A System Dynamics Model of Soybean Production in India

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Abstract

An effort has been made to develop a system dynamics simulation model for soybean production in India. Soybean has been a relatively new introduction to Indian agriculture as a cash crop. Soybean industry in India is typified by high (1520\%) annual growth in area as well as production. It is also typified by negligeble consumption on farms and far advancing rate of growth of processing capacity as compared to the annual production. Soymeal has been a major earner of foreign exchange for the country with advancing years. The model presented here analyses the mechanics of flow of area between various crop options, productivity of soybean and competing crops, annual production, prices and the benefitcost ratio. The values of constants were determined through survey of farmers and expert opinion poll. Policy options have been analysed with the objective of higher profitability for the growers in the long run.

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BACKGROUND

Soybean (Glycine max) has become one of the important oilseed crops in India. From an area of nearly 5000 hectares (ha) during the year 1960-61, it occupied 0.6 million hectares (m ha) during 1980-81 and an estimated 3.8 m ha by the year 1993-94 (Pandey and Biswas, 1986, Bhatnagar and Tewari, 1991, Anon, 1993). Soybean contributed 7.6 \% of the total edible oil requirements in the country during the year 1992-93. Exports of soymeal during the same year were valued US \$ 382 million (Anon, 1993). Soybean processing industry consisted of nearly 117 plants and employed nearly 30,000 people (Jain 1992, Ali 1992).

Soybean is basically a leguminous crop. It consists of 38-42\% proteins, 18-22\% edible oil, 22-23\% carbohydrates, 5\% minerals and the rest as moisture. Soya protein is considered to be of high quality (Miner 1976, Wolf 1983) as food. However, soya foods developed and launched by a number of companies and R\&D units could not gain wide acceptance because of typical beany flavour and unfamilier taste. Soya oil have been successful in penetrating the kitchens of the households primarily because of its lower price as compared to conventionally used oils. Also, extruded soya flour (chunks) have gained some degree of consumer acceptance as there were 3 manufacturers in organised sector besides 20 small ones in unorganised sector by the year 1992-93 together producing about 40,000 t of soya chunks annually.

Soybean is primarily raised as summer crop (called 'Kharif') in India. It is sown in the months of June-July. The crop gets ready for harvesting within 95-130 days of sowing (Bhatnagar and Tewari, 1991). Among the reasons cited for high growth of soybean area are; a) its potential as an edible oil crop at a time when the country was importing edible oils to the tune of 0.5-1.0 mt annually (Anon, 1993), b) absence of any remunerative crop during Kharif specifically in black cotton soil belts in central parts of India, and c) success of local R\&D in adopting, and developing location specific suitable varieties, and enthusiasm and faith of farmers towards these. Yet another reason for the unprecedented growth recorded by soybean has been the establishment of large number of process plants which created a ready and competitive market for soybean (Varadrajan 1992, Jain 1992).

This study was undertaken with the objective of evaluating various policy options using system dynamics, to ensure long run profitability for the growers.

MODEL DESCRIPTION

Influence diagram for soybean production in India has been shown in Fig.1. It consists of basically the following major loops;

a) Soybean area--production--price--profitability--area, and
b) Competitive crops area--production--price--profitability--area.

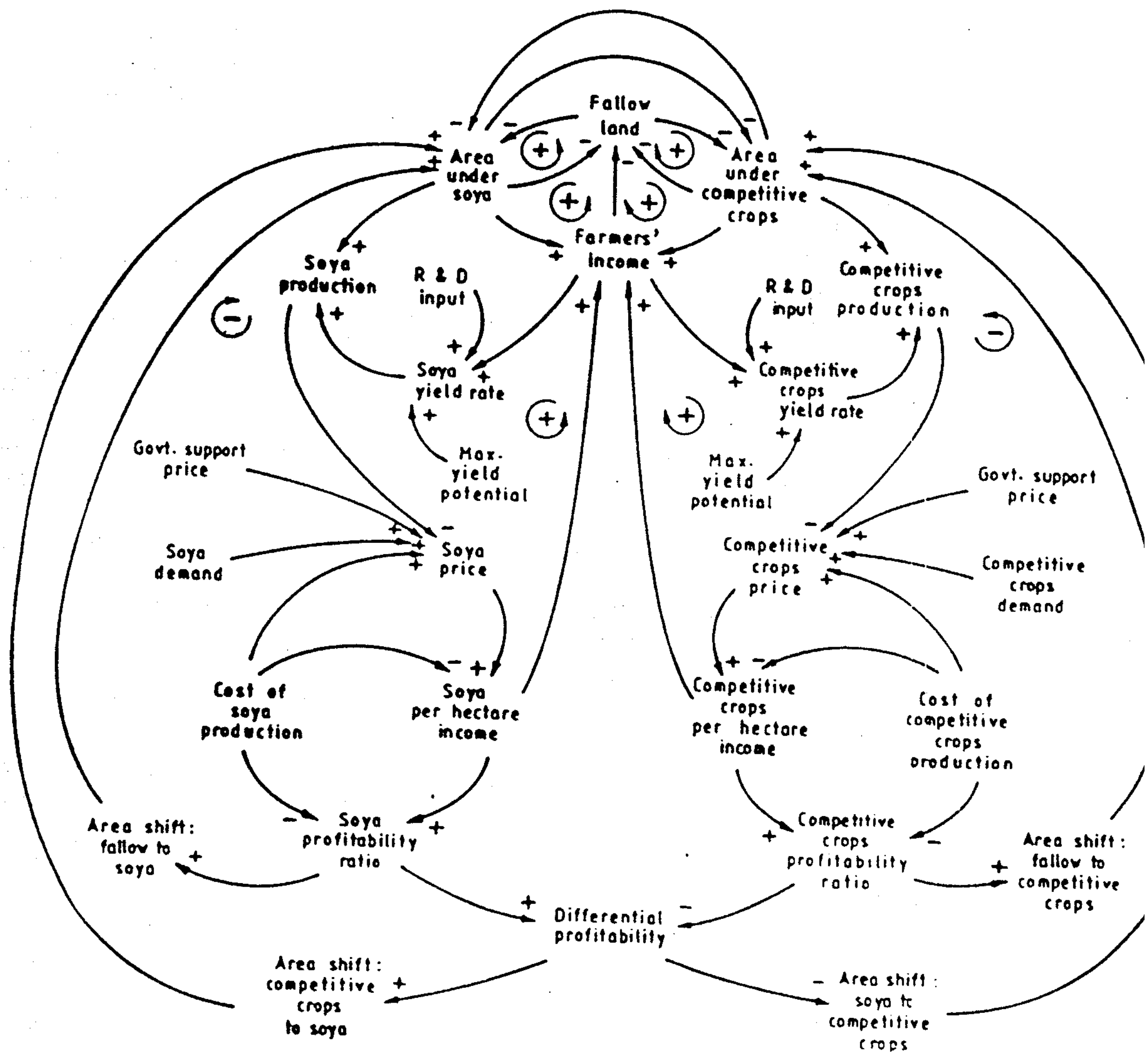

FIG. 1: INFLUENCE DIAGRAM FOR SOYBEAN PRODUCTION, AREA, SELLING PRICE AND FARMERS' INCOME.

Land area allocated to soya (AAS), area of competitive summer crops (AAC), and area under fallow (current fallow+converible waste land) (AUF), have been taken as the level variables (Fig. 2). A similar work reported by Chembezi (1991) for tobacco farmers in Malavi reported that the farmers diverted their land for tobacco from maize keeping in view the price benefits and the risk factors. Williams et al (1974) assessed that the potential of soya area in central parts of India was 2.03 m ha. They assumed 10\% land contributed by kharif fallow and sorghum and 5\% by minor millets and upland paddy. Work was also reported by Wilkerson et al (1983) on development of SOYAGRO model for short run decision making in view of pests and irrigation management. The model presented here comprises of the following key relationships for long run policy modelling using system dynamics. To start with, the equations for level variables representing area allocated to soya (AAS), to competing crops (AAC) and area under fallow land (AUF) have been;

L AAS.K=AAS.J+DT*(AFFS.JK+AFCS.JK-ADSF.JK-ADSC.JK)
L AAC.K=AAC.J+DT*(AFFC.JK+AFSC.JK-ADCS.JK-ADCF.JK)
L AUF.K=AUF.J+DT*(AFSF.JK+AFCF.JK-AAFS.JK-AAFC.JK)

The rate variables connecting the above levels have been expressed as;

R ADSF.KL=AAS.K*FSF.K
R ADSC.KL=AAS.K*FSC.K
R ADCS.KL=AAC.K*FCS.K
R ADCF.KL=AAC.K*FCF.K
R AAFS.KL=AUF.K*FFS.K
R AAFC.KL=AUF.K*FFC.K

Rate variables namely AFFS, AFCS, AFFC, AFSC, AFSF, and AFCF have been defined as the delayed rates of AAFS, ADCS, ADSC, ADSF and ADCF respectively (Fig. 3). The auxiliary variables FSF, FSC, FCS, FCF, FFS, and FFC have been expressed as TABHL functions of DFFS, DFCS, DFSC, DFFC, DFSF, and DFCF respectevely. Further these auxiliary variables have been worked out as;

A DFFS.K=CLIP(SBCR.K,0.0,0.001,SBCR.K)
A DFCS.K=CLIP(DBCR.K,0.001,DBCR.K)
A DFSC.K=CLIP(DBCR.K,0.0,DBCR.K,0.0)
A DFFC.K=CLIP(CBCR.K,0.0,0.001,CBCR.K)
A DFSF.K=CLIP(SBCR.K,0.0,SBCR.K,0.0)
A DFCF.K=CLIP(CBCR.K,0.0,CBCR.K,0.0)

The profitability indicators SBCR, CBCR, DBCR have been defined as;

A SBCR.K=SONI.K/SCOP.K
A CBCR.K=CCNI.K/CCOP.K
A DBCR.K=(SBCR.K-CBCRB.K)/SBCR.K
A CBCRB.K=CLIP(CBCR.K,0.0,CBCR.K,0.0)

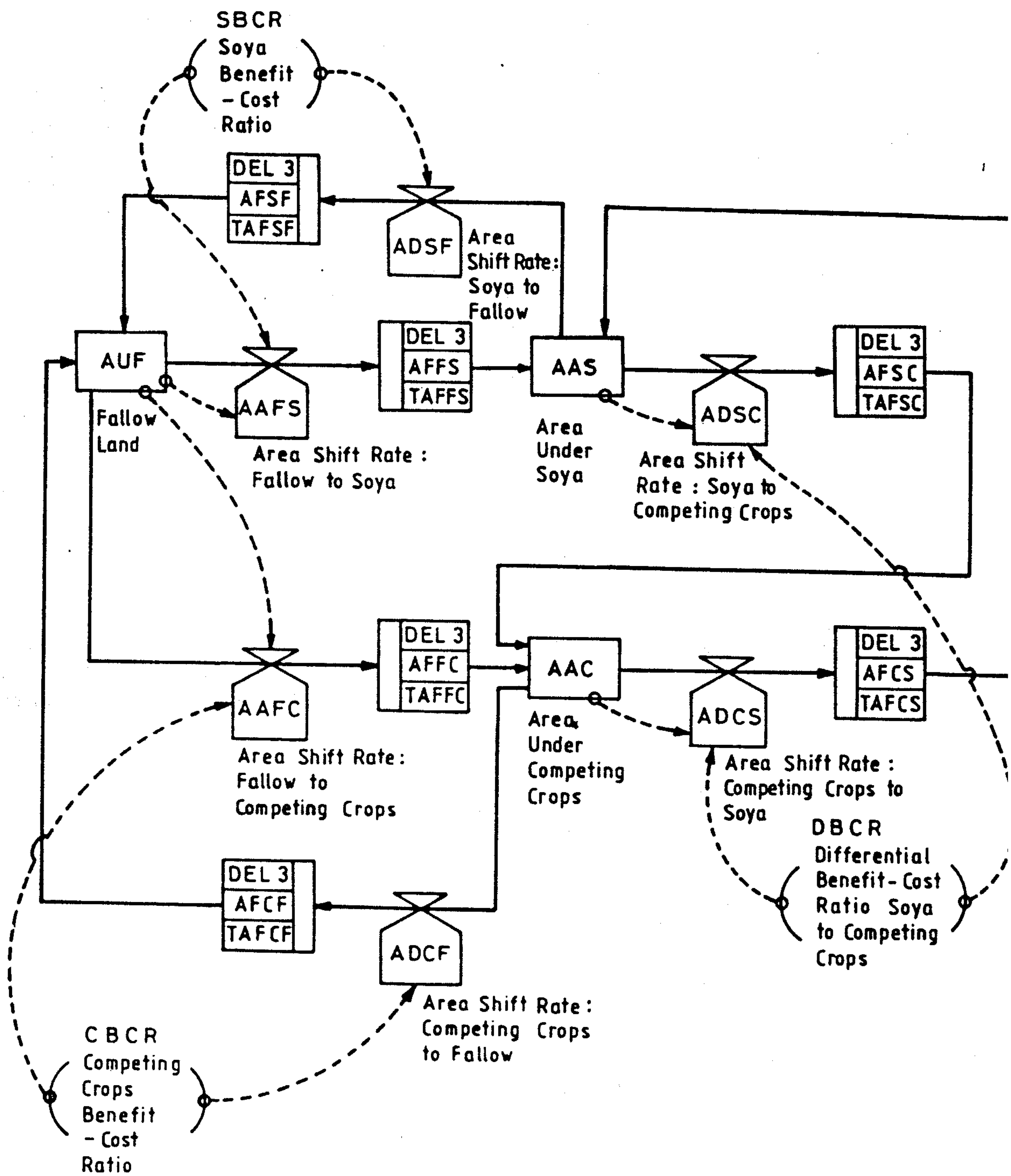

FIG. 2 : SHIFTING OF LAND AREA BETWEEN SOYA, COMPETING CROPS AND FALLOW.

Soya per hectare net income (SONI), and that of cmpetitive crops (CCNI) were calculated by deducting the cost of production of these crops from their revenues (Fig. 4). Gross income of the farmer per unit area (GRIPH) was calculated on annual basis where it was taken as a level variable for the sake of simplicity in computations and understanding (Fig. 4). The selling price received for soya (SPS) was modelled as a function of the cost of soya production (SCOP), support price announced by the government (SUPPS), and the TABHL function of the ratio of order backlog for soya (OBFS) to the soyastocks (SOYSTOC) (Fig. 3). Cost of production of soya (SCOP), and that of competitive crops (CCOP), yield rate of soya (SYPH) and that of competitive crops (CYPH) were defined as varying with time. Gompertz growth models were fitted to the historical data to arrive at the representative relationships as defined by Martino (1983).

The model was run by using DYSMAP2 simulation package (Vapenikova,1987). The base year for the simulation was taken to be 1980 (starting January 01). The model was simulated for a period of 300 time units (months) ending by December 2004 A.D..

MODEL BOUNDARIES

The model is better applicable to soybean farming states in central parts of India. Efforts have been made to keep the model simple and objective oriented (as argued by Forrester, 1987). The model does not include the structure of ownership of land influencing the yield rates and returns (as discussed by Saeed, 1982) and assumes inequalities to be smoothened out on aggregation.

MODEL BEHAVIOUR

The model could reproduce cyclic behaviour of soya price (SPS), and inventory on farms (SOYSTOC) as revealed in Fig. 5. Soya production being seasonal in nature, soya inventory builds up on farms after harvest each year by October-November months. The farmers start releasing the stocks gradually. The stocks get released depending upon the relative profitability (SBCR value) prevailing during the time. Hence, soya price start falling by October and keep downward trend touching annual lowest in the month of January (Fig. 5). The price starts rising as soon as the order backlog to stocks ratio builds up. The price reaches its peak for the year by the month of August and September. Soya price as well as production and stocks reveal chaotic situation when the plots are obtained for the entire length of simulation time. This kind of behaviour have been analysed by Anderson and Sturis (1988). They have argued that deterministic chaos may be one of the possible modes in a number of commonly occuring structures in ecological, biological, macroeconomic, and managerial systems.

The simulated values of annual average price of soybean showed an increasing trend all through the advancing simulation time (Fig. 5). The model could not capture the erratic behaviour of price observed historically for the years of abnormal rains and price falls on expectations of edible oil imports.

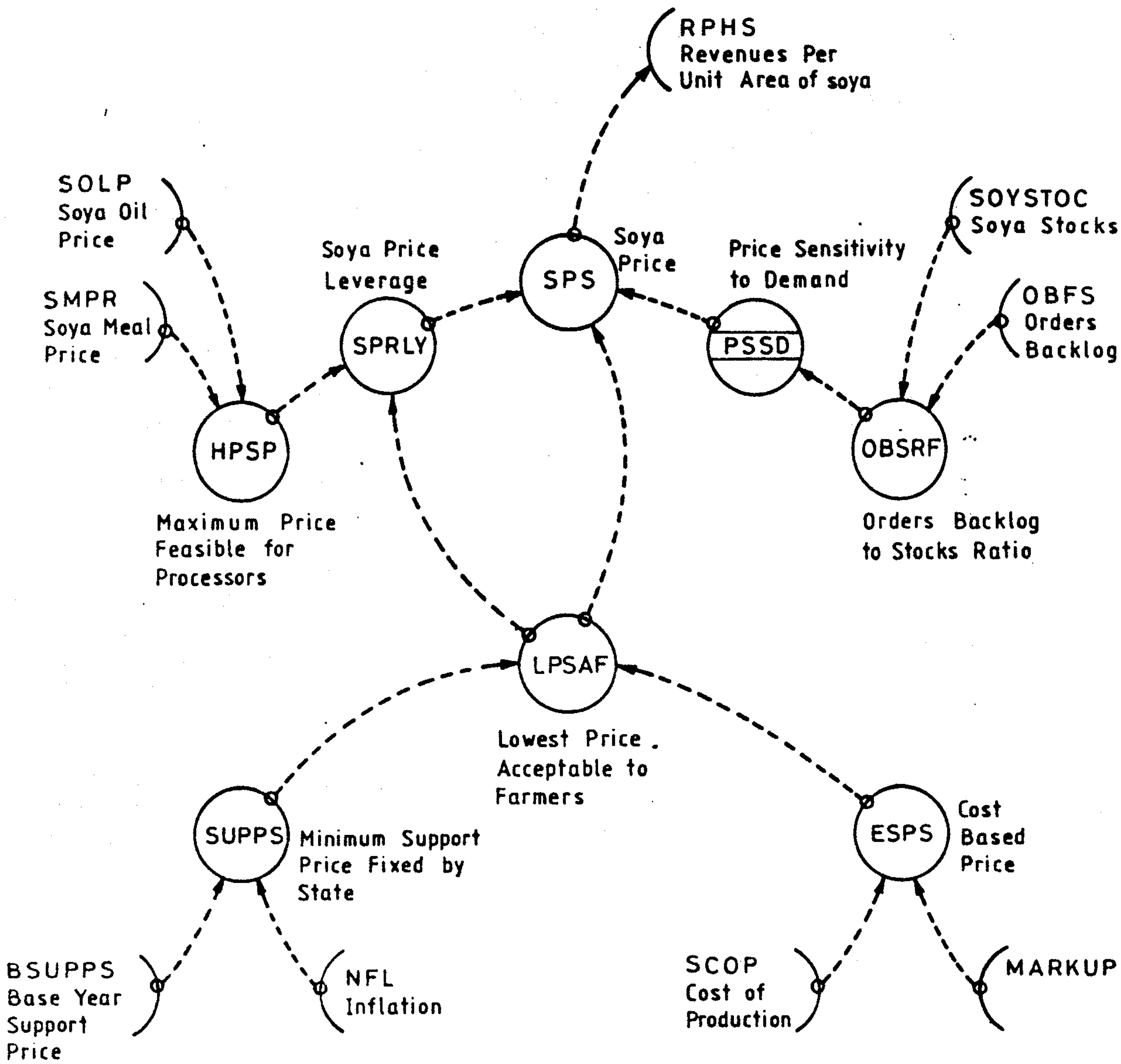

FIG.3 : DETERMINANTS OF SOYBEAN PRICE.

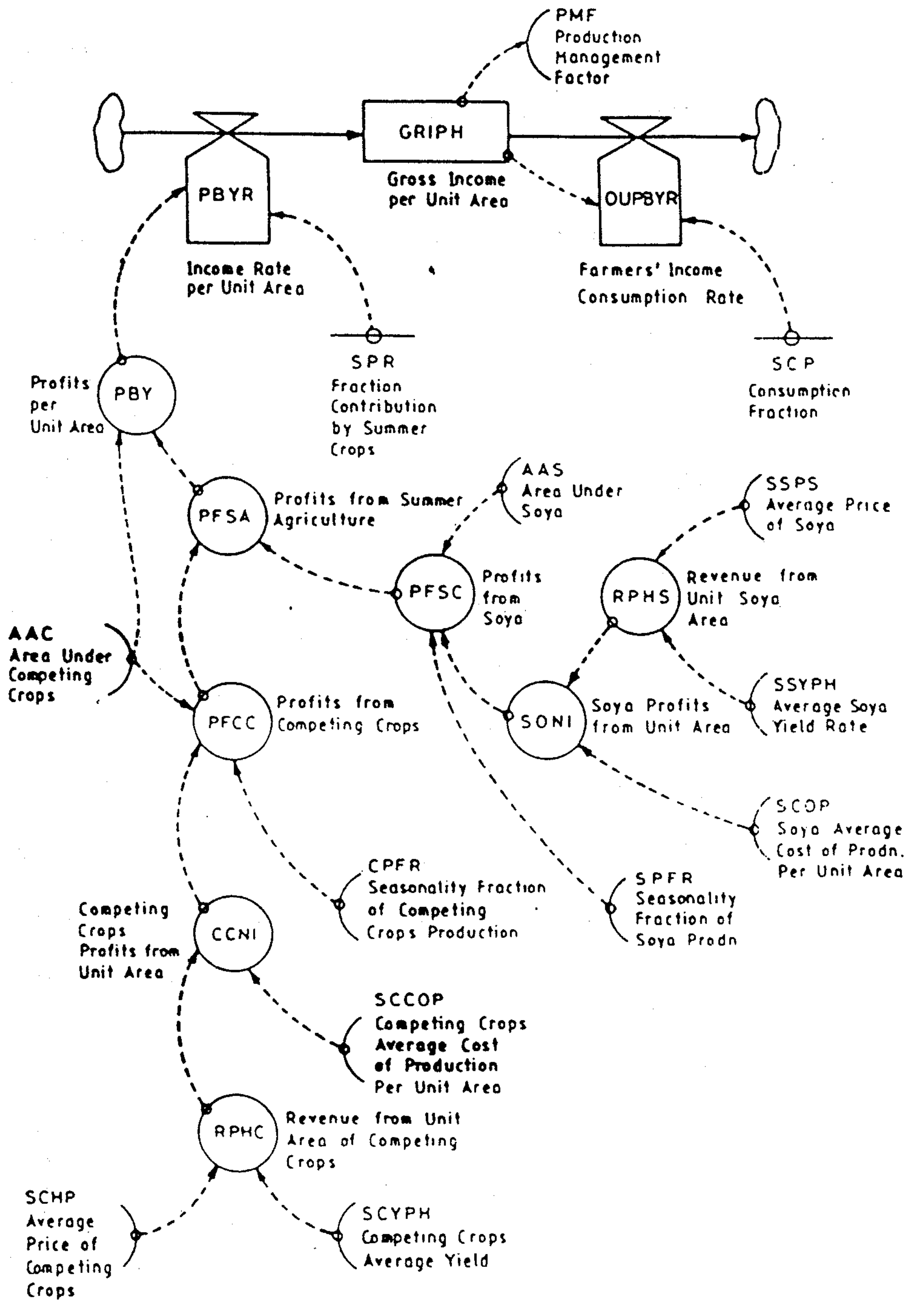

FIG. 4: FARMERS' SAVINGS FROM SUMMER AGRICULTURE.

Besides the base run, the following policies were tried for evaluation.

1. Step increase in support price of soybean (SUPPS) incorporated at TIME=168 i.e. 168th month from January 1980 (i.e. December 1994) by Rs. 1000/t. This was in addition to Rs. 5800/t fixed by the government for the year.

2. Soya area growth stopped after 168th month.

3. Step increase in the demand for soybean by 2.0 mt on account of increased capacity for processing by 168th month onwards.

4. Step increase in cost of production by Rs 500/ha at 168th month onwards in addition to the normally growing cost of production.

5. A joint policy (J) incorporating policy-3 and 4 together.

Effect on Soya Price:

Policy-1 and 4 resulted in price trends similar to that of the base run (Fig. 6). Policy-3 resulted in the highest price of soya, and policies 2 and J produced lowest values of price in long run. The behaviour could be explained by the argument that the soya price remains higher to that of the support price announced by the government as long as the demand for soya from processors exceeds the supply. Increased demand for soya wouldinflate the value of order backlog (OBFS) resulting in higher price negotiated by the farmers in their favour. The farmers would therefore favour policy-3 in view of receiving highest selling price for soya.

Effect on Soya Benefit-to-Cost Ratio:

Policy-3 resulted in highest soya benefit-to-cost ratio (SBCR) followed by policies 1, 2, J, and 4 respectively. The base run SBCR ranked in the middle. Increasing demand would result in higher price for soya, and hence higher profits as long as the production costs do not increase proportionally. Policies J and 4 resulted in low SBCR as they incorporate increased cost of production of soya (SCOP), hence lowered profitability. From the viewpoints of farmers therefore policy-3, and policy-1 would be desirable.

Effect on Area:

Policy-J resulted in highest area under soya cultivation followed by policies 4, 1, 3, B, and 2 (Fig. 7). Increasing demand for soya resulting in increased price and increased profitability would motivate farmers to put more and more area under soybean. Also the increased cost of production, turns the competitive crops less remunerative as the leverage between their revenues per unit area of land may not be able to compensate for the increased costs. This would force farmers to take away more area from competitive crops and allocate it to soya. The policy of installing more capacity of processing plants would therefore result in the highest soybean area as compared to other tested policies.

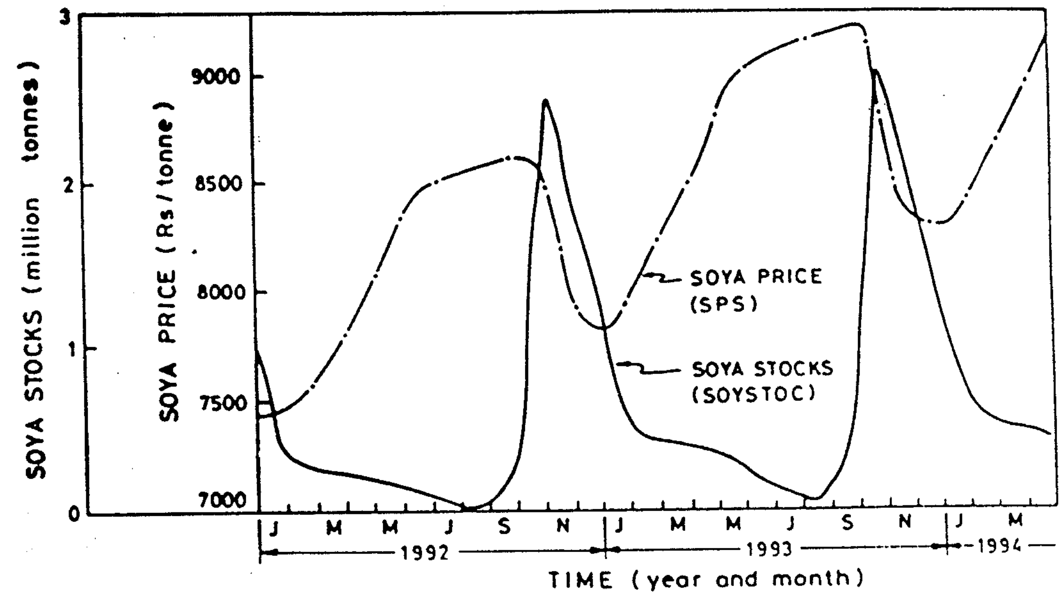

Fig. 5 Simulated seasonal behaviour of soya stocks on farms, and soya price.

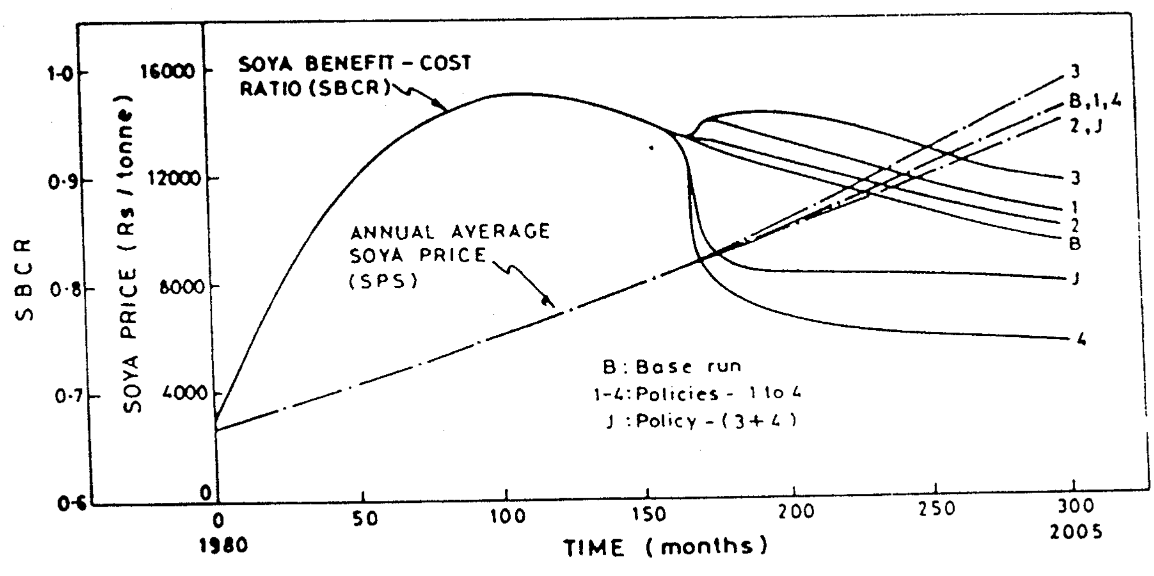

Fig. 6 Soya price and benefit - cost ratio.

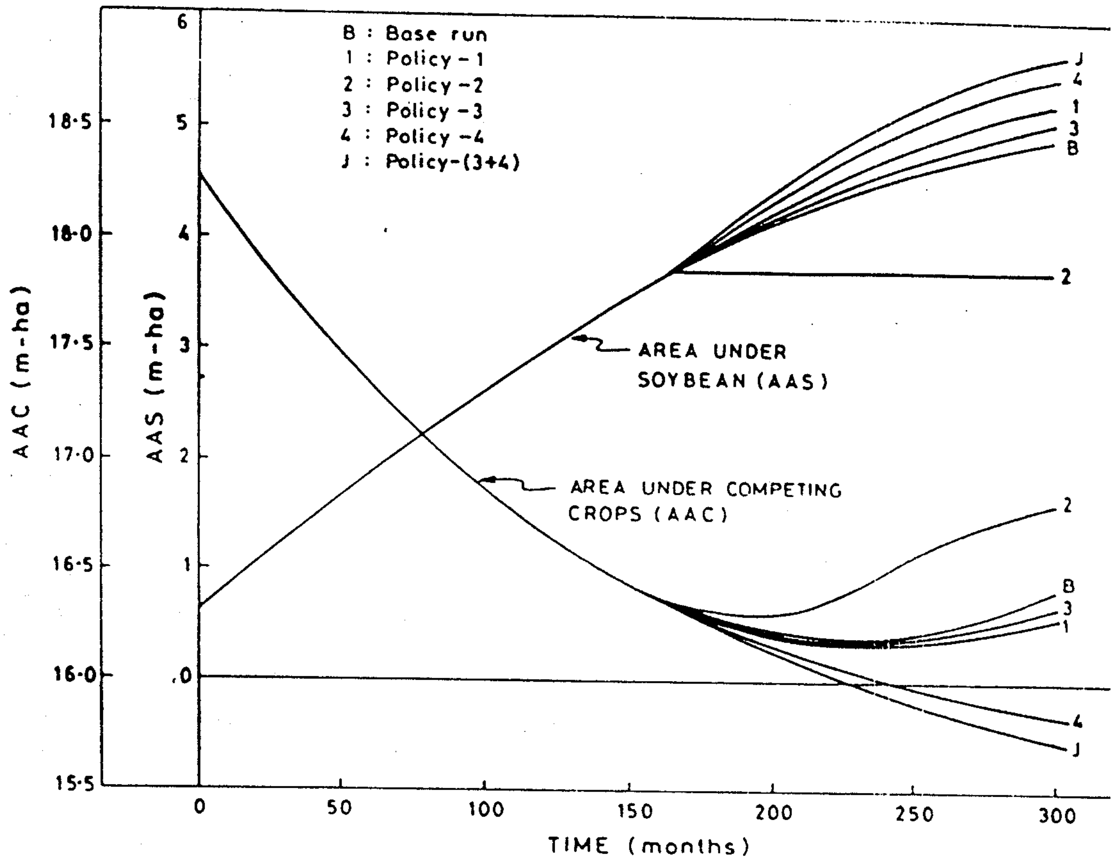

Fig. 7 : Area under soybean and competing crops.

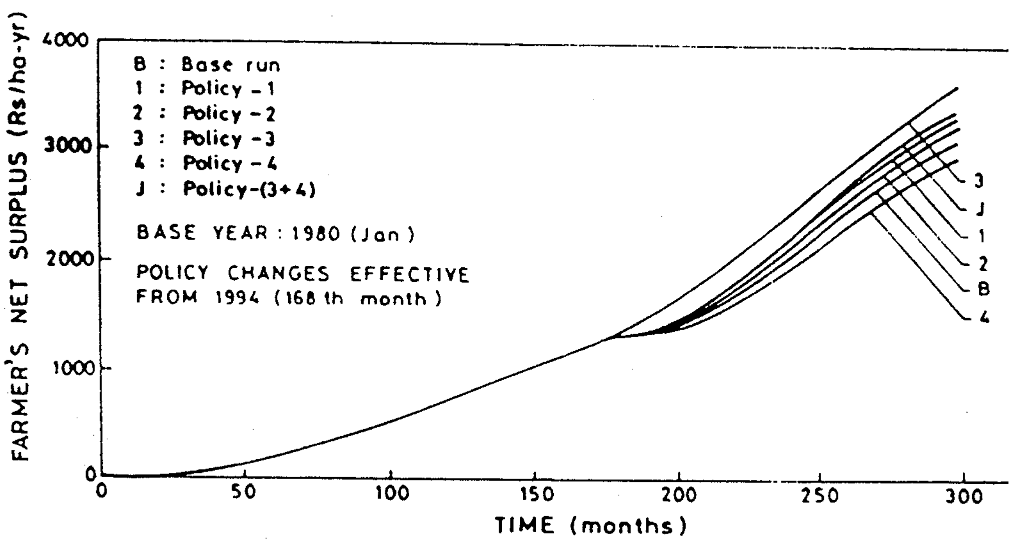

Fig. 8 : Farmer's net surplus from summer crops.

Effect on Farmers' Net Surplus:

Farmers' net surplus per unit area of cultivation (GRIPH), as reveled by the simulated results were highest for policy-3 (Fig. 8). This was followed by policies J, 1, 2, B, and 4. Increased demand resulted in increased price of soya and hence higher profitability. Under this condition the farmers acquire additional bargaining power in view of higher competition among processors for buying limited stocks. Policy-4 results in higher cost of production hence lowered profitability for farmers. Thus the value of GRIPH was the lowest for this policy.

CONCLUSIONS

The area under soybean is expected to keep growing under all policies evaluated except for the case when it is forced to remain static by the influence of exogenous factors. Also, with the growth in soya area its production would grow. Increased demand of soya would enhance the growth of its area.
Soybean price showed seasonal variations within an year. The lowest and the highest being observed to occur in the months of January and August respectively. The annual average price is expected to increase with time. The policy of increased demand would result in the highest price increase followed by other policies.
The benefit cost ratio for soya (SBCR) would have a declining trend in long run. The highest SBCR was obtained for the policy of increased demand followed by the policy of increased support price for soya and so on.
Farmers' gross annual income from unit cultivated area would be maximum for policy of increased demand followed by the policies of joint increase in demand and cost of production, increased support price and so on. Hence, from the view point of farmers, the policy of increased demand could be the most desirable among the tested policies.

REFERENCES

Ali Nawab, 1992, Soybean processing and utilization in India, unpublished background paper for the planning workshop for establishment of Asian Component of the Global Network on Tropical and Subtropical Soybean, Bangkok.

Anderson D.F. and Sturis J., 1988, Chaotic structures in generic management models, *System Dynamics Review*, {\bf 4 (1-2)}, 218-232

Anon, 1993, Agrticulture, *Economic Survey 1992-93*, Govt. of India, 153-169.

Anon, 1993, Soybean paidawar main bridhi se videshi mudra ki prapti badhegi (increased soya production would lead to increased foreign exchange), *The Dainik Nai Dunia,* Sept. 24.

Bhatnagar, P.S., and Tewari, S.P., 1990, Soybean varieties in India, The National Research Centre for Soybean, Tech. bulletin no.{\bf 2}, 1-11.

Bhatnagar, S.P., and S.P. Tewari, 1991, Soybean in edible oil economy in India, *The Agricultural Situation in India*, Ministry of Agri., Govt. of India, Aug., 295-301.

Chembezi,D.M., 1991, Modeling acreage response with risk considerations: The case of estate tobacco in Malavi, *Agricultural Systems*, 427-438.

Coyle, R.G., 1977, *Management system dynamics*, New York, John Wiley Sons, 180-237.

Forrester J.W., 1987, Lessons from system dynamics modelling, *System Dynamics Review*, 3 (2), 136-139.

Jain, N.N., 1992, Soybean industry: problems and prospects, *The Economic Times*, Feb. 2, 1992.

Martino,J.P., 1983, Technology forecasting for decesion making, North Holland, 53-67.

Miner, B.D., 1976, Edible soy proteins:operational aspects of producing and marketing, Farmers Coop. Service, U.S. Deptt. of Agri., FCS Res. Report 33 1-11.

Pandey, P.N.,and M.K. Biswas, 1986, Marketing of soybean in India, Deptt. of Rural Dev., Ministry of Agri., Govt. of India, 34-181.

Saeed, Khalid, 1982, Public policy and rural poverty: a system dynamics analysis of a social change effort in Pakistan, *Technology Forecasting and Social Change*, 21, 325-349.

Shah, Suresh, 1992, Promishing outlook: edible oils, *The Economic Times*, Sept. 26.

Vapenikova, Olga, 1987, DYSMAP2 Implementation on 80386-based PC's, Salford University.

Varadrajan, V.K., 1992, Soya processing, limited crop, major hurdles, *The Hindu Survey of Indian Industry 1991*, The Hindu, 389-391.

Wilkerson, G.G., J.W. Jones, K.J. Boote, K.T. Ingram, and J.W. Mishoe, 1983, Modelling soybean growth for crop management, *The Trasactions of the American Soc. of Agri. Engineers*, 63-72.

Williams, S.W.,W.E. Hendrix, M.K. Von Oppen, 1974, Potential production of soybean in north central India, International Soybean Program, University of Illinois, Urbana-Champaign, tech. report no. 5.

Wolf, W.J., 1983, Edible soybean protein products, *CRC Handbook of processing and utilization in Agriculture*, 1 (2), Plant Products, 23-55.