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A System Dynamics Model for Evaluating Investment Strategies for Agriculture Development

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A SYSTEM DYNAMICS MODEL FOR EVALUATING INVESTMENT STRATEGIES FOR AGRICULTURE DEVELOPMENT

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ABSTRACT

This paper presents a System Dynamics model to analyze the consequences of investments in agriculture. The data is taken from the various case studies of agriculture in India and is used as an example in the simulation model. A number of investment strategies are simulated to see the performence of the overall system. Some results are presented from the simulation providing insight into the intricacies of the system variables which may be used as guidelines for investing large funds in agro-projects to maximise the benefits and to reduce the undesired consequences. The model can be used to study the effects of changes in one or more controllable variables in the performance of the system. It provides insight into the system variables which are important in making the planning a success and to optimize the profits from the investments .

The paper describes in detail the system dynamics flow diagram of the agriculture system model, the factors which are important for investments to be profitable.

INTRODUCTION

The investments to improve agricultural productivity are in the areas of irrigation and in other ifrastructures such as in fertilizer plants and in agro-machinery. These investments are huge and are undertaken by the Governments particularly in the developing countries where funds for scarce. The objective of this research was to construct a simulation model to study the dynamics of large agriculture investments in the development of regional economy. The investments are meant to increase food production mostly by improving the productivity of the land already in use. The increased food prduction should primarily meet atleast two goals which are nutrition and inducement of industrialization of the region through increased farm income. In the past such investments have not always yielded the desired effects and in many cases the investments were mostly wasted. Therefore it is necessary that a detailed systems analysis is performed to maximize the benefits from such investments. The analysis should identify the important factors that are necessary to make the investments profitable.

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. In the absence of any analytical model that can be formulated with the sytems complexities a computer simulation model can serve as analternative. Such a model 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. 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

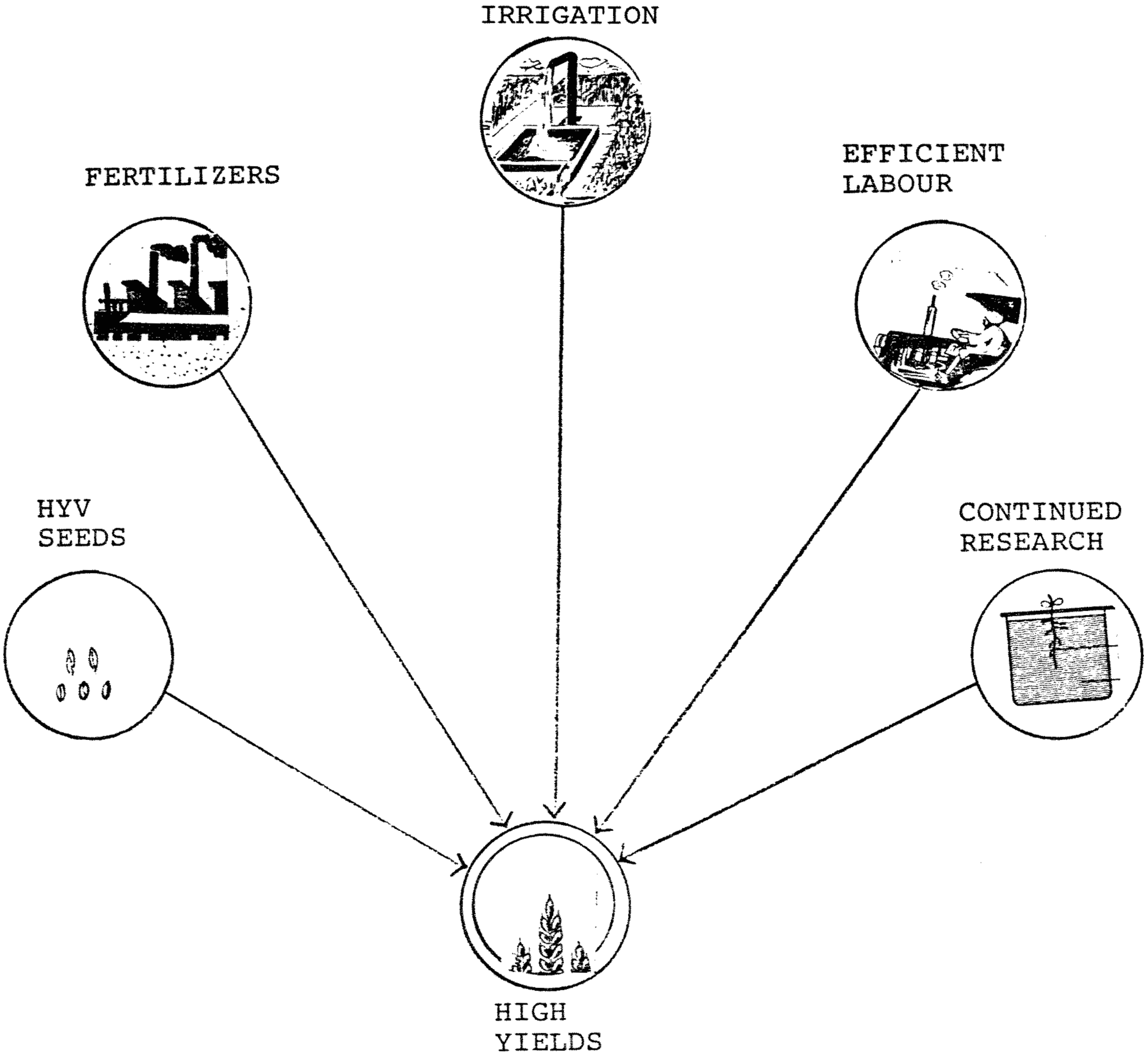
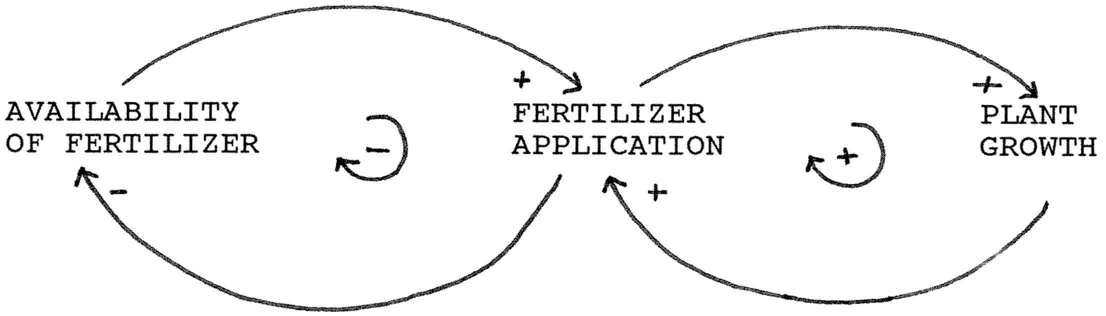


Figure 1 shows the important components of the green revolution technology. For the success of green revolution the most fundamental requirement is availability of timely water for irrigation. Other inputs are significantly effective only if the water is available as and when necessary. This emphasizes 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



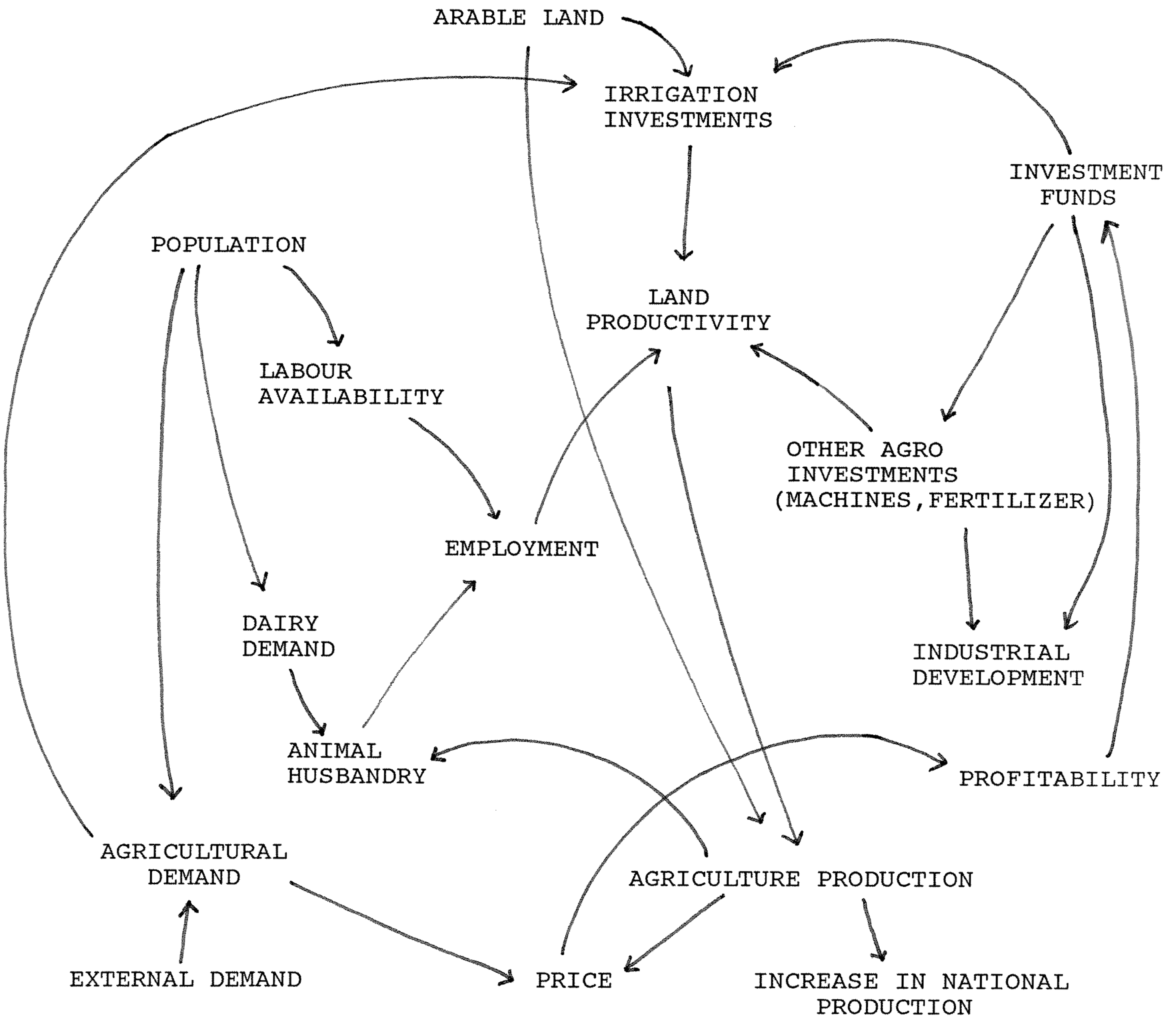
SYSTEM MODEL STRUCTURE

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. System Dynamics flow diagram of the model is given in Figure 4. Relationships have been developed with data analysis from India's experience in the last three decades. For a detailed data analysis see the reference 1. A brief description of the relationships and principle feedback structures are explained here.

FIGURE 3
CAUSAL DIAGRAM OF THE SYSTEM



The above mentioned sectors in the model are framed as level equations representing dynamic behavior in the system which increase or decrease by their associated rates of flows.

The rates depend on system levels through an information network as shown by the dotted lines and circles. A system structure is made of only levels and rates. The circles in the diagram are parts of the rate but are separate- ly represented as they are concepts and they can be independently defined. Names in the parentheses are from the system diagram in figure 4 representing the concepts as explained here.

The decision to invest in development of surface water (INDEC) irrigation is influenced by the following factors

a - Expected shortfalls in agriculture in near future (DEMINC)
b - Availability of arable land (ARABLE)
c - Potential water source for irrigation (SWATER) development
d - Availability of credit (LIMITS)
e - Profitability (PROFIT)

ARABLE is a constant and is the limit of cultivable area in the region. SWATER is the cost of full development of potential surface water irrigation potential in the region. LIMITS is the budget restriction on yearly credit availability for irrigation development such as for construction of dams, barrages and canals. The costs would vary from a region to another depending upon the type and source of water and its distance from the farms. ISPH is the investment required to develop surface water irrigation for each hectare. Because of the delay involved in the construction of canals and dams between the time of decision to invest (INDEC) and the time when benefits of the project are

FIGURE 4
SYSTEM DYNAMICS FLOW DIAGRAM OF THE SYSTEM

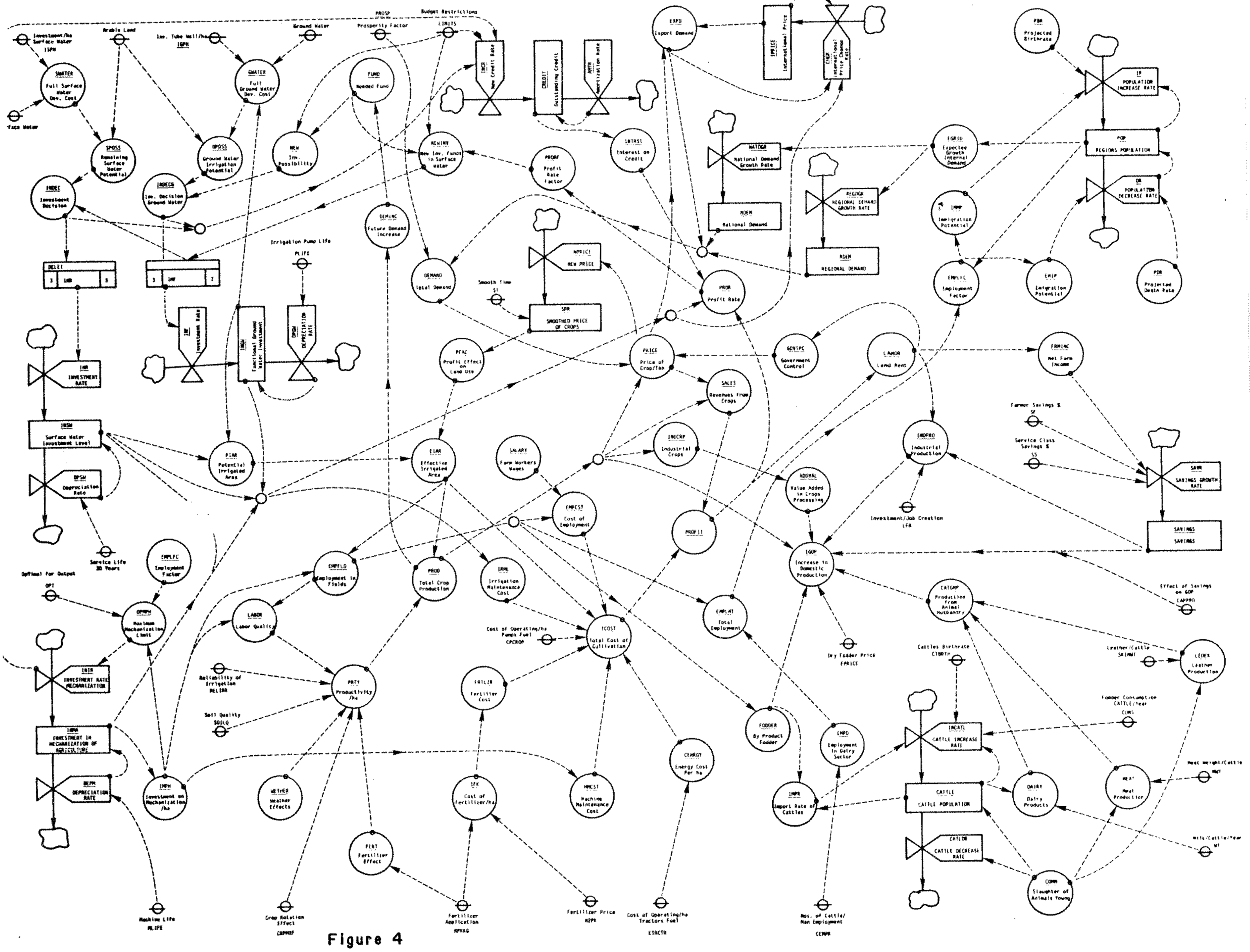

System Dynamics Flow Diagram

Figure 4

available to farmers (INSW), a delay function DELAYI is included in the model. It is a third order exponential delay. Delay time of five years have been defined as the average period to build the reservoir and the construction of all the necessary canals. INSW is operational level of the total investment on the surface water development. Similarly INDECG is the decision of investment in groundwater irrigation which depends upon available land, future demand gap and presence of groundwater (GROUND). GWATER is the cost of developing all the groundwater present in the region. DELAY3 function with two years of average delays is used in this case. These figures are only indicative and can be replaced with estimated figures for the projects in question which may vary from country to country.

The total effective irrigated area (EIAR) under cultivation multiplied by average productivity per hectare (PRTY) gives the total crops production (PROD). The productivity of land depends on several factors e.g. - the soil quality (SOIL), the climatic effects (WETHER) the use of fertilizers (FRTLZR), the level of farming know-how and techniques used by the farmers (TEKNIK), the crop mix (CRPMIX) i.e. the effect of the crop rotation, the salinity treatment and the insecticides sprayed before and during the crops. The model could be used to simulate using different crops or taking the value of aggregated crops. The model presented here is used to simulate aggregated crop mix and value which should be of primary interest to investment planning agencies. Auxiliary function MAX is determined as the maximum potential of investment in mechanization which is determined to be US$ 250/hectare. The future investments in mechanization will depend on the difference between the maximum possible and the current investment on machines/hectare (IMPH) in the region. Total investment in machines is given by the variable INMA. The life of such machines (MLIFE) is assumed to be approximately ten years in the model.

The total cost of cultivation (TCOST) in the region is computed from the following costs:

1. Employment cost (EMPCST)
2. Depreciation on farming machines (DMA)
3. Depreciation of irrigation?? investments (DPWW) included in water charges
4. The cost of fertilizers and insecticides (FRTLZR)
5. The cost of energy to operate the farming machines and irrigation pumps (CENERGY)
6. Cost of maintenance of machines (MMCST)
7. Cost of transportation and storage of crops (CDISTR)
8. Miscellaneous cost (MISC)

The total revenue of crops (SALES) is obtained by the amount of production(PROD) of agricultural crops multiplied by its price (PRICE) in the market. The price is a function of demand (DDEM) and supply and Government price policy (GOVTPC). The current price is theoretically a function of demand and supply in a free economy. However, in most parts of the world the agricultural prices are controlled by the governments (GOVTPS) in some cases directly and in some others indirectly. The Government must insure that the local farmers get profits for their investment and labor. The prices cannot be too high either as it would be a burden for the non-farming community. The third level in this structure represents the population of the region in the command irrigation area. The growth of population depends upon the present potential population of child bearing couples, their desire to have children, their education in family planning, social and religious structure of the communities, and the economic pressures, etc. The growth rate is defined by the birth rate (BR) of the population and immigration rate (IMM) caused by better economic prospects in the region and due to the shortage of labor force in the region. The decrease rate (DR) is the rate at which the deaths are expected in the region and the rate at which the people are emigrating (EMI) to other places when they cannot find any work in this region within a reasonable period of time and they can find some jobs in other regions.

The demand of agricultural crops has been represented by two identical level equations. One represents the demand of foodgrains for the regional population (RDEM). The second level structure represents the demand (NDEM) as shortfall from the rest of the nation. And a demand auxiliary represents the potential export market. The prices of agricultural commodities are affected by its demand (DEMAND), its production (PROD) and the governments price policy. However, the government intervention is limited in controlling the prices of only those crops which can be easily stored for a reasonable period in case of a sudden over-production etc., or which could be timely imported to cover the unexpected shortages.

The total revenues from the sales of all the crops (SALES) minus the total cost (TCOST) in their production is the gross profit (PROFIT) made from the agricultural operations. The land rent (LANDR), the net profit on land cultivation is derived from the gross profit minus interest charges paid on government credit for irrigation projects and on loans to buy agricultural machinery to farmers. LANDR is one of the very critical factors in controlling the prices to protect the consumers from over charges and to cultivators and farmers from losses.

The level of credit (CREDIT) represents the government controlled credit which may come from government funds and/or international aid agencies like world bank, United Nations Development Programs (UNDP) etc. The irrigation credit is for the construction of dams on rivers and for the construction of canals for the distribution of water to the fields. The credit (CREDIT) due depends opon investment rate (INRC) and the repayments of the principal (AMTR). The amortization rate may vary from three to thirty years depending upon the type of credit sanctioned. All the figures in the model are based on prices of 1972. Part of animal food is obtained as by-products in the agriculture. Dry straw from foodgrain crops as well as residue from oilseeds are all used as fodder. The availability of the fodder influences animal husbandry (INCATL) in the region. The rate of increase in the cattle is dependent upon the present population of cattle (CATTLE) and the availability of the fodder in the region. The slaughtering rate (CATLDR) is dependent upon the natural life span of cattle and the commercial suitability of slaughtering age of animals. The cattle population (CATTLE) initiates economic activities in the dairy industries (DAIRYP) producing milk, cheese, butter, yogurt, etc. The industry increases income and employment potential of the local population. This is also one of the most important sectors for better nutrition of the population. The skin from these animals such as cows, buffaloes and goats etc. is used to make leather (LEDER) when they are slaughtered for meat consumption. The dairy products and the meat not only provide nutrient food to the local population but also contribute to better and sustained economic development in the region.

The increase in domestic production (IGDP) is divided by the total local population to get the increase in per capita income (IPCI) of the population as a result of increased agriculture production triggered irrigation. IGDP's main contributors in the model are agriculture production, sum of products from live stock (CATGNP), the additional crop value (ADDVAL) from its processing in agro-industries, the industrial production (INDPRO) for consumers (agriculture sector) and the increase in industrial production and services with the savings of farmers and other labors (SAVING). This variable is also represented by a level equation where the savings are accumulated.

All the relationships described above are further detailed and quantified. Following are sample equations written in Dynamo programming language representing level equation and rates equations connected with the ground water investment sector. For complete dynamo program and details of data and their relationships see authors thesis (Reference 1).

```
L INGW.K=INGW.J+(DT)(INF.JK-DPGW.JK)        Invest. in ground water irr.
N INGW=NGW                                         $
R INF.KL=DELAYI(INDECG.K,2,IINVG.K)+DPGW.K         $/Year
A INDECG.K=MIN(GPOSS.K,NEW.K)                      Investment Rate
A GPOSS.K=MIN(GWATER.K-INGW.K,RAREA.K*IGPH)        Possibility (Max)
A NEW.K=MIN(GAREA.K,LIMITG)                 Available Credit Use
C LIMITG=25E6                               Credit Limit
A GAREA.K=PRORF.K*DEMINC.K*IGPH-IINVG.K     Motivation to Invest
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C IGPH=200      $/HECT                  Development Cost Gwater Irr.
R DPGW.KL=INGW.K/PLIFE                  Depreciation Rate
C PLIFE=10                              Years - Pump Life
A INWW.K=INSW.K+INGW.K                  Total Irr. Investments
A DPWW.K=DPSW.K+DPGW.K                  Depreciation in Irrigation
```

In the above dynamo equations, prefix L indicates that the equation is a level equation, R indicates that this is a rate equation, A stands for auxiliary equations which are used as part of rate equations. N indicates that this is the initial value for the variable defined in level equation. C stands for constants and are used in Auxiliaries or rate equations. See reference 2 for details of the explanations of a dynamo program.

INGW.K represents the presently functional ground water irrigations investment value which keeps on changing as a consequence of past investments rate (INF.JK) and depreciation rate (DPGW.JK). Future investment rate (INF.KL) is defined using a third order delay function after investment decision (INDECG.K) is activated. As a policy,the model assumes that replacement and maintenance investments would be made to cover depreciation at all times. The decision to invest is a minimum of the possible (GPOSS.K) and the economically required (NEW.K). GPOSS.K is evaluated from remaining ground water potential, technology and available investment funds.

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)

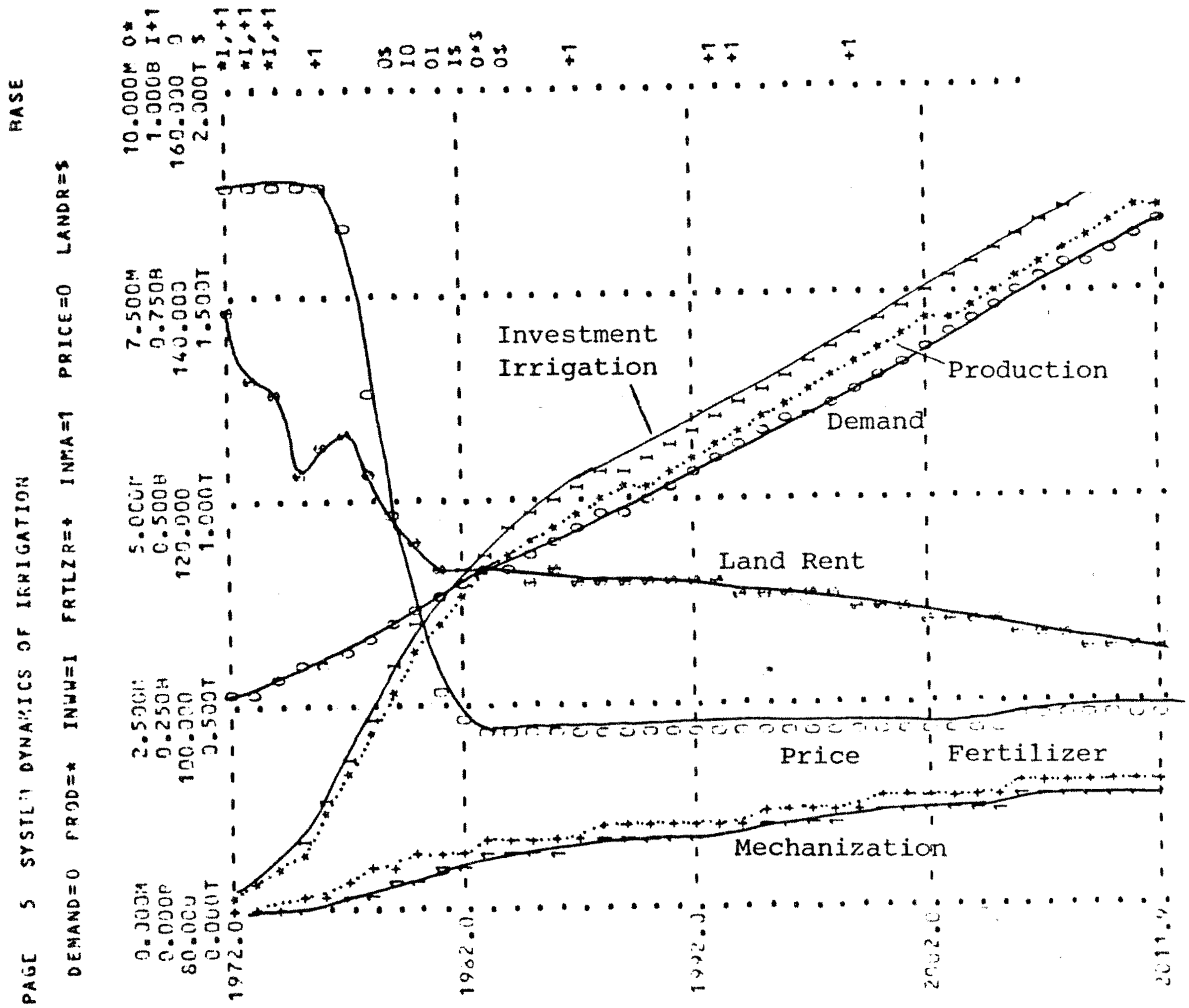


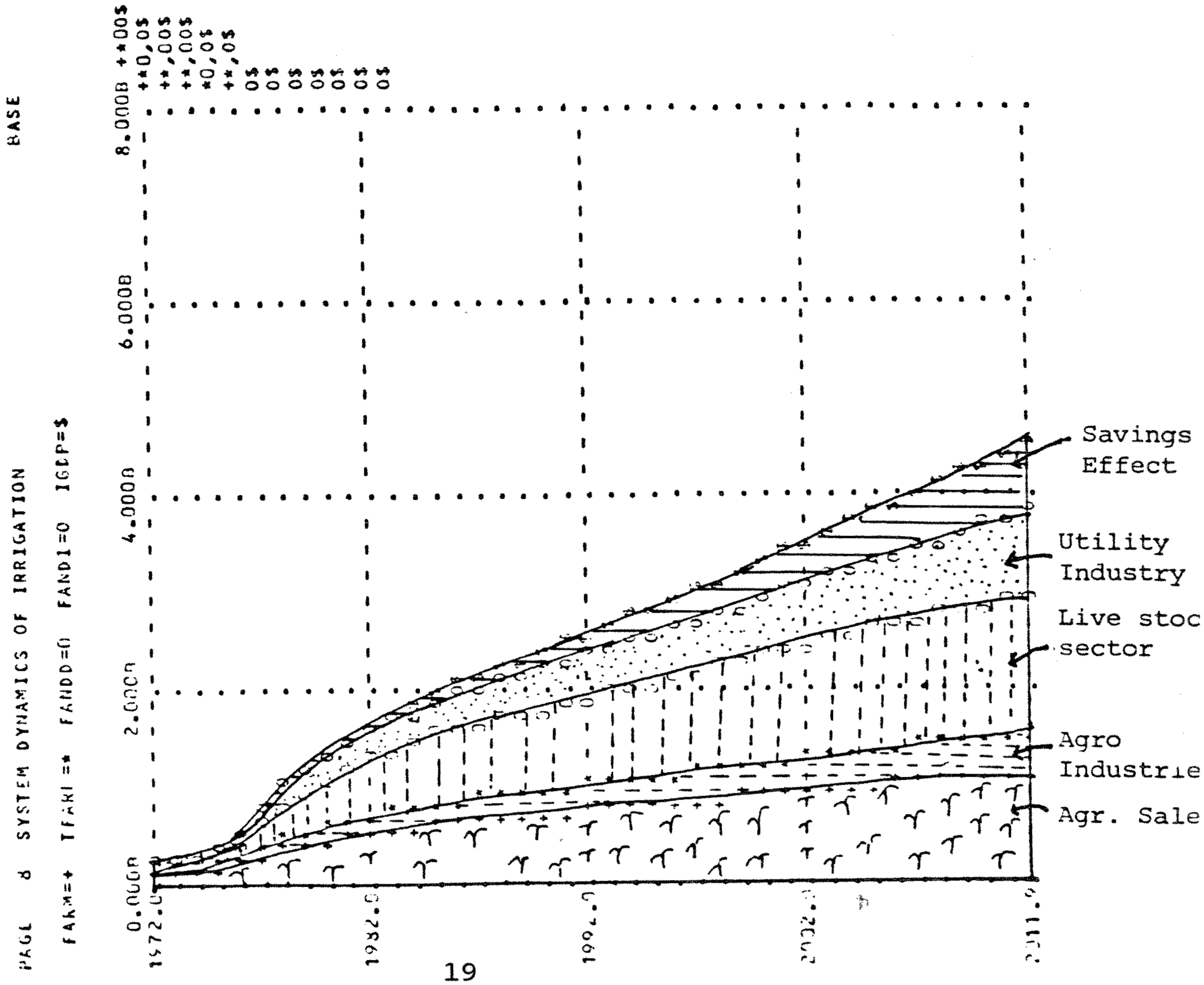
Figure 5 is obtained by simulating the strategy of intensive farming using modern cultivation methods requiring full mechanization and optimal use of fertilizers. It is assumed that the area is undeveloped and little irrigation, relying mostly on rains, is available at the start of period in 1972. At 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.

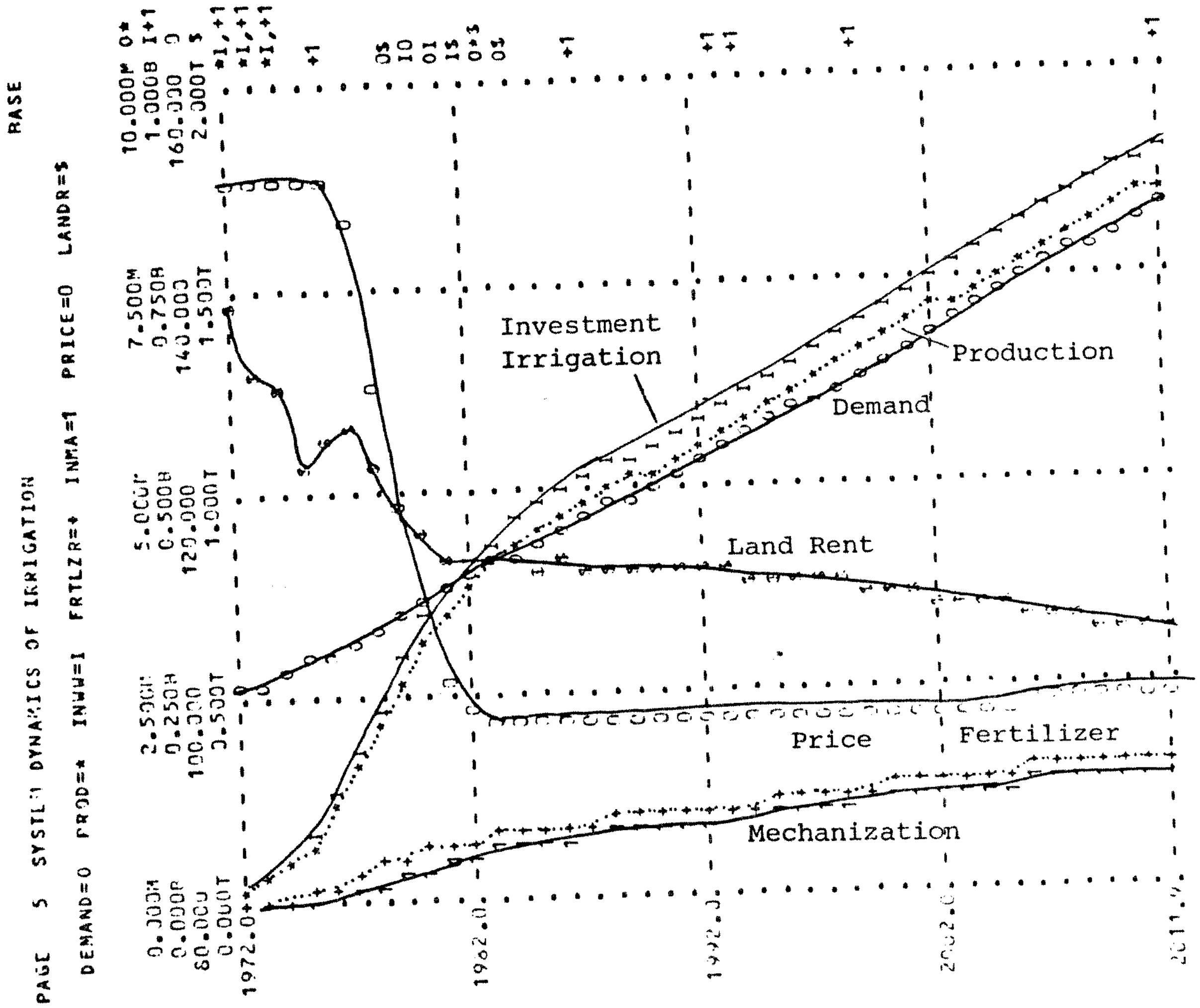
As investments in irrigation increase and demand is met through local production, the land rent ($) comes down to an aggregate of $720 fluctuating between $630 and $820. This return can be considered reasonably good on the investments. The plot in figure 6 shows the projection on the increase in gross domestic product IGDP ($) 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. 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.

Figure 6
INCREASE IN GDP



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. 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.



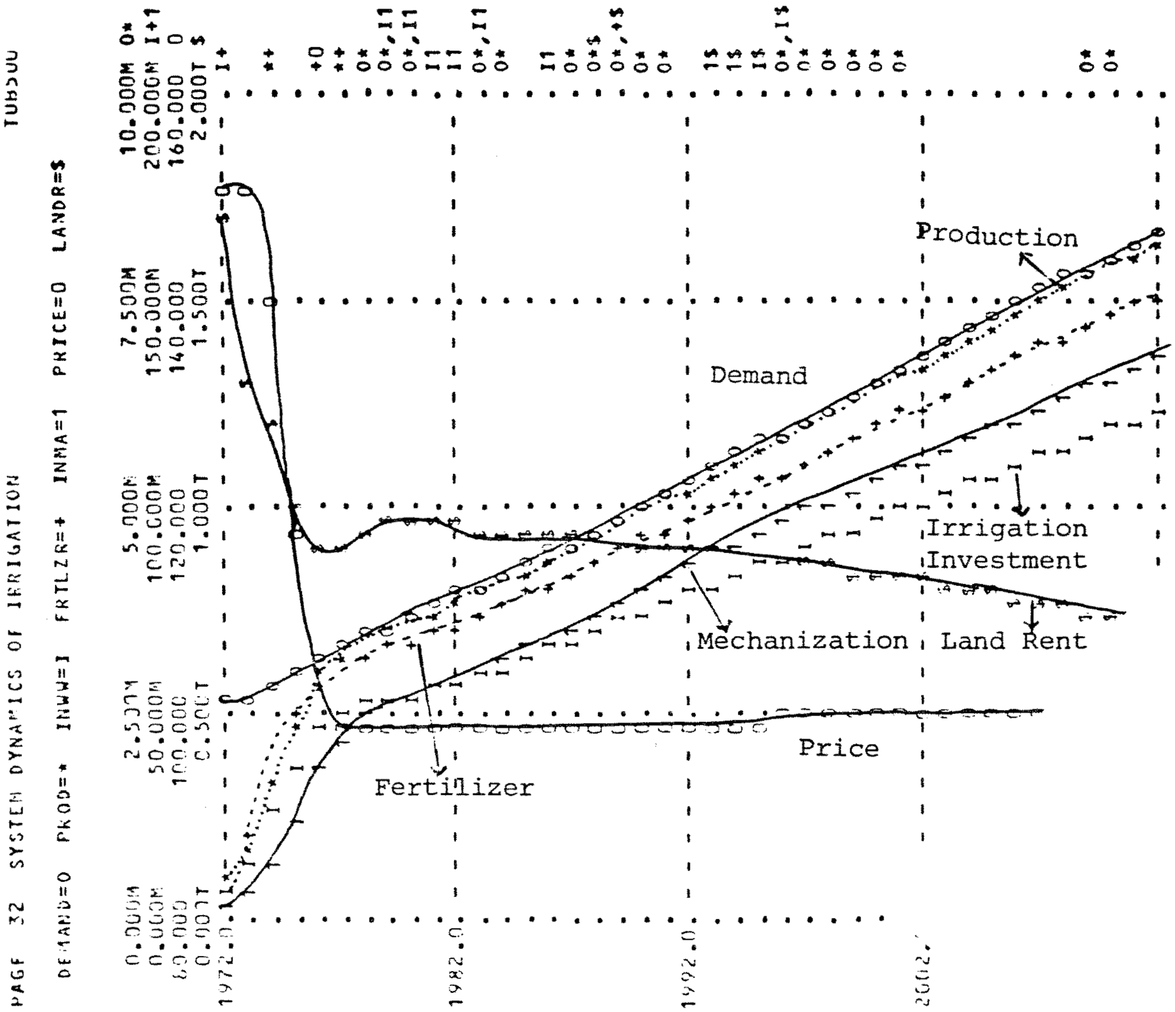
The indirect effect on production of consumer industry and savings is less than $1 billion in the year 2012 in comparison to about $2 billion in the first case. The difference between IGDP in 2012 in two cases is close to $2 billion per year. This clearly demonstrates that more intensive farming would 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 - The Computer Output of Simulation from Groundwater Irrigation

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)



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 hard 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 irrigat is more remunerative than the surface water irrigation at the 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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