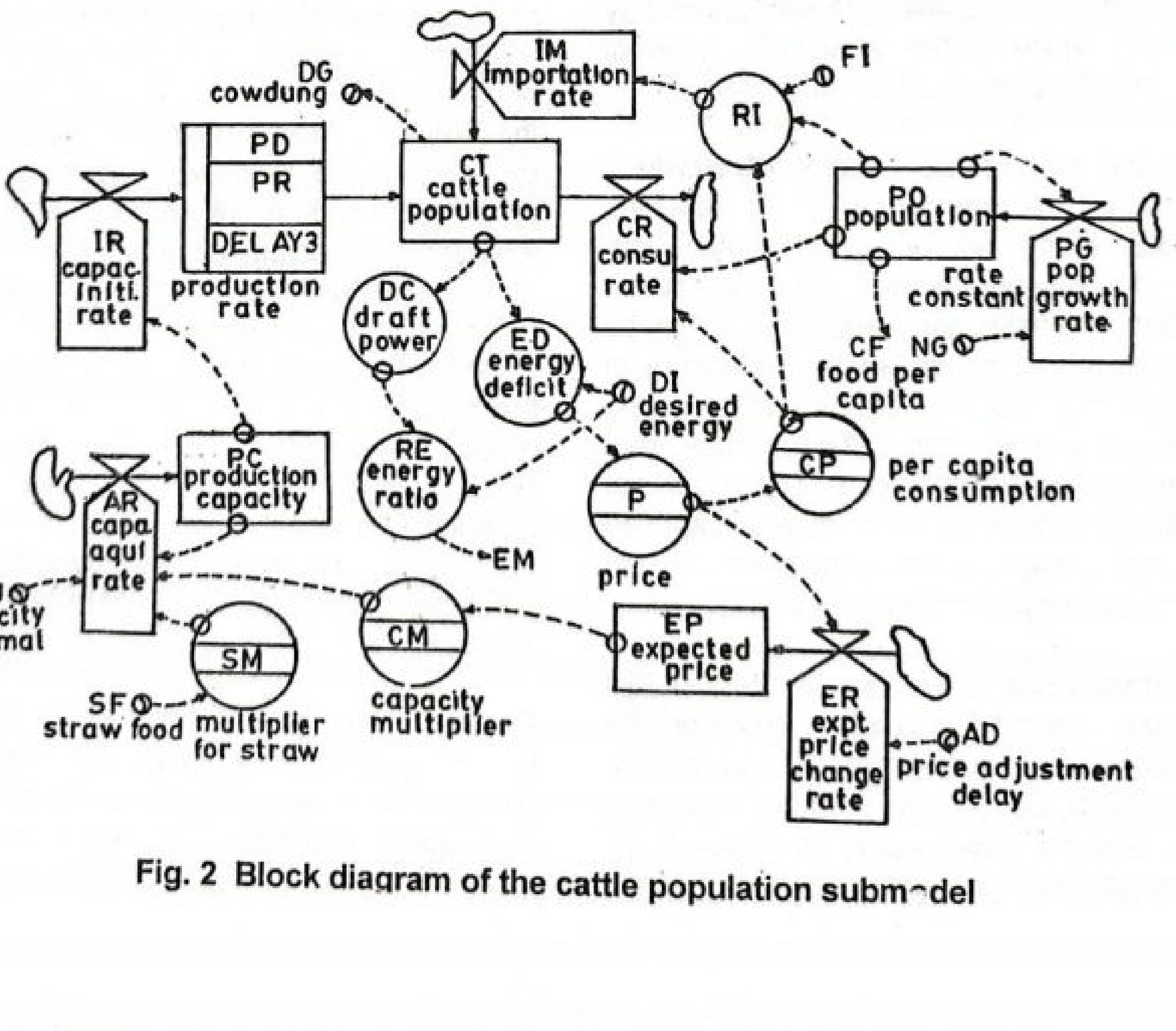

Fig. 2 Block diagram of the cattle population subm~del

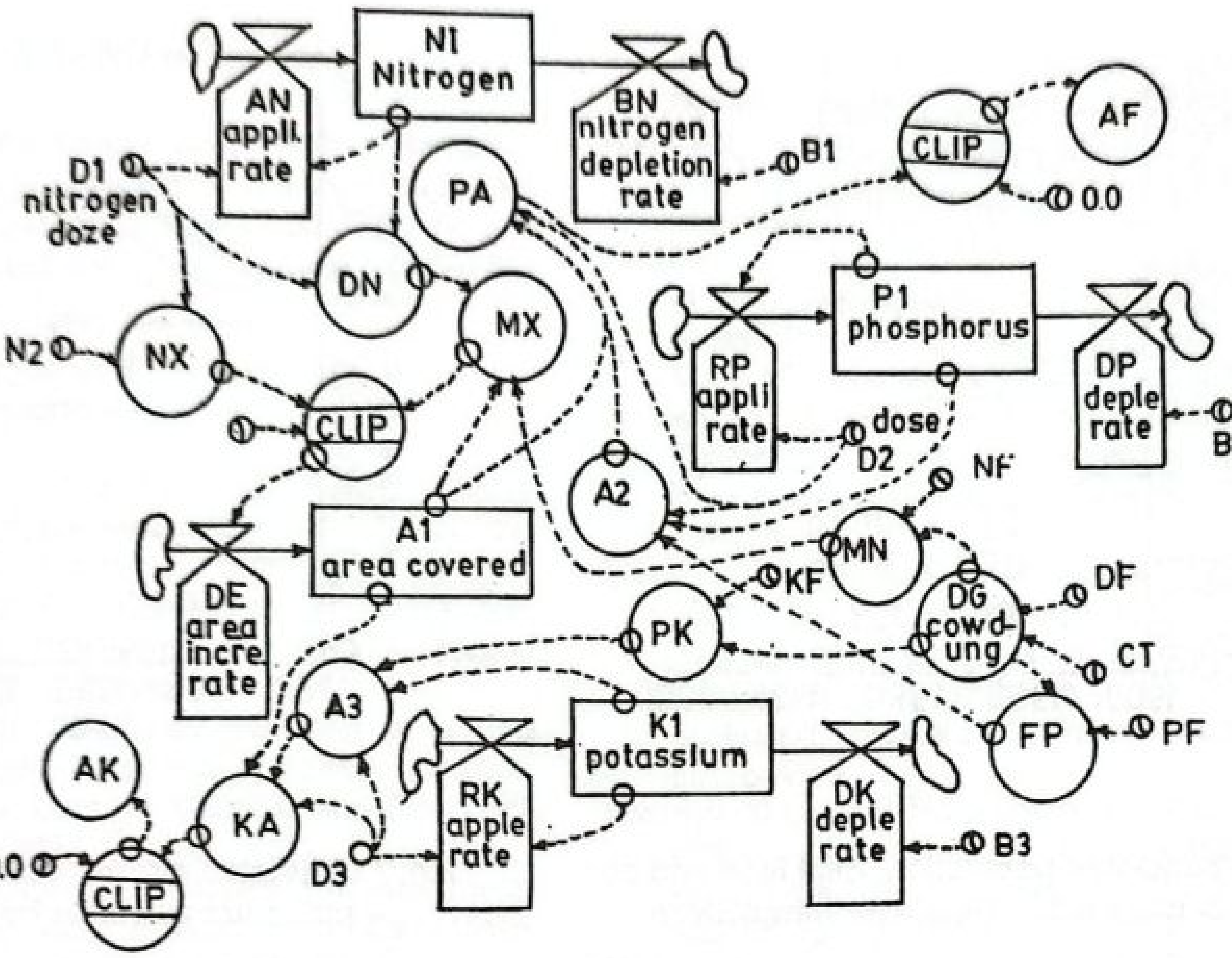

Fig. 3 Block diagram of the cowdung manure submodel

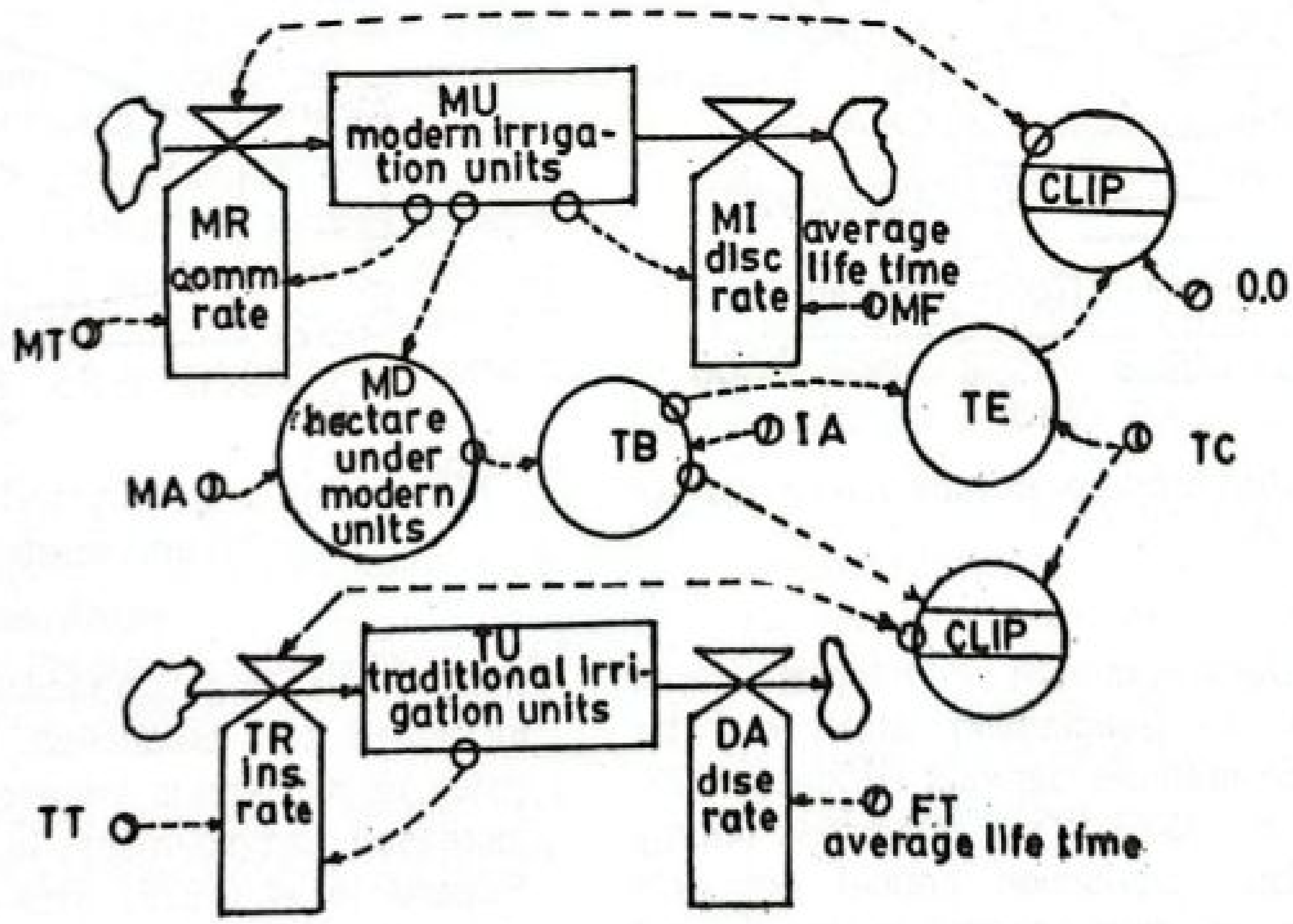

Fig. 4 Block diagram of the irrigation device submodel

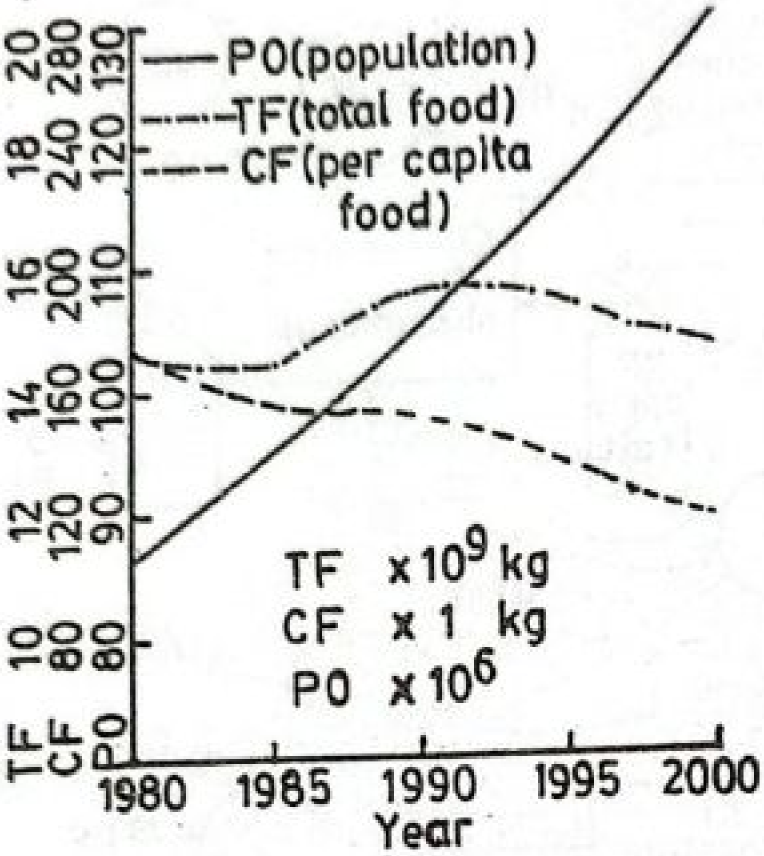

Fig. 5 Simulated population, total food and per capita food available for Bangladesh

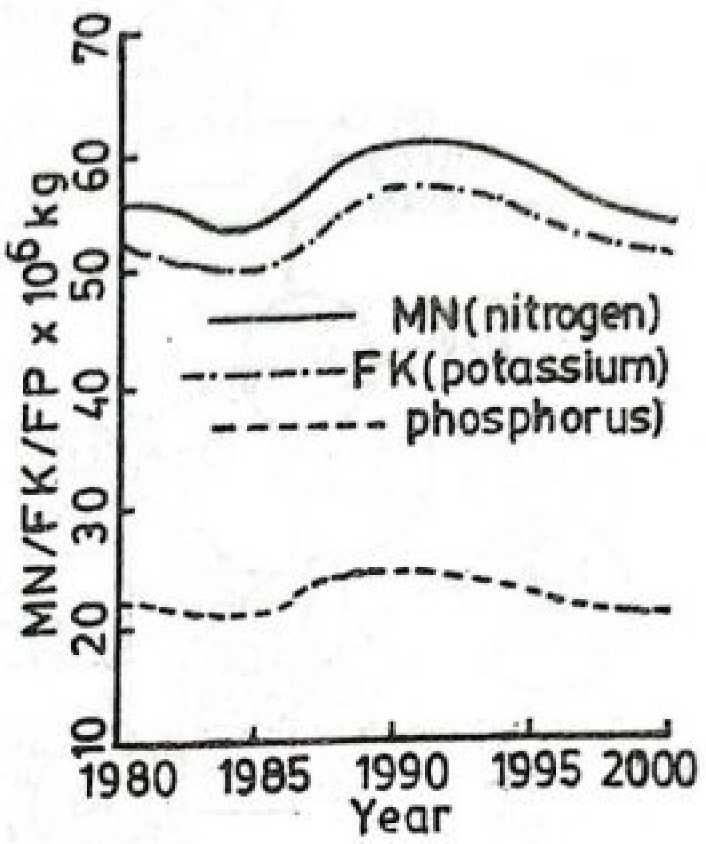

Fig. 7 Simulated nitrogen, phosphorus and potasium available from cowdung

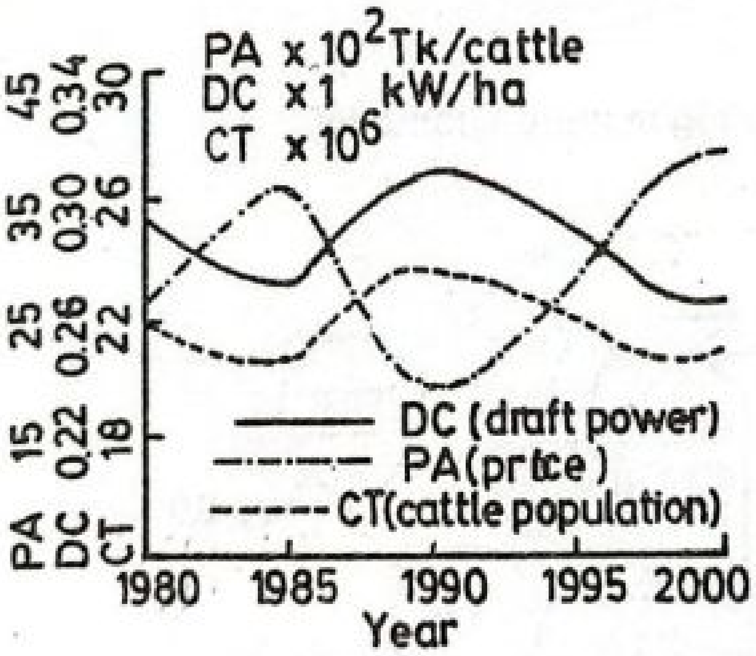

Fig. 6 Simulated cattle population, draft power and price

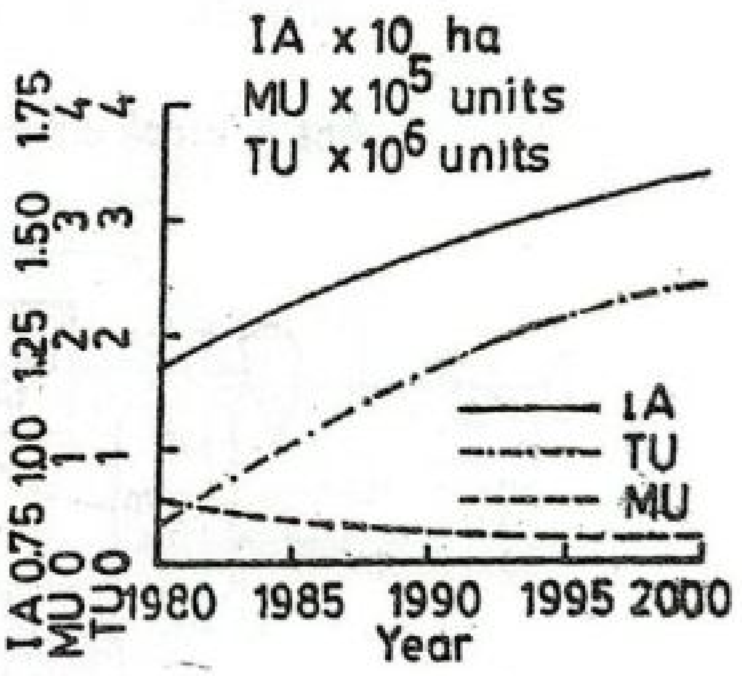

Fig. 8 Simulated irrigated area (IA), traditional unit (TU) and modern unit (MU)

Animal draft power and manure are integral parts of food production in Bangladesh which can be utilized with considerable benefits (Hoque, 1977; O'Callaghan *et al.*, 1973). Thus integrated energy systems for food production should not only consider the animal draft power but also the full potentiality of animal dung and biogas production considering the whole system.

Expansion of irrigation facilities is indispensable for increased food production, but priority should be given to indigenous irrigation systems to provide increased employment in irrigated agriculture Edwards *et al.* (1978). This policy of irrigation has been simulated in this study. Both water quality and quantity conditions are important in irrigation and can be incorporated in the irrigation sub-model with some modification and elaboration.

Rural domestic energy production and consumption from tree plantation and biomas is also an important integral part of food production system and the self reliance in food and energy is essential to raise the quality of life.

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