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ABSTRACT

This paper discusses the results of simulation from anextensive System Dynamics model of agriculture system. A computer simulation model is written in Dynamo with System Dynamics techniques to study the complex agriculture system using data from a number of case studies of India. The results presented in this paper are obtained from the simulation of the system with different infrastuctral and technological investment strategies. The results are summerised here which may be used as a basic plannining guidelines for developing large scale agriculture particularly in developing countries. These guidelines may be used to make such a project a successful venture rather than a waste as has already happened in a number of cases.

INTRODUCTION

Many developing countries are still facing chronic food problems and hunger and malnutrition is visible in most of them. The agricultural scientist generally agree that even with the present state of agriculture technology, all the countries in the world except five (geological constraints) can become self-sufficient in food production before the end of the century. This technology is commonly known as Green Revolution. However, the complex task of feeding all the people in the world continues to remain a mirage and only a few of the developing countries have had success in improving their food production with modern technology while many others have failed and are skeptical about the technology itself. Therefore, this study was undertaken to develop a computer model of the agriculture system particularly in view of the problems in developing countries. The model takes into account all the important factors and variables and their interactions for developing agriculture and for assessment of the technology with respect to economic and some environmental consequences. The computer simulation model developed can be used to understand the intricacies of the system and to study in advance the effects of changes in various internal and external variables in the system. With close monitoring on controllable variables the production can be optimized, costs can be kept under control and environmental consequences such as pollution and land erosion can be eliminated or reduced to tolerable limits. Modernization of agriculture in the developing countries is sometimes like changing traditions and cultures in a society, very often it is misunderstood and implemented poorly with questionable outcomes. It involves far too many factors and their understanding is essential before large sums of precious development funds are directed towards them. Capital investments are huge particularly in irrigation projects without which green revolution cannot succeed. Investments in irrigation are long-term and therefore some amount of risk lurks behind it. Unless the future trends in demand and supply of a region are analyzed in advance, they may cause overproduction depressing prices and insufficient advance investments may create food shortages.

The impacts of using alternative methods of sophisticated advance technologies and the common prevailing practices in the region should be compared. Should Irrigation be developed by building dams and canals, which is very capital intensive but may provide hydro-power generation, or underground water be exploited using water lifting pumps. Find the appropriate balance of labor between man and machine in the region so that productivity is increased without any negative effects on local employment of the labor force. To plan the requirements of farm inputs such as chemical fertilizers, energy for irrigation and cultivation, pesticides, etc.

Selection of the crops among the feasibles and their demand in the region, within the nation, and their export potential has to be analyzed and monitored as changes occur with time. Creation of an infrastructure for the timely processing, storing, transporting, and marketing of crops must be foreseen. The development of the livestock sector as a direct result of increased crop production and fodder availability are all related and influence the system. Consequences in demography such as population and migration, in economy such as employment and income, in health such as nutritional factors and in environment such as pollution, soil erosion etc. and their possible remedies c be included in the system planning.

In the past, much of the research has been concentrated on just a few of these aspects at a time as, understandably, it would be very difficult to solve the problem analytically integrating all the important variables and their interactions unless many simplifications and assumptions are made at the cost of the real system. This research presents a computer simulation model developed with system dynamics techniques identifying the feedback structures in the system. The program is written in Dynamo for easy implementations of the concepts.

GREEN REVOLUTION TECHNOLOGY

Generally green revolution refers to the development of high yielding variety (HYV) seeds mainly of cereal crops which have caused the revolution in agriculture production technology. It was developed in the early sixties in Mexico by Dr. Bourlag, Noble Peace Prize winner of 1971, for introducing higher yielding varieties of wheat. Since then a lot of research has been done in improving the qualities of various grain crops in particular and agriculture methods in general. Many hybrids have been developed in India's labs which were more suitable and more productive in Indian climate. I refer here to green revolution as a modern agriculture technology in all crops where research has produced improved varieties of seeds and provided accomplished cultivation methods including fixing of inputs like various fertilizers etc. resulting in considerable gains in their productivity. Continued research in their further development to suit their adoption in regions and most importantly in controlling the undesirable consequences in environment and social structure of the region are part of green revolution technology.

Figure 1
ELEMENTS OF GREEN REVOLUTION

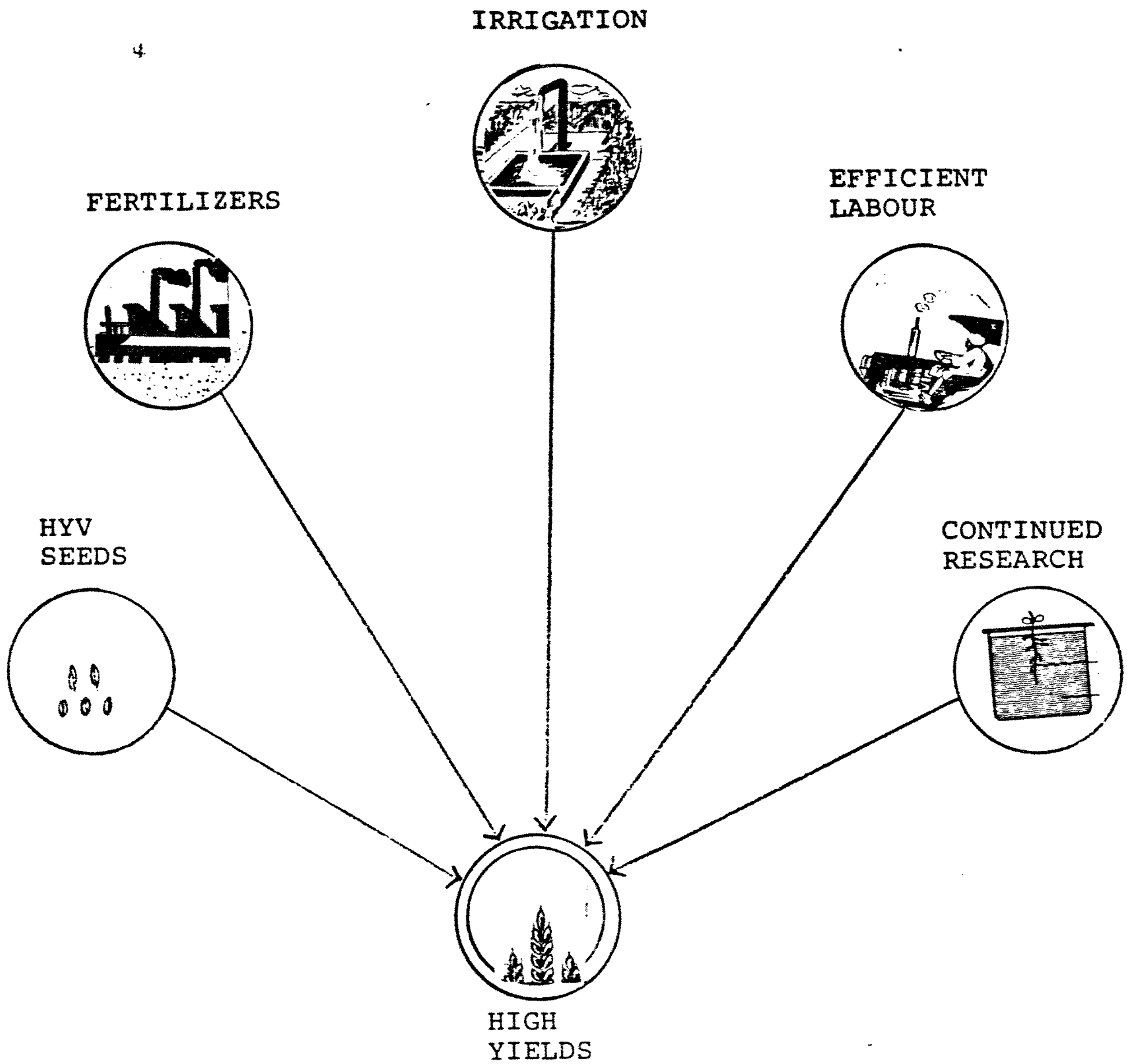
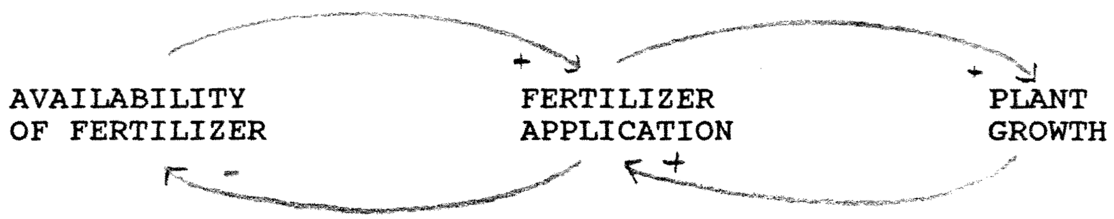


Figure 1 shows the important components of the green revolution technology. For the success of green revolution the most fundamental requirement is availability of timely water for irrigation. Other inputs are significantly effective only if the water is available as and when necessary. This emphasizes that before green revolution technology can be adopted, reliable irrigation system must be developed, which is the single most important factor responsible in green revolution. The other important factors is application of chemical and organic fertilizers and pesticides to which HYV seeds respond very favorably. Mechanization has an important role to play at least in intensive agriculture. With irrigation, drainage facilities are almost a must. Even though these all may seem to increase the yields but it can only be sustained through continuous research to improve varieties, yields and to contain undesirable effects.

METHODOLOGY

Many variables and their relationship as mentioned earlier of the system are non linear and change with the time. In fact it is difficult to quantify accurately some of the relationships in any form. It would be almost impossible to fit the entire system into any known method of mathematical analysis. Computer Simulation seems to be a reasonable alternative. System dynamics has been applied successfully to structure and represents similar economic systems for computer simulation and analysis. See references 7 to 12. System Dynamics is the idea of a two-way causation called feedback and is very convenient to represent dynamic behavior in a system. The decisions lead to actions to change state in a system but the actions taken may or may not lead to a change in the system as desired. However, the information on new state of the system could influence corrections and further decisions of actions. Such a closed chain of causal relationship forms a feedback loop. A system may contain many such loops which are connected together. Figure 2 represents two feedback loops as a simple example which are connected together as part of a system.

Figure 2
A FEED BACK SYSTEM



SYSTEM MODEL STRUCTURE

The following are some of the important sectors linked together which form the central structure of the model.

- Regional population
- Demand and production of crops
- Prices
- Technology, productivity and its consequences
- Investments on irrigation
- Farm mechanization
- Development in animal husbandry
- Employment, income and profitability
- Industrialization

There are over 300 system variables in the model and approximately 200 equations representing their relationships, See Figure 3 for a causal diagram of the system. For System Dynamics flow diagram of the model and its complete description see reference 15 and for a detailed description of the model and data analysis and discussion on relationships of system variables see reference 1.

FIGURE 3
CAUSAL DIAGRAM OF THE SYSTEM

ARABLE LAND

IRRIGATION
INVESTMENTS

INVESTMENT
FUNDS

POPULATION

LAND
PRODUCTIVITY

LABOUR
AVAILABILITY

OTHER AGRO
INVESTMENTS
(MACHINES, FERTILIZER)

EMPLOYMENT

DAIRY
DEMAND

INDUSTRIAL
DEVELOPMENT

ANIMAL
HUSBANDRY

PROFITABILITY

AGRICULTURAL
DEMAND

AGRICULTURE PRODUCTION

EXTERNAL DEMAND

PRICE

INCREASE IN NATIONAL
PRODUCTION

RESULTS FROM SIMULATION OF DIFFERENT STRATEGIES

The model has been simulated to evaluate a number of strategies and sensitivity of many of its variables are tested and validated to reasonable degrees. Results of simulating some of the strategies are given here. The sensitivity of various parameters, particularly of assumptions, was tested throughout the development process of the model to see their effects on the other variables in the system. The structure of the model seems to function as preestablished theories and assumptions defining the model.

A - The Results of Simulation from the Investment in Surface Water Irrigation

Figure 5
CANAL IRRIGATION (Fertilizer use 500/Kg/ha/year)

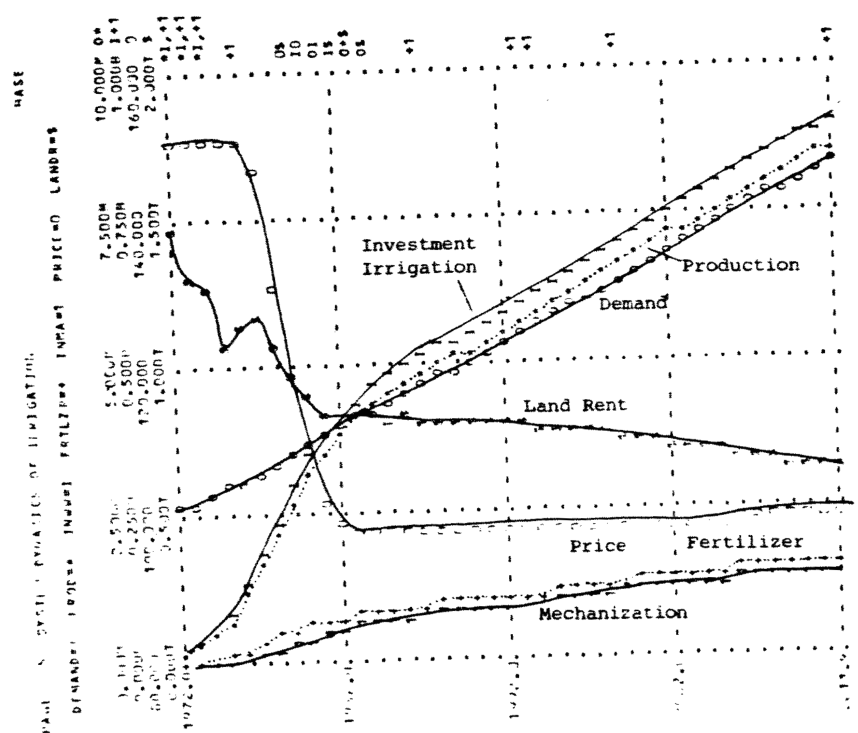


Figure 5 is obtained by simulating the strategy of intensive farming using modern cultivation methods requiring full mechanization and optimal use of fertilizers. It is assumed that the area is undeveloped and little irrigation, relying mostly on rains, is available at the start of period in 1972. At that time decisions are taken to invest in irrigation and develop other infrastructures to support the intensive farming in the area. Initially prices are high and profitability to farmers is artificially high as imports are unaffordable.

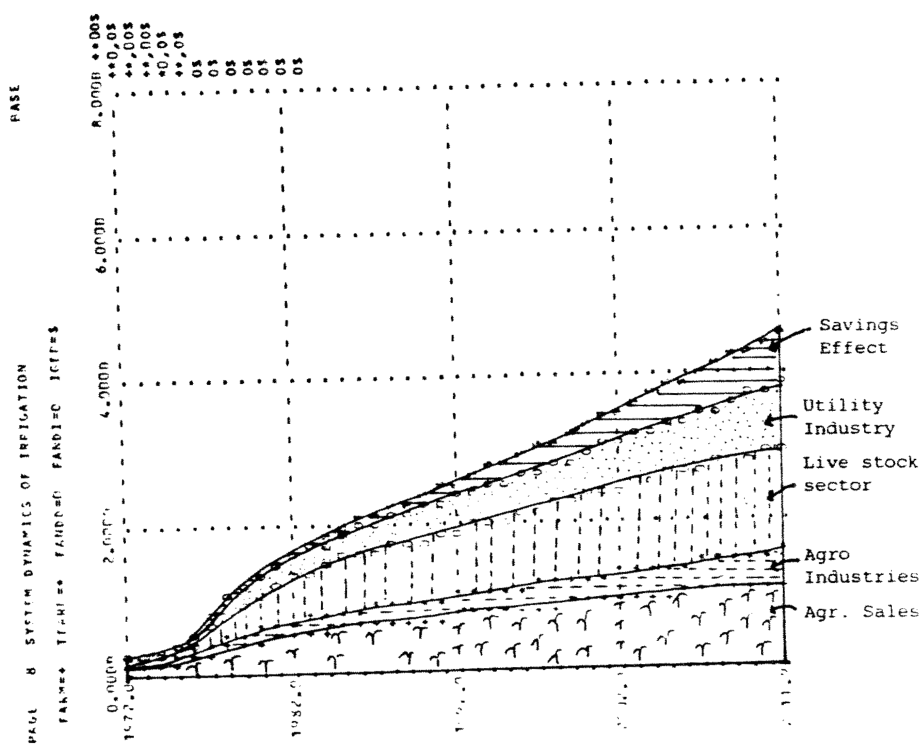
The agriculture production (o) is merely 213,000 tonnes in the year 1972 which is a fraction of the requirements in the region. The production increases to 1.8 million tonnes in 1977 matching the regional demand (*) and it reaches to 3.7 million tonnes in 1982 keeping up with the total demand in the country. In 1982 for the first time, ten years after the start of planned development, the production reaches to the demand target. And then afterwards the production keeps pace with the demand growth for the rest of the thirty years simulated in the model. Effective investments in irrigation (I) are $20 million in 1972, $412 million in 1982, $702 million by the end of the century and $904 million in the year 2012. The investments in farming machines(1) for the corresponding years is projected as $4.5, $55.5, $109 and $147 millions respectively. Yearly requirements of fertilizers would be,approximately, of the same order as the value of the farm equipments (+). The prices (0) are high at the start due to the large gap between the demand and supply. As the production approaches the demand the prices fall and then stabilize when the demand remains almost equal to the supplies. Price level is stabilized at around $100 per ton for the model's crop mix ($) represents the land rent which is the profit to farmers from one hectare of cultivation per year. The net gain from one hectare is the value of its farm output minus all the costs such as input, seeds, fertilizers, pesticides etc., farming machines depreciation, maintenance and running costs, full water charges, workers wages and the miscellaneous expenses. This is the net return on the use of one hectare of land, which in 1972 was $1470/hectare. At the time local demand far exceeded the production. And the high return is only due to a higher level of prices at the time. If the grains are imported, foreign exchange would be needed then the prices would come down as well as profits. If the grain is not imported that means the population is under-fed and only a handful of land-owners would largely benefit.

As investments in irrigation increase and demand is met through local production, the land rent ($) comes down to an aggregate of $720 fluctuating between $630 and $820. This return can be considered reasonably good on the investments. The plot in figure 6 shows the projection on the increase in gross domestic product IGDP ($) related to the increase in agricultural production in the region. (+) represents the revenues from crops. (*) represents the sum of crops revenues and the value added to a portion of crops while processing and packaging industrially. (0) is the sum of processed and unprocessed crops (*) and the unexpected output from animal husbandry and related development in the region such as the production of milk, other dairy products, meat, poultry and leather. The shaded area with dots represents the revenue from the dairy development sector. (o) is the sum of (0) and the production of consumption goods.

The model assumes that the induced industrial production is equal to 20% per year of the accumulated savings. By assuming even a low production effect from these savings their accumulative effect is quite large toward the end of the output period. By adopting this strategy sufficient food can be produced to meet the growing demand and income to farmers is reasonably assured.

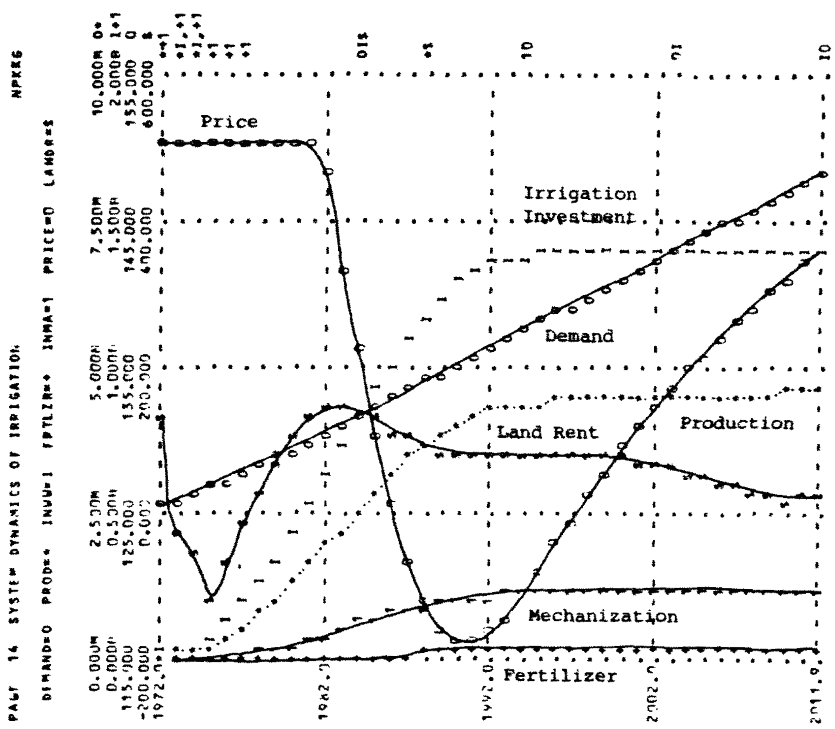
Figure 6

INCREASE IN GDP



ALso new jobs are created both in agriculture and industrial sectors. The development of agriculture , in this scnario is optimum benefitting in terms of food self sufficiency, cost effective and as a inducement for industrial development. The model is rerun by changing the scenario by changing constant NPKKG from 500 Kg per hectare per year to merely 40 Kg per hectare per year. India falls under this category at present. Most of the fertilizers are consumed in areas where irrigation is well developed and other areas which rely mostly on rains use very little or no amounts of fertilizers. The graph in figure 7 is obtained from the simulation of this strategy.

Figure 7
CANAL IRRIGATION (Fertilizer use 40 Kg/ha/yr)



With this strategy more than 1.7 million hectares of arable land are required by the year 2012 to meet the total demand. Not only more land but also more investments are needed to irrigate them because of low productivity. Land rent during the initial period is negative when the investments are initiated. Later the average land rent is less than $100/hectare/year, far less than $720 of the first case. Low land rent is caused by low productivity even though the prices are generally higher than in the previous case.

The indirect effect on production of consumer industry and savings is less than $1 billion in the year 2012 in comparison to about $2 billion in the first case. The difference between IGDP in 2012 in two cases is close to $2 billion per year. This clearly demonstrates that more intensive farming would benefit the community and economy faster. Also it will have less negative consequences in deforstation as considerably less land is needed to sustain the development in the region.

B - <u>The Computer Output of Simulation from Groundwater Irrigation</u>

The following results are obtained with the strategy to develop irrigation through exploration of groundwater by investing in electrical and diesel operated tube wells to pump the underground water for irrigation. Plot in figure 8 is obtained when modern methods are used in good soil with high inputs of fertilizers (500 kg of nitrogen, phosphoras and potassium combined per hectare/years) in fully irrigated crops. As investments are initiated in groundwater irrigation developments, the production reaches to the level of the demand, in 1977, within five years. With surface water irrigation it took 10 years to achieve the same, within the constraints of development and finances. The land rent ($) is a little higher in the groundwater irrigation than in the surface water irrigation. It is on average around $850.00 per hectare/year.

The comparisons of the results from the surface water irrigation and ground water irrigation, it is noted that ground water irrigation is more profitable, has much better control on timely irrigation and most of all is relatively much quicker to implement and much less capital intensive in comparison to building dams and canals for surface water irrigation. Capital requirements are less than one fourth in tubewell irrigation.

Figure 8
TUBEWELL IRRIGATION (FERTILIZER USE 500 kg/ha/year)

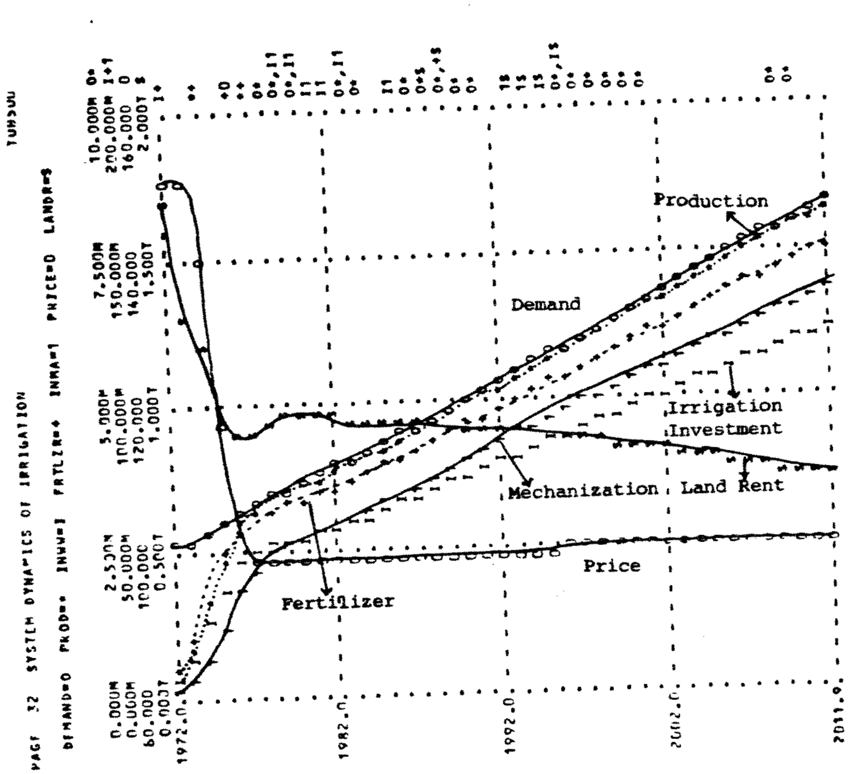
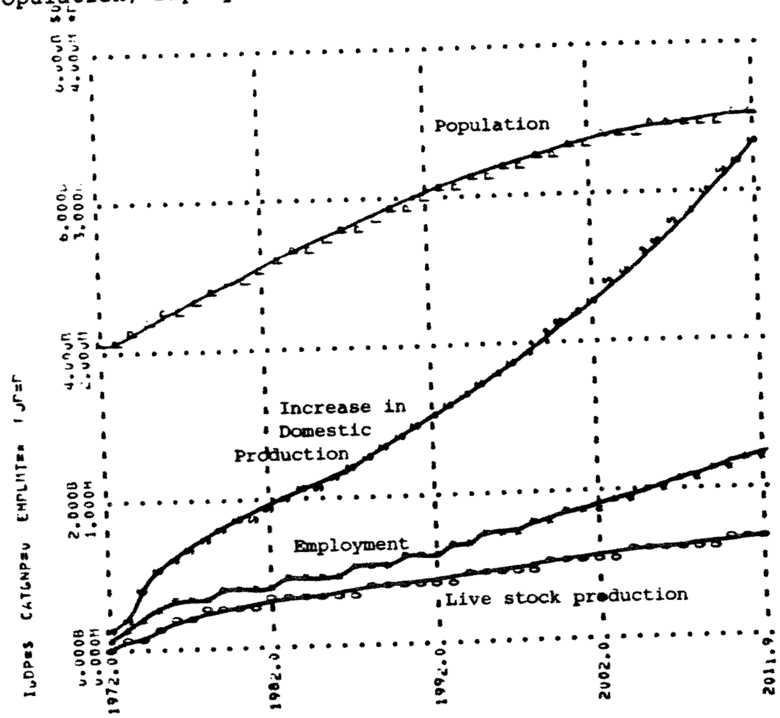
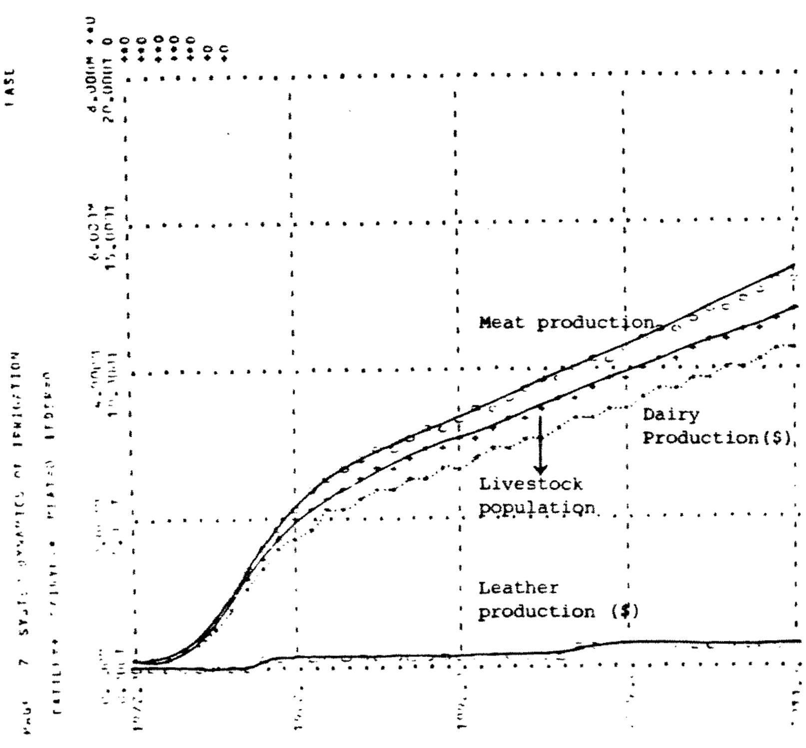


Figure 9

Population, Employment, Livestock and GDP



Livestock Sector Performance



CONCLUSION

The investment analysis of simulation results of various strategies for agriculture development and its effects on economy are given in the following. These results are listed quanlitatively in the following.

1 . Much of the arable land in developing countries depends upon unreliable rains affecting the yields and cropping intensity. And lack of irrigation inhibits the use of green revolution technologies responsible for high yields. The results show clearly that to improve agriculture the irrigation investments are necessary. It also induces the economic development of the region through increased agriculture production and in livestock and agro-industries and indirectly by increasing the farmers income and employment. Also savings from farmers influence industrial production and further employment in the region. Increase in agricultural production stimulates industrial production which in turn sustains the agricultural production. However, irrigation alone is not a profitable investment but when it is coupled with the adoption of new agriculture technology using appropriate amounts of fertilizers and necessary mechanization then the system turns into a profitable venture with good returns on overall investments.

2. Investments in irrigation should be first to utilize underground water for the following reasons:

(i) The project development time is relatively much shorter.
(ii) Initial capital investment in ground water irrigation is har 20% of surface water irrigation.
(iii) Tube wells provide more timely and efficient irrigation.
(iv) The comparison of the results show that the tube well irriga is more remunerative than the surface water irrigation at tl present cost structure.

(v) Soil salinity problem is reduced.

3. Application of fertilizers in appropriate quantities is very productive particularly with new HYV seeds. 5. Most of the published studies show that the mechanization of agriculture does have positive effects on productivity basically due to better preparation of the land and timely operations vital for multiple cropping. However, a lot of controversy persists about labor displacement from farm mechanization in developing countries. The model shows that there are no adverse effects on overall employment in a region from farm mechanization which is well supported by the evidence in India particularly in the States of Punjab, Haryana and Western Uttar Pradesh.These regions are well irrigated and where farming is relatively much more mechanized than other parts of the country.

4. Agricultural priorities in the developing countries should be directed toward meeting the national food requirements. They should abstain from new investments in agriculture development with the purpose of entering or increasing crop exports. After achieving self-sufficiency in the production of food,it is best to use the investment funds in industrialization.

5. Planning as well as professional management are musts for efficient implementation and cost controls. The delay in project implementation causes costs run ups. They are often caused by a lack of investment analysis. This model should be very useful in this regard. Other factors include not planning for the availability of adequate financial, material and personnel resources,and corruption at various levels which has become a way of life in many developing countries including India.

The system Dynamics model presented in this paper to analyze the consequences of investments in agriculture for developing countries can be used with significant ease for almost all the strategy options. It should provide much deeper insight into functioning of agricultural economy for different regions in the world. The computer model is extremely flexible and relationships could be easily modified to accommodate any changes in their forms. Continued research and innovations in green revolution is necessary for a long term sustained growth and reduced negative consequences.

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