Agricultural Water Demands: Preliminary Results of Silistra Case Study

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AGRICULTURAL WATER DEMANDS:
PRELIMINARY RESULTS OF SILISTRA CASE STUDY

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PREFACE

Interest in water resources systems has been a critical part of resources and environment related research at IIASA since its inception. As demands for water increase relative to supply, the intensity and efficiency of water resources management must be developed further. This in turn requires an increase in the degree of detail and sophistication of the analysis, including economic, social and environmental evaluation of water resources development alternatives aided by application of mathematical modelling techniques, to generate inputs for planning, design and operational decisions.

In the years of 1976 and 1977 IIASA has initiated a concentrated research effort focusing on *modelling and forecasting of water demands*. Our interest in water demands derived itself from the generally accepted realization that these fundamental aspects of water resources management have not been given due consideration in the past.

This paper, the second in the IIASA water demand series and undertaken at IIASA in collaboration with the Bulgarian Ministry of Agriculture and Food Industry reflects our desire to demonstrate the applicability of the results from our studies on water demand modelling and forecasting.

The results presented in this report are of a preliminary nature and can only be interpreted within the limitations of the model's objective and input data. Since this objective and these data may not be fully reflective of actual conditions in the Silistra region, the results of the model should not be taken as specific policy recommendations for the development of this region.

Dr. Janusz Kindler
Task Leader

ABSTRACT

Preliminary results of the Silistra Water for Irrigation Model (SWIM) for determining agricultural water demands in the Silistra region of Bulgaria are presented. For various areas of irrigated and non-irrigated land, and various volumes of water supply, SWIM uses linear programming to select the optimal combination of crop areas and production inputs so as to maximize annual net benefits from crop production in excess of target production quantities of each crop. Both normal and dry weather conditions are examined. The region's import-export balance is investigated for areas of irrigated land between 10,000 and 50,000 hectares and it is shown that total costs of crop production are minimized when the region is just self-sufficient in crop production. By means of demand curves it is demonstrated that the marginal values of land and water for irrigation are greater than their unit costs of development so that it is optimal to develop irrigation to the maximum area considered by the model.

ACKNOWLEDGEMENT

CONTENTS

1. INTRODUCTION

The Silistra region having a population of 200,000 and covering a territory of about 2700 km^2, is situated in the north-eastern part of Bulgaria. The agricultural activities in the region are concentrated in a large agro-industrial complex called Drustar. The term agro-industrial complex means that all individual enterprises dealing with crop production and it's processing as well as with livestock growing and processing are coordinated by one administrative body. This body is responsible for overall planning, development, and management of the complex. Since the complex is developing rapidly, it is essential to choose the best way of directing future agriculture activities and investments. In the list of problems to be investigated in this respect, water resources appear to have a key role. The reason is at least twofold:

a) a vast irrigation development is to take place in the coming 5-10 years to meet the feed requirements of meat and milk producing livestock; hence, to ensure stable agricultural production, a large reliable water supply has to be made available in the region.

b) water resources in the region are rather scarce being limited to the bordering Danube river. No other rivers exist in the region. Ground water is available only in small quantities in depth exceeding 400 m. which makes it an unimportant resource.

To overcome these difficulties intensive investigations have been carried out in this region over the past few years. As a result, a number of alternatives for augmenting the available water supply have been proposed. Some of them include construction of several reservoirs in various parts of the region; others envisage combine use of pumping stations and reservoirs, constructing long distance canals , etc. The common characteristic of all alternatives is that firstly, they rely on Danube river water (which is reliable but water use is restricted by several international agreements) and secondly, all of the alternatives are rather costly. Obviously one way of

decreasing supply cost would be to reduce agricultural water
demands for irrigation which constitute the major demand part
of the region keeping at the same time the production targets
at the desired level. It is furthermore obvious that reducing
agricultural water demands involves additional costs. The
problem is: are these costs greater than the supply cost and
where is the point at which the water resource system is in
equilibrium, e.g. the point at which incremental cost of addi-
tional supply is equal to incremental benefit from demanded water?

The main objective of the study is to make a thorough
analysis of factors that influence both agricultural water
demands and associated agricultural production taking into
account the major goal of the Drustar complex, which is to
maximize the total agricultural and livestock production with-
in the limited regional resources. In the course of the study
we have focused the main objective towards providing an adequate
answer to the following questions:

- what is the amount of crops able to be produced from the
  complex given various possible volumes of water supply
  within the constraints of available resources of other
  types: labor, machinery, fertilizer, etc?

- how much area should be developed for irrigation and
  which crops should be irrigated?

- what is the export-import balance in the complex in
  case of favourable and unfavourable weather conditions?

- what is the marginal productivity of water and irrigated
  land in the complex i.e. how much would the benefit
  (or cost) change if one additional unit of water or
  irrigated land were provided?

The scope of the study is closely related to the afore-
mentioned problems. To provide an adequate answer to them at
least three major activities are worth modelling: feed crop
production, non-feed crop production (tobacco, vegetables, vine-
yards, etc.), and livestock production. Only the first activity,
which has the greatest direct impact on water resources, is paid
appropriate attention in the model. The non-feed crop production
has less impact on water resources because of small area occupied
by these crops and less water demands (about 10%) when compared

with feed crop ones. Bulgarian scientific organizations and
IIASA have been intensively studying livestock production
(Carter, Csaki, and Propoi, 1977; Propoi, 1977). For this
reason the livestock feed requirements are considered as
being externally specified in the model.

The model reported herein is a preliminary one using data
mainly provided for us in a development plan for the complex
prepared for the Bulgarian government agency Rodopaimpex by
the consulting firm Globe Services International. A draft of
the report describing the model was translated into the Bulgarian
language and reviewed in Bulgaria during August 1977. As a re-
sult, some better data were obtained and many suggestions
received for extending the model structure to more closely
represent the Drustar complex. On this basis a second version
of this model has been developed. Since the later version omits
some of the features of the earlier one, we have decided to
publish this complete description of the preliminary model and
its results at this time and to report on the subsequent work
on this model when it is complete.

2. DESCRIPTION OF THE MODEL

2.1 Overview

The Silistra Water for Irrigation Model (SWIM) has been developed to estimate the amount of water needed for irrigation in the Drustar complex. In the conventional approach to evaluating these water demands the following method is usually employed:

- the area to be developed for irrigation is specified;

- the area of each type of crop to be grown with irrigation is decided taking into account the crop production from nonirrigated land;

- considering the weather conditions, the depth of water which must be irrigated onto each crop is determined;

- the total volume of water needed for the irrigated area is found as the product of the depth required for each crop and the crop's area, summed over all the irrigated crops.

Clearly this method should be applied a number of times to estimate the effect on water demands of different assumptions concerning the area of land to be developed for irrigation, weather conditions, crop production, etc.

With SWIM the conventional approach is both computerized and extended. One can follow the conventional approach, in which case for a given area of irrigated land SWIM determines the optimal crop distribution for maximum production on both irrigated and nonirrigated land and the volume of water needed for irrigation under normal weather or drought conditions. However, SWIM can also operate in the opposite direction: for a given volume of water available, SWIM can determine the optimal crop distribution, which crops are irrigated, and hence the area of land which should be developed for irrigation. Moreover, since SWIM is computerized, with little extra cost it can be used many times to determine the optimal solution for different assumptions concerning irrigated land area, water availability, weather conditions, etc.

A verbal description of SWIM now follows. A detailed mathematical description is given in Appendix 2.

In SWIM, the crop production system of the Drustar complex is visualized as shown in figure (2.1). The system consists of three parts: resource inputs, crop production, and crop outputs. These outputs may be used to meet the requirements of the population and livestock in the region, or they may be exported to other regions within or outside the country.

From the overall viewpoint, Drustar is an agricultural-industrial complex whose primary output is from animals: pigs, dairy cows, cattle, and sheep. Based on the necessary diets of these animals, and the number of the different types of animals in the complex, the total amounts of feed required for livestock of each of the crop outputs may be calculated and these are considered as being externally specified to SWIM. Likewise the requirements of the population for cooking oil and flour are externally specified. All of these requirements are met in the solutions of SWIM. Any extra production beyond these requirements is assumed to be sold for export at internal Bulgarian prices. In case of unfavourable weather, maize grain can be imported at a price greater than that for export (for example 50% greater).

The objective of SWIM is to maximize the value of these exports minus the costs of all production, including the costs of the crop outputs used within the region. All costs and prices are measured in Bulgarian Leva (1 Lv= 1$US). The production costs are calculated in the following way. For each crop the basic unit of production is one hectare. The amounts of the input resources of water, seeds, fertilizer, fuel, labor, and machinery needed for one hectare of crop are estimated, and their costs computed as the product of the amount of the resource and its unit cost. All other production costs which are not directly connected to the input resources (such as the cost of storage buildings, or administration) are summed up and assigned to the unit hectare of each crop as a lumped cost. For any area of each crop the corresponding production cost can then be calculated. There are seven crops, see figure (2.1), each of which may or may not be irrigated, so SWIM considers 14 crop alternatives in all.

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┌─────────────────╲      ┌─────────────────────╲        ┌──────────────────────╲
│                  ╲     │                      ╲       │                       ╲
│  INPUTS           ╲    │  CROP PRODUCTION      ╲      │  OUTPUTS               ╲
│  ───────           ╲   │  ───────────────       ╲     │  ───────                ╲
│                     │  │                         │    │                          │
│  LAND               │  │  Irrigated and          │    │  Maize      - grain      │
│                     │  │     Nonirrigated:       │    │             - silage     │──┐
│  WATER              │  │     Maize Grain         │    │  Wheat      - grain      │  │
│                     │  │                         │    │             - bran       │  │
│                     │  │     Maize Silage        │    │             - flour      │  │
│  Seeds              │  │                         │    │  Barley     - grain      │  │
│  Fertilizers        │  │     Wheat               │    │  Soybeans   - meal       │  │
│  Fuel               │  │     Barley              │    │  Sunflowers - oil        │  │
│  Labor              │  │     Soybeans            │    │             - meal       │  │
│  Machinery          │  │     Sunflowers          │    │  Lucerne    - hay        │  │
│                    ╱   │                        ╱     │                         ╱   │
└───────────────────╱    └────────────────────────╱    └────────────────────────╱
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Maize	- grain
	- silage
Wheat	- grain
	- bran
	- flour
Barley	- grain
Soybeans	- meal
Sunflowers	- oil
	- meal
Lucerne	- hay

Exports

Population
Requirements

Livestock
Requirements

FIGURE 2.1 CROP PRODUCTION SYSTEM OF SILISTRA REGION

SWIM determines the optimal area of each crop alternative so as to meet all the production requirements and maximize the objective previously stated.

SWIM is formulated and solved on the computer as a linear program. All quantities to be optimized in SWIM are included as decision variables (e.g. areas of each crop, amounts of each resource used). These variables are interrelated through a number of constraint equations which express the physical limitations of the system (e.g. sum of all crop areas must equal the total area, water used cannot exceed water available). All of these equations are linear which means that a change in one variable leads to directly proportional changes in all the other variables related to it. SWIM currently contains 60 decision variables interrelated through 70 constraint equations involving 400 data values. It has been solved more than 50 times for the different sets of conditions described in this report.

In the following sections, the structure of SWIM is described in more detail following the scheme of Figure (2.1). In section (2.2) the methods of calculating the amounts of resource inputs and their unit costs are given. Section (2.3) describes the production schedule of field operations for each crop and their cost. The crop outputs are shown in detail in section (2.4).

2.2 Input Resources

2.2.1 Land

There are 151,785 ha of arable land in the complex of which 30,185 ha is assumed to be used for growing special crops for domestic consumption as follows:

- Tobacco	5,450 ha
- Drybeans	9,000 ha
- Flax	2,500 ha
- Vegetables	3,000 ha
- Vineyards and Orchards	10,235 ha

Because data on water requirements of these crops were not available to us, SWIM does not consider their irrigation needs. The remaining arable land amounts to 121,600 ha of which a small

part (about 3000 ha) must be reserved for seed production.
SWIM determines this seed area in its solution.

The main soil type of the region is Chernozem (Black Earth),
which is subject to erosion in some areas. Although there are
natural variations in soil structure and productivity in the
district, we have no data at present on the variation in crop
yields for different soil types so SWIM considers the whole
121,600 ha to be a homogeneous block of uniform soil type and
productivity. No costs of land are included in SWIM. Small
amounts of land may be needed for pasture for sheep grazing but
these have not been included in SWIM.

2.2.2 Water

The Danube River is the only source of irrigation water for
the region as there are no other significant rivers and ground-
water is available only at great depth (400-600 metres). The
climate is moderate with an average annual rainfall of 550 mm.
However the summer is hot and potential evaporation exceeds
average rainfall throughout the growing season from April
through September, as shown in table (2.1). Thus irrigation
is necessary to ensure consistently high crop yields. Because
of the rolling hills, potential for erosion, and scarcity of
water resources, sprinkler irrigation is the only application
method being considered in the complex. Although there will
be losses in transportation and application of the irrigation
water we do not have sufficiently good information to include
these losses in SWIM at the present time. Hence the volumes
of water computed are the volumes needed to be delivered to the
root zone of the plants. The amounts of water needed in other
parts of the agricultural-industrial complex, such as for clean-
ing and processing in animal production, are not considered
separately in SWIM because it is assumed that this water will
eventually be irrigated onto the land as a method of waste
disposal of manure, etc.

Table 2.1 Rainfall, Evaporation, & Moisture Deficit

Month	Rainfall (mm)	Evaporation (mm)	Deficit (mm)
January	38	14	+24
February	31	20	+11
March	33	42	- 9
April	43	74	-31
May	52	98	-46
June	76	122	-46
July	65	141	-76
August	36	135	-99
September	48	93	-45
October	44	54	-10
November	34	27	+ 7
December	46	17	+29

Table 2.2 Depth & Period of Irrigation

Crop	Period Irrig.	April	May	June	July	August	Total	Total Depth in Drought
Lucerne	Apr 15 to June 30	78	231	231	–	–	540	648
Maize Silage	May 20 to Aug 30	–	22	66	109	143	340	408
Maize Grain	May 20 to Aug 30	–	22	66	109	143	340	408
Wheat	Apr 1 to May 30	36	54	–	–	–	90	108
Barley	Apr 1 to May 30	36	54	–	–	–	90	108
Soybeans	June 1 to Aug 30	–	–	48	79	103	230	276
Sunflowers	June 1 to July 31	–	–	49	80	–	129	155

The depth of water needed for irrigation by each crop is estimated where possible by reference to Donev (1972). This total depth is then divided into the depth needed in each month of the irrigation period in proportion to the deficit of rainfall in that month. The results are given in table (2.2).

To estimate the crop water requirements under drought conditions, all the irrigation depths are arbitrarily increased by 20% over those for normal weather conditions. It would be relatively easy to modify the water requirements in SWIM to reflect those measured in individual years, where data are available.

In all cases the total volume water made available was assumed to have a unit cost for pumping of 0.022 Lv/cubic metre.

2.2.3 Seeds

All seeds required are assumed to be grown within the complex on irrigated land. SWIM computes the area of land needed for seed growing per hectare of field crop production by dividing the seed planting rate for each crop by its seed crop yield rate and summing the resulting seed crop areas. Seed crop yields are assumed to be the same as the irrigated field crop yields in the case of grains. The cost of seed production is assessed as 90% current Bulgarian price plus 10% foreign import price. This cost includes the production, processing, and distribution of the seed. The data used for seed planting rates, seed crop yields, costs, and seed area, are given in table A3.1 in Appendix 3.

2.2.4 Fertilizers and Pesticides

Three nutrients must be supplied with fertilizers: nitrogen, phosphorus and potassium. The corresponding fertilizers are ammonium sulphate (34% active nitrogen), super phosphate (20%

active phosphorus), and potassium sulphate (44.5% active
potassium). The amount of each fertilizer needed per hectare
is calculated in the following way: first, the amount of each
nutrient removed by crop production is estimated; next, to
compute the amount of nutrients needed to be applied, the re-
moval amounts are modified to allow for application losses
and the natural ability of the soil to absorb or release nu-
trients; finally the amounts of fertilizers required are found
using the proportion of active nutrient in each.

SWIM calculates the total amounts of fertilizers needed
for all crops. These total amounts must be decreased to allow
for the nutrient value of the manure being supplied to the
land by irrigating animal wastes. For 1980 conditions, the
amounts of active nutrients in the manure are taken to be 2419
tons nitrogen (N), 1738 tons phosphorus (P_2O_5) and 3086 tons of
potassium (K_2O); these amounts represent about a quarter of the
total requirements for nitrogen and phosphorus, and half the
total requirement for potassium.

Where possible the fertilizer application rates have been
compared with national average application rates for Bulgaria,
as given in the Bulgarian Statistical Yearbook (1975)
and found to be not excessive. Also, the total amounts of
fertilizers needed in the complex are not excessive when com-
pared with the total production of fertilizers in Bulgaria.

The fertilizer costs are taken as 107.10 Lv/ton for
ammonium sulphate, 58.00 Lv/ton for superphosphate, and 86.75
Lv/ton for potassium sulphate. All data on fertilizer quan-
tities are given in table A3.2 in Appendix 3. Fertilizer
application costs are given the production cost tables for
each crop in Appendix 4, calculated at 3 Lv/Ha per trip over
the field.

As far as pesticides are concerned, there are too many individual chemicals involved to make an accounting for each one separately as is done for fertilizers. Instead, a lumped cost per hectare is specified for each crop for chemicals and is given in the production cost tables in Appendix 4.

2.2.5 Fuel

The fuel needed by the field machinery is computed on the basis of amounts used for individual field operations: plowing, cultivation, planting, and harvesting, as shown in table A3.3 of Appendix 3. For irrigated crops, the fuel use for harvesting is higher than for nonirrigated crops because of the higher yield. The average fuel consumption per hectare for tractors varies from 25 to 30 litres/hr depending on the crop. Fuel is assumed to cost 0.072 Lv/litre.

2.2.6 Labor

The labor needed for field operations is calculated on the basis of the number of hours each machine is in the field, assuming one operator per machine, as shown in table A3.4 of Appendix 3. This labor has a cost of 2 Lv/hour. The additional labor required for administration and support services is not directly computed but is assigned a cost of 2.82 Lv/Ha. Labor for irrigation is included in the costs of irrigation.

2.2.7 Machinery

To determine the number of machines, such as tractors, which will be needed in the complex, the critical period in the schedule of field operations must be known when all of the available machines are being used. The schedule of field operations is shown in figure (2.2). SWIM determines the number of tractors, combine harvesters, and silage choppers in the following way. Allowing for some lost time due to bad weather during the critical period, and a 10 hour working day, the number of working hours is known. The area per hour which a machine can cover is also known; hence, the area which can

FIGURE 2.2 SCHEDULE OF FIELD OPERATIONS

CROP	ACTIVITY	March 5 10 15 20 25	April 5 10 15 20 25	May 5 10 15 20 25	June 5 10 15 20 25	July 5 10 15 20 25	August 5 10 15 20 25	September 5 10 15 20 25	October 5 10 15 20 25
Lucerne	Plowing								
	Cultivation								
	Planting								
	Hay making								
	Irrigation								
Maize Silage	Cultivation								
	Planting								
	Chopping								
	Irrigation								
Maize Grain	Cultivation								
	Planting								
	Cultivation								
	Harvest								
	Irrigation								
Wheat	Plowing								
	Cultivation								
	Planting								
	Harvest								
	Irrigation								
Barley	Plowing								
	Cultivation								
	Planting								
	Harvest								
	Irrigation								
Soybeans	Cultivation								
	Planting								
	Cultivation								
	Harvest								
	Irrigation								
Sunflower	Cultivation								
	Planting								
	Harvest								
	Irrigation								

be covered by one machine during the critical period can be computed, and once the crop distribution is fixed, the number of machines may be determined.

For tractors, the critical period occurs during spring cultivation from 20 March to 20 April, for combine harvesters it occurs during the soybean-maize harvest from 20 September to 30 October, and for silage choppers it occurs during the maize silage harvest in July.

To determine the number of center-pivot irrigation sprinklers, the critical period is in June when lucerne, maize grain, maize silage, and soybeans could be irrigated. It is assumed that one sprinkler can irrigate 52 hectares during this period, so the number of sprinklers can be found from the crop areas. In the case of wheat and barley it is assumed that if these are irrigated the same sprinklers can be used as for maize grain and silage, and soybeans. If insufficient sprinklers are available then they must be purchased especially for wheat and barley. Likewise, the sprinklers needed for irrigating lucerne can also be used to irrigate sunflowers.

The costs of machinery other than irrigation sprinklers are given for each crop in the production cost tables in Appendix 4. The fixed costs are based on capital costs of the machines, depreciated over their working life; the variable costs are calculated to account for maintenance and lubrication. The capital cost of developing irrigated land is taken as 2000 Leva/Ha, which is depreciated over 40 years to give 50 Leva/Ha in each year. The depreciated capital cost of irrigation sprinklers is also taken as 50 Leva/Ha. The variable costs of irrigation include the cost of labor and maintenance of the equipment.

2.3 Crop Production and Outputs

2.3.1 Production Costs

Moving now to the central box of figure (2.1), the crop production schedule and costs are described. Only one year of crop production is considered. At present, SWIM does not explicitly account for crop rotation from year to year, or double

cropping within one year, but these refinements could be included if necessary. The schedule of field operations for all crops is shown in figure (2.2). While lucerne is the only perennial crop considered, wheat and barley are planted in the autumn for harvest the following summer. All other crops are planted and harvested within one growing season. The crop production costs per hectare for each crop, both irrigated and nonirrigated are given in Appendix 4.

Lucerne is assumed to be grown only for hay and is replanted every three years. Accordingly, the costs associated with planting have been depreciated in a straight line fashion over this period. No allowance has been made for the ability to supply nitrogen of the legumes, lucerne and soybeans, except that no nitrogen fertilizers are required for them. Maize is grown both for fodder as silage, and grain. When maize is harvested as grain it is assumed that the stalks are plowed back into the soil; for wheat and barley, likewise, it is assumed that the straw is not harvested.

2.3.2 Crop Yields

Crop yields are the most sensitive parameters of SWIM. The relation between crop yield, weather, and irrigation is central to any analysis of irrigation. The yields used in SWIM under normal weather conditions are based where possible on average yields obtained in the Drustar complex, as shown in table (2.3). When the crops are not grown with irrigation at present in the region, the increase in yield due to irrigation can only be assumed. For such crops, where no better data are available, the increase in yield typical for Bulgaria as a whole has been adopted.

In the case of the decrease in yield in response to drought, percentages of decrease in yield used were chosen as follows: maize, 50%; soybeans and sunflowers, 30%; wheat, barley, and lucerne, 15%. Wheat, barley, and, lucerne are more drought-resistant because they are in the ground over the winter and the moisture absorbed by the soil during that time is not lost through cultivation in the spring. Maize has a large response

Crop	Nonirrigated		Irrigated
	Drought	Normal	
Lucerne	5.1	6.0	10.6
Maize Silage	14.0	28.0	50.0
Maize Grain	2.35	4.7	8.6
Wheat	2.72	3.2	3.7
Barley	2.63	3.1	3.6
Soybeans	1.05	1.5	2.7
Sunflowers	1.4	2.0	2.2

Table 2.3 Crop Yields (in Tons/Ha)

to drought because it has a large amount of vegetative growth
and small roots. The yield of irrigated crops during drought
is assumed not to change because the loss in rainfall is made
up by adding 20% more irrigation water.

2.3.3 Processing

The crops harvested from the field can be processed into
a number of outputs. Since the requirements for feeding live-
stock are expressed in terms of processed outputs, SWIM has some
processing activities included within it. The fodder crops,
lucerne hay and maize silage are not processed off the farmland.
Wheat may be milled for flour in which case 78% of the grain
becomes flour and 14% becomes wheat bran which is fed to live-
stock. Both soybeans and sunflowers are crushed and the oil is
extracted. The residual is livestock meal which comprises 75%
by weight of the soybean grain and 41% of the sunflower seeds.
Maize and barley must be milled before being fed to pigs but
there are no significant weight losses in this process.

2.3.4 Requirements for Population and Livestock

The requirements of population for crop outputs are taken
as 40,000 tons of flour and 8,400 tons of cooking oil for 1980.
The requirements for livestock for 1980 conditions are calculated
on the basis of the diet of each animal and the estimated number
of animals in the complex. The numbers of animals assumed are:
23,760 breeding sows; 434,404 pigs raised for slaughter; 24,000
dairy cows with associated calves and heifers; and 80,000 ewes.
The corresponding feed requirements assumed by SWIM are: 174,100
tons of maize grain, 327,000 tons of maize silage; 37,380 tons
of soybean or sunflower meal; 117,100 tons of lucerne hay; and
2805 tons of wheat bran. These values for amounts of feed
requirements can easily be changed in SWIM if necessary. It
is assumed that 1.1 ton of barley grain can substitute for
1 ton of maize grain.

2.3.5 Imports and Exports

Maximization of production is a goal of the agricultural-industrial complex. Once the livestock and population feed requirements are met, SWIM exports extra production of maize, wheat, and barley grain at internal Bulgarian prices of 113, 114, and 101 Leva/ton, respectively. In case of unfavorable weather conditions when the production requirements as specified in the previous section cannot be met, maize grain can be imported to the region at a price of 170 Leva/ton.

3. RESULTS OF APPLICATION OF THE MODEL

When the capital investment required to develop the Drustar agricultural-industrial complex is considered, a significant part of this investment must be devoted to the development of irrigated land and the water supply facilities needed for this irrigation. SWIM is applied to measure the benefits and water demands of various levels of irrigation development, both under normal weather conditions and under drought conditions. Two basic decisions are investigated:

- How much land should be developed for irrigation?
- How much water should be made available for irrigation?

The major results of these investigations are summarized in this section while the details are tabulated in Appendix 1.

3.1 Land for Irrigation

Of the 121,600 ha of arable land considered in SWIM, it is expected that between 25,000 and 40,000 hectares will be developed for irrigation by 1980, the year for which SWIM is applied. The range of development from 10,000 ha to 50,000 ha of irrigated land is investigated in 5,000 ha steps by repetitively running SWIM on the computer, with each computer run having a different amount of irrigated land available. All water needed is assumed to be available. Two series of computer runs were performed, one for normal weather conditions and another for drought weather conditions. In each run, SWIM determines the optimal crop distribution on both irrigated and nonirrigated land to maximize production while also meeting the minimum production requirements for livestock and population. The results for various levels of irrigated land development are shown in figures (3.1) to (3.8).

3.1.1 Water Demands

In figure (3.1), the volume of water needed, or water demand, for irrigation is plotted for both normal weather and drought conditions. For drought conditions, about 3900 cubic

metres per hectare (390 mm) are required, which is an increase
of between 25% and 55% over the water demand in normal weather
conditions as shown in figure (3.2). In SWIM, the crop water
requirements are increased by 20% for drought conditions and
it appears from figure (3.2) that for large areas of irrigation
the water demands increase by a little more than 20%, because
different crops are being irrigated.

3.1.2 Crop Distribution

The distribution of crops grown for different areas of
irrigation under normal weather and drought conditions are
shown in figures (3.3), and (3.4), respectively. In these
figures the vertical axis represents the total arable land and
the horizontal axis the amount of this land which is irrigated.
The 45^0 line beginning at the origin is the boundary between
irrigated and nonirrigated land. The area of each crop grown
for a given area of irrigated land is plotted cumulatively in
a vertical direction, beginning at the bottom with the seeds
area, which is always irrigated, continuing with the irrigated
crops, and then the nonirrigated crops. In some cases, one
crop may be grown partially irrigated and partially nonirrigated
e.g. maize silage for 10,000 ha irrigated land in figure (3.3).
By looking from left to right across each figure, the change in
the crop distribution as more land is irrigated can be observed.
In normal weather conditions, soybeans is the first crop irrigated,
followed by maize grain once soybeans are completely irrigated.

A very important feature of the results, which is the sub-
stitution of water for land, can be observed by comparing the
total areas of soybeans in figure (3.3) for 10,000 and 15,000 ha
of irrigated land. These areas are 19925 ha and 15883 ha, re-
spectively. In both cases the total production in tons of soy-
beans is the same but because a greater proportion of the crop
is grown under irrigation in the second case, where it gives a
higher yield, the total land area occupied by soybeans decreases,
thus leaving more land available for growing other crops with-
out irrigation. Hence water and capital investment in irrigation
are being substituted for arable land to grow the same amount of

soybeans. This is a key feature of the operation of SWIM and
it underlies all the results which follow.

By comparing figures (3.3) and (3.4), it can be seen that
different crops are grown under irrigation in drought conditions
as compared to normal weather conditions. In a drought, maize
silage is irrigated first instead of soybeans, followed by maize
grain, and then soybeans for large areas of irrigated land.
The reason that maize is irrigated first is that this crop is
the most sensitive to drought (50% loss in nonirrigated yield)
compared with soybeans and sunflowers (30% loss in nonirrigated
yeild), and lucerne, wheat, and barley (15% loss in nonirrigated
yield). The losses in yield of nonirrigated sunflowers, wheat
and lucerne mean that larger areas of these crops are required
to grow the production requirements in drought conditions. For
lower irrigated area in drought conditions, a small area of
barley is grown as a substitute for maize grain in feeding live-
stock. In normal weather conditions, the yield of maize grain
(4.7 ton/ha) is much higher than that of barley (3.1 tons/ha),
so that it is more productive to grow maize grain than barley,
and barley does not appear in the crop distribution.

3.1.3 Imports and Exports

If the production from the complex is not sufficient to meet
the livestock requirements, SWIM may import maize grain from out-
side the complex in sufficient quantities to allow the requirements
to be met but at a very high price (170 Lv/ton compared with the
normal price 113 Lv/ton). Conversely, when there is a production
surplus, SWIM can export maize grain, wheat, barley from the region.

The balance of imports and exports is given in figure (3.5),
which demonstrates that it requires very little irrigation (6,890 ha)
for the region to become self-sufficient (no imports or exports) in
normal weather conditions but in drought conditions a much larger
area of irrigated land (32,750 ha) is required to achieve self-
sufficiency. Figure (3.6), which has a rather unusual shape, shows
the corresponding total production costs, including the costs of
imports. Under drought conditions the minimum total costs (Lv 21.7
million) are attained just at the point of self-sufficiency. If

less land is irrigated, total costs rise because of the cost of imported maize which outweighs the savings made by irrigating less land. Even if imported maize were priced at the export price of 113 Lv/ton the total cost would still rise slowly if less land is irrigated, assuming the same amounts of imports are required.

Since imports are not required under normal weather conditions, the total cost curve is continually rising as more land is irrigated and the production surplus is exported. Another striking feature of figure (3.6) is that total production costs are very similar under both weather conditions when the area of irrigated land is greater than that needed for self-sufficiency. Of course, the difference is that in normal weather conditions, exports are much larger in this range of irrigated land development.

To determine whether it is economic to develop more irrigated land than that needed to achieve self-sufficiency, the value of the surplus production which can be exported should be compared to the extra costs necessary to produce this surplus. These extra production costs can be found by subtracting the total production cost to achieve self-sufficiency from the total production costs when more land is irrigated to produce exports. The net value, or net benefit, of exports is then found by subtracting these extra production costs from the value of the exports, and is plotted in figure (3.7), which shows that the net value of exports continually increases, in a linear fashion, as more land is irrigated. The benefit-cost ratio, which is the value of exports divided by the extra production costs, is fairly constant at 2.0 for normal weather conditions and 2.4 in drought conditions.

3.1.4 Value of Irrigated Land

While it might be expected that the cost of developing each new unit (hectare) of land for irrigation would not change greatly with the scale of development, the value of each new unit of irrigated land might change quite considerably with the scale of development. Intuitively, it seems clear that the first

units of irrigated land will have the greatest value, as
measured by extra production, because the crops giving the best
response to water can be irrigated. As more land is irrigated,
less responsive crops are included so that value of each new
unit, or marginal value, of irrigated land decreases with the
scale of irrigation development. (This marginal value is the
shadow price of the constraint on irrigated land in SWIM.)
In the economics of supply and demand, the optimal scale of
irrigated land development occurs when the cost of developing
each new unit of irrigated land is equal to that unit's marginal
value.

Figure (3.8) shows the demand curve for irrigated land which
is the change in the marginal value of irrigated land with the
scale of irrigated land development, for normal weather and
drought conditions. As expected, the marginal value of irrigated
land in drought conditions is much higher than in normal weather
conditions. In figure (3.8) each demand curve is composed of
horizontal segments, where the marginal value does not change
with the area of irrigated land, and inclined segments (dashed)
in which there are considerable differences in marginal value.
In the solutions of SWIM, the horizontal segments occur when
each new hectare of land is being used to irrigate the same crop
as the previous hectare, while the inclined segments occur when
a new crop begins to be irrigated, or when self-sufficiency is
attained. Actually, if all possible areas of irrigated land
had been evaluated, the dashed segments would be vertical, and
located at the exact point where a new crop begins to be irrigated.

The cost of irrigated land development of 103.25 Lv/ha,
which is assumed in SWIM is also plotted in Figure (3.8). Since
this cost line always lies below the demand curves, it may be
concluded that the marginal value of irrigated land is always
greater than the unit cost of developing it within the range of
area considered and the accuracy of SWIM.

3.2 Water For Irrigation

In section (3.1), the area of irrigated land is considered
as the limiting resource with all water demands able to be met;
in this section, water is considered as the limiting resource
with up to 40,000 ha available for irrigation development.
Two series of computer runs were performed, one for normal
weather conditions and one for drought conditions. In each
series, the first computer run was made assuming all of the
optimal amount of water demanded for 40,000 ha of irrigated land
is available. It should be noted that this optimal amount is
higher for drought conditions ($159.26 \times 10^6 m^3$) than for normal
weather conditions ($122.64 \times 10^6 m^3$). Succeeding runs were then
made limiting the available water to 10%, 20%,..., 90% of the
optimal amount.

It is found that it is not economical to develop all of
the 40,000 ha of irrigated land when the water demanded is not
available, figure (3.9). As expected, for a given amount of
water available, the optimal area of irrigated land is less in
the case of drought conditions than in normal weather conditions
because the crop water requirements are higher in a drought.

The corresponding crop distributions are shown in figures
(3.10) and (3.11) (which can be compared with figures (3.3) and
(3.4), respectively). The distribution for normal weather con-
ditions, figure (3.10), is very similar to that discussed pre-
viously, figure (3.3). For drought conditions, figure (3.11),
the solution is identical to the previous case, figure (3.4)
for sunflowers, lucerne, wheat, and maize silage, but non-
irrigated barley assumes a more important role as a substitute
for maize grain in livestock feed.

The amount of available water and production cost necessary
to reach self-sufficiency in the complex can be found from the
balance of imports and exports as in section (3.1.3). Figure
(3.12) shows that this production cost is the minimum attainable
for the range of water availability considered.

The demand curve for water can be developed using the same
method described in section (3.1.4) for irrigated land. As

shown in figure (3.13), the marginal value of water is higher
in drought conditions than in normal weather conditions, and
for both weather conditions the demand curves lie above the
unit cost of pumping water (0.022 Lv/m^3) so that it is always
optimal to supply all the water demand.

3.3 Input Resources

Besides land and water, SWIM also determines the required
amounts of the other input resources: seeds, fertilizers, fuel,
labor, and machinery. As can be seen from the tabulated results
in Appendix 1, these amounts do not vary a great deal in the
various solutions of SWIM, so only average data are given in
this section.

The distribution of water required over the irrigation
season from April to August is approximately as follows:
April, 2%; May, 8%; June, 20%; July, 30% and August 40%.

The required input resources when 40,000 ha of land are
irrigated consist of:
- 2870 ha of land for seed production;
- 24,000 tons of ammonium sulphate; 30,000 tons of
  superphosphate; 7,500 tons of potassium sulphate;
- 7 million litres of fuel;
- 240,000 hours of labor for operating machines;
- 120 tractors;
- 75 combine harvesters;
- 35 silage choppers;
- 710 centre-pivot sprinklers.
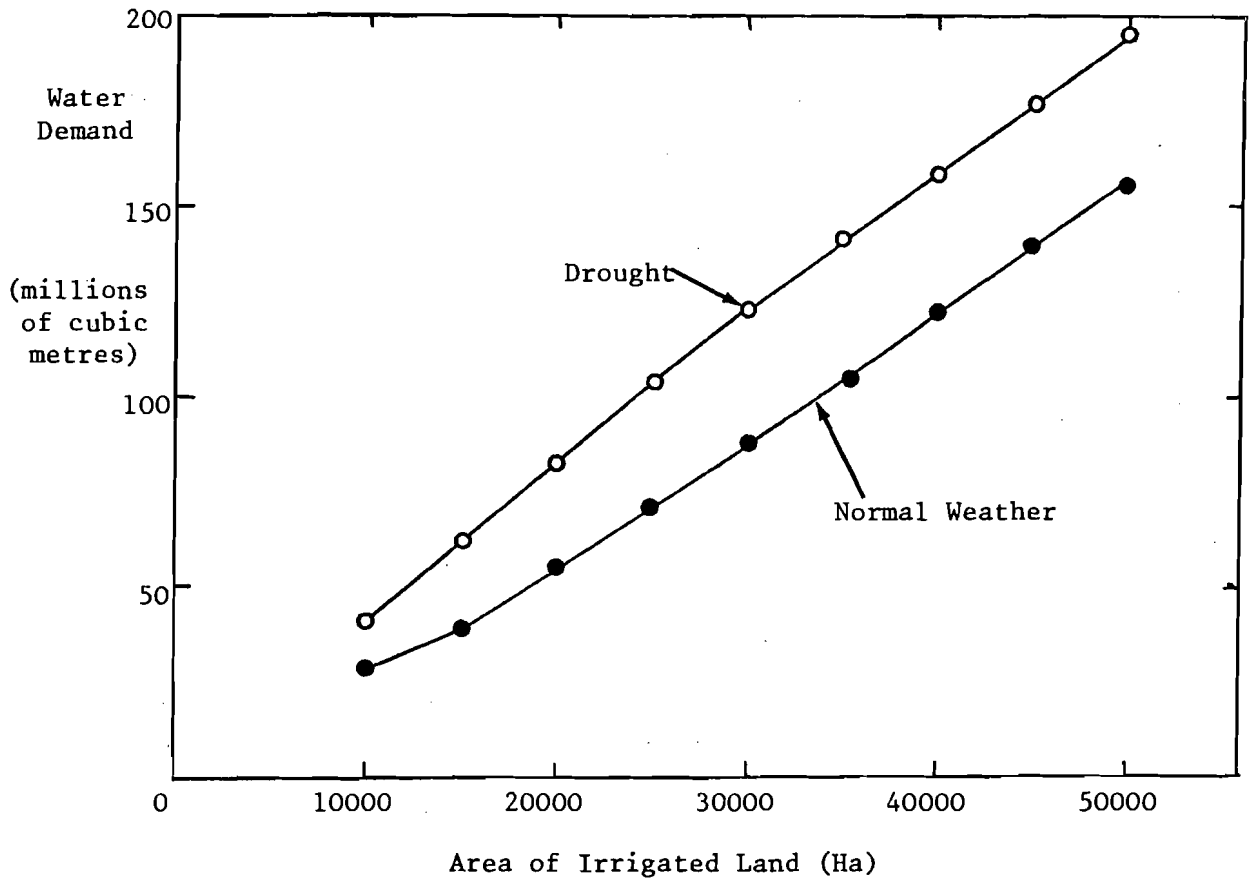
Figure 3.1   Water Demand vs. Area of Irrigated Land
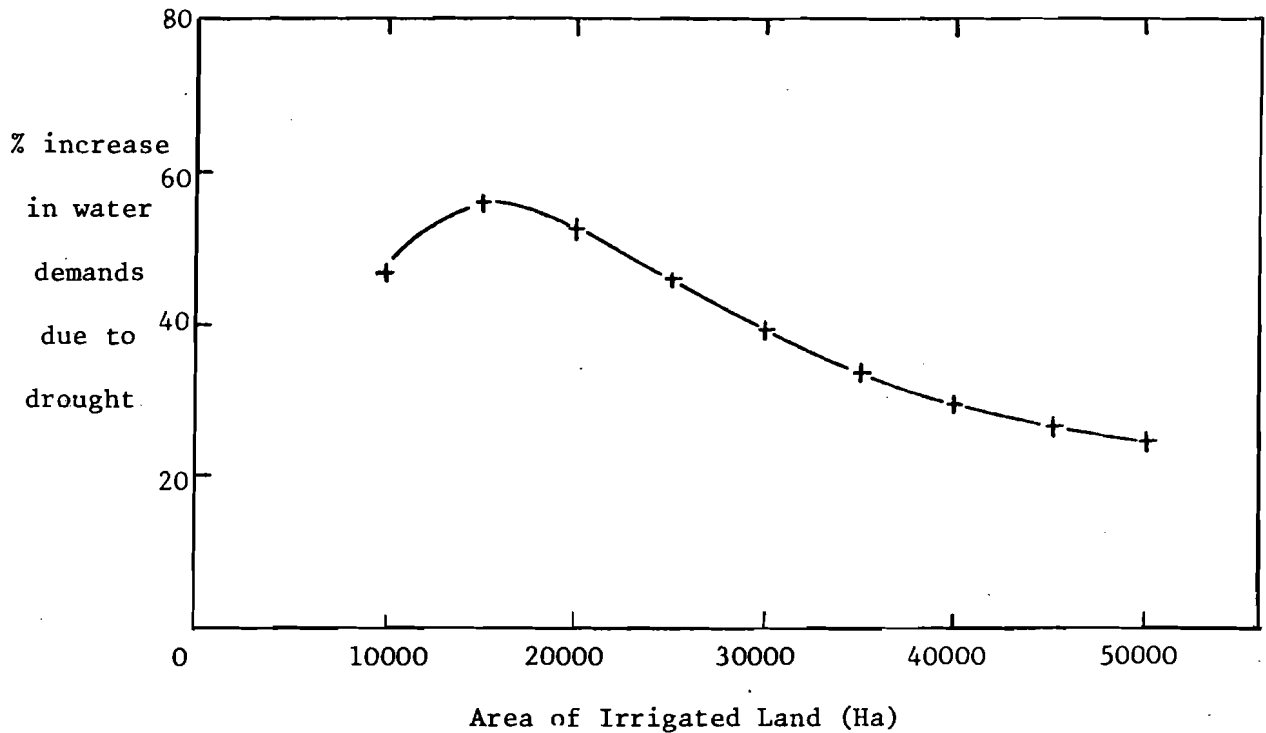
Figure 3.2   Increase in Water Demands due to Drought
vs. Area of Irrigated Land
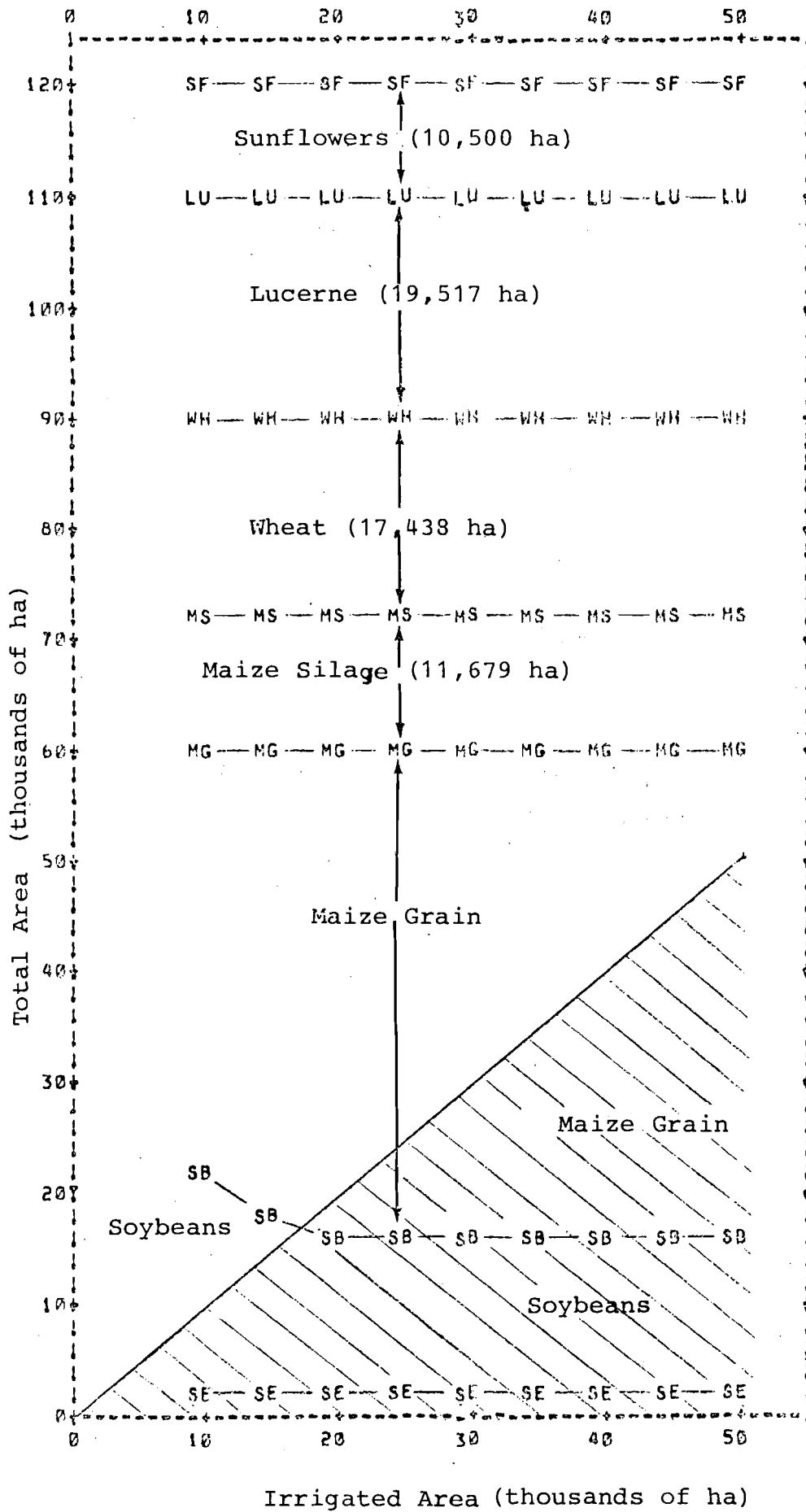
Fig. 3.3 Crop Distribution vs. Area of Irrigated Land (Normal weather)
(shaded portion is area irrigated)

Irrigated Area (thousands of ha)
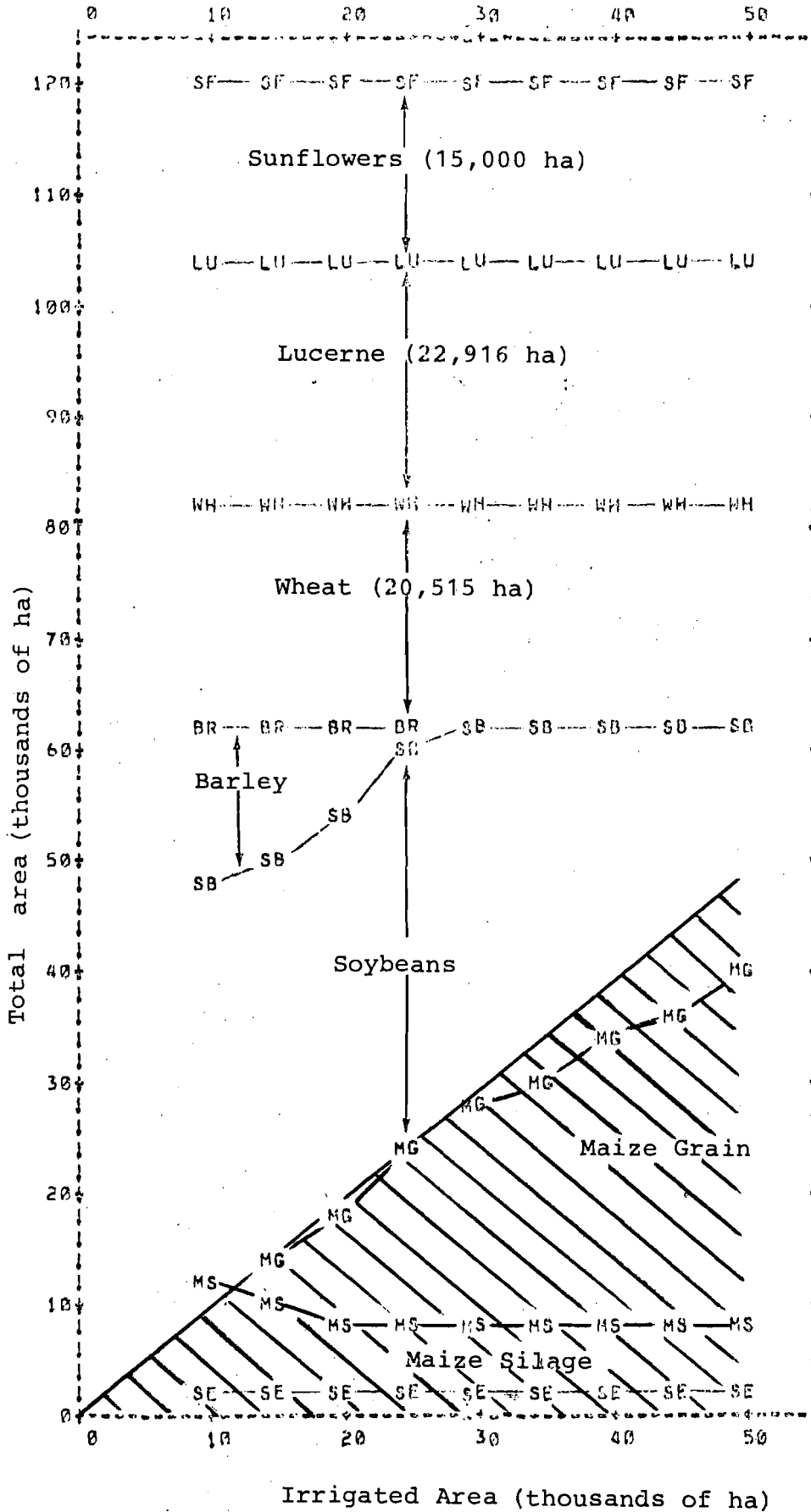
Fig. 3.4 Crop Distribution vs. Area of Irrigated Land (Drought)

(shaded portion is area irrigated)
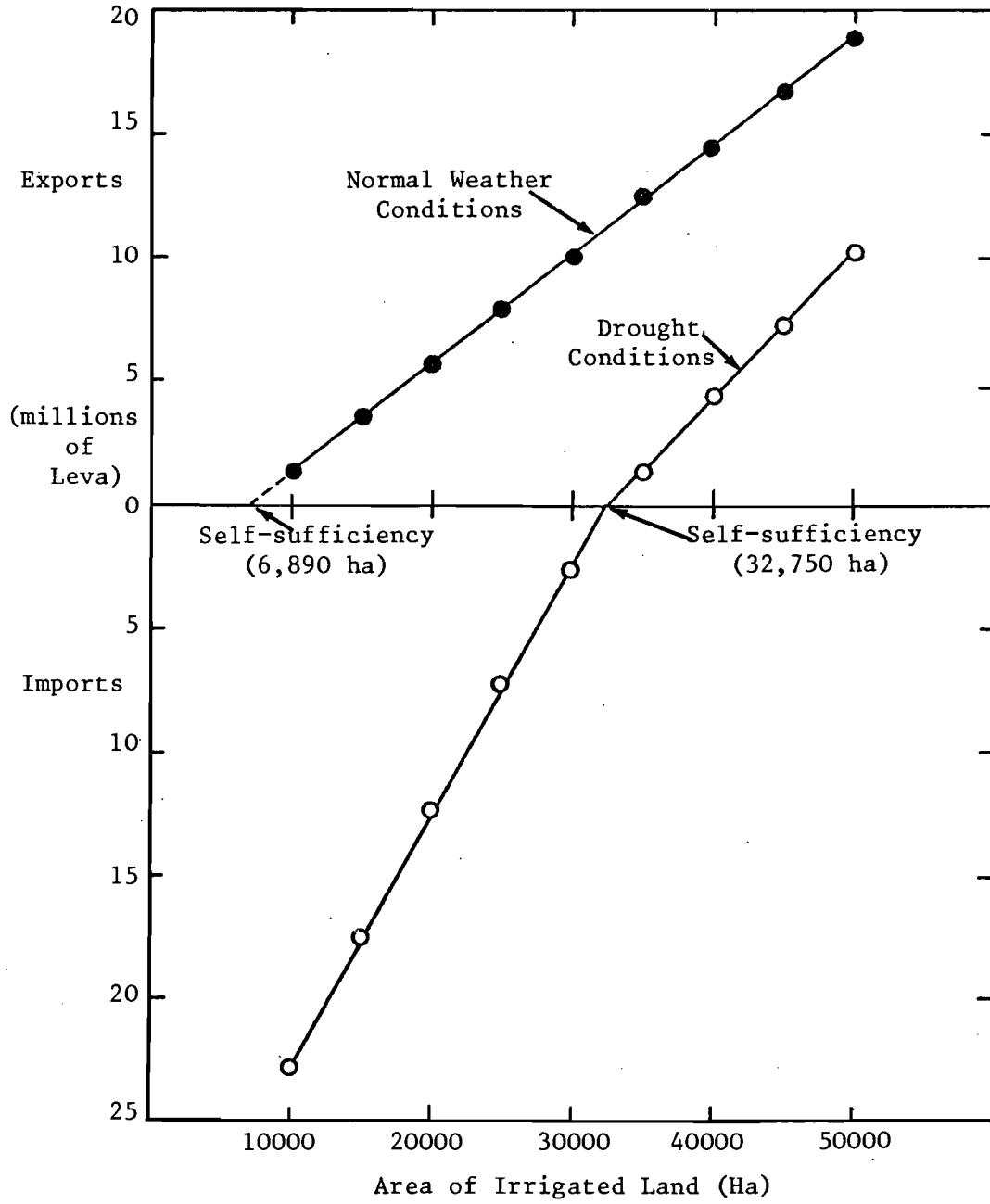
Figure 3.5 Value of Imports and Exports vs. Area of Irrigated Land
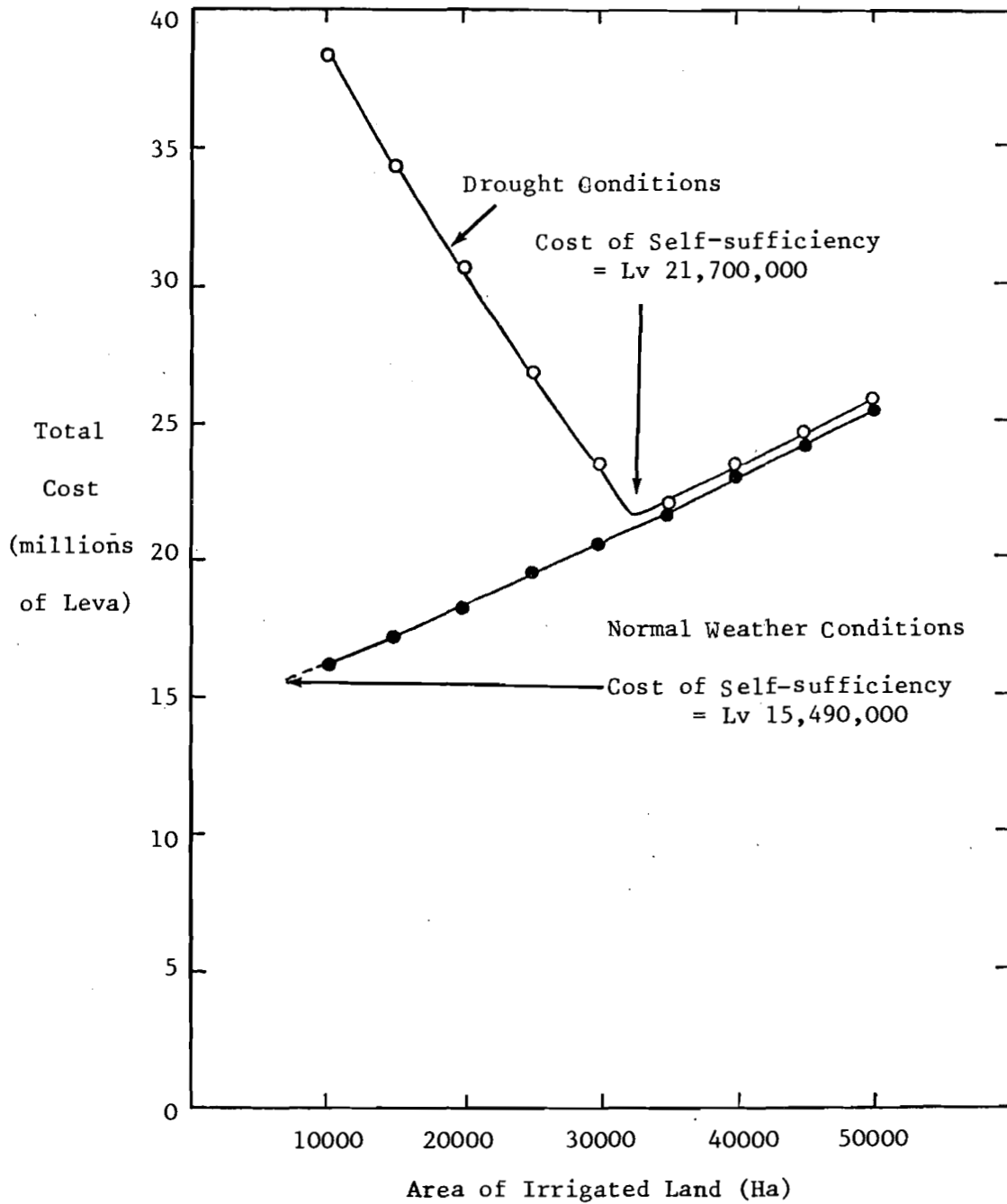
Figure 3.6 Total Costs vs. Area of Irrigated Land
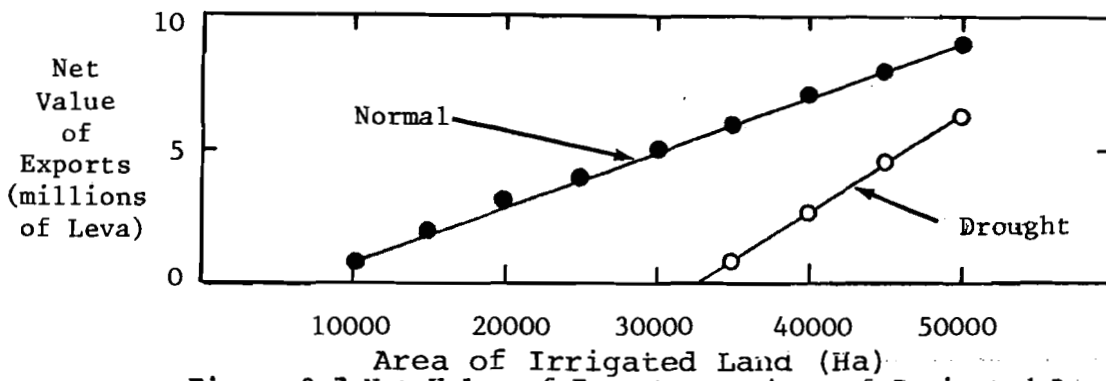
Figure 3.7 Net Value of Exports vs. Area of Irrigated Land
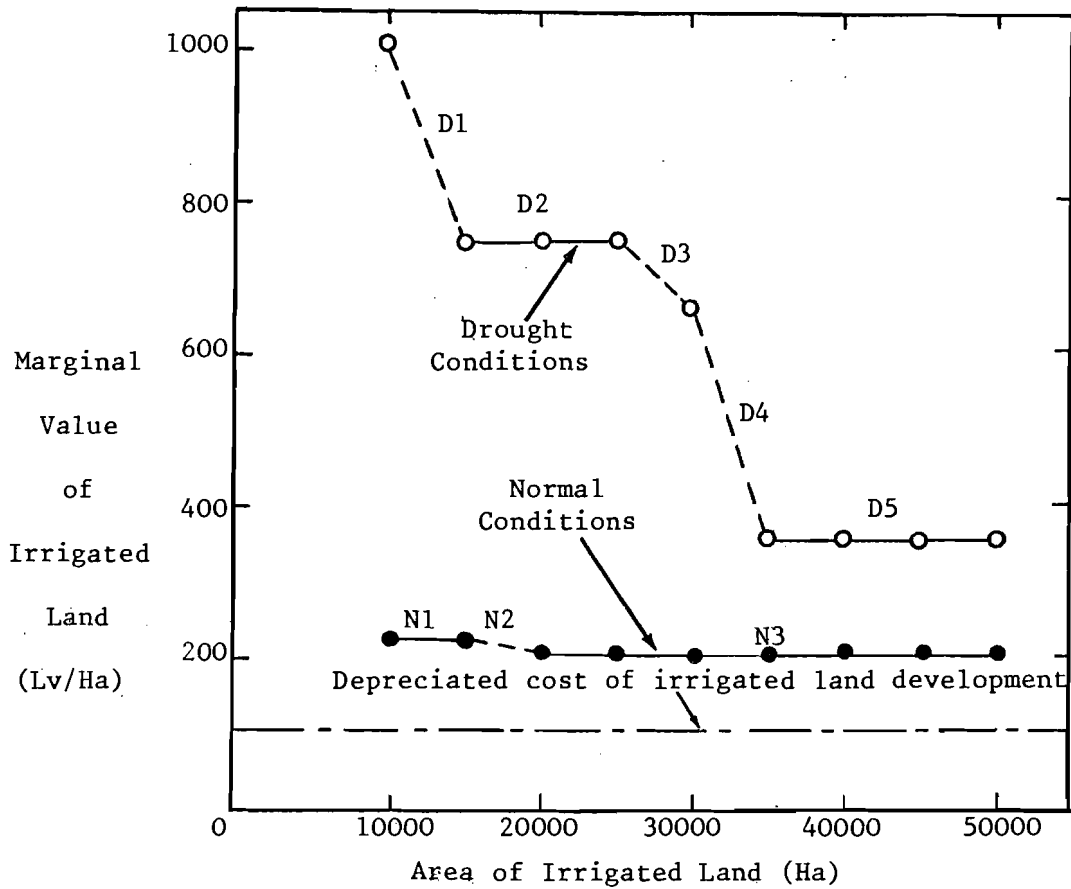
Figure 3.8 Demand Curves for Irrigated Land

Explanation of Regions of Demand Curves:

D1- Maize grain begins to be irrigated, barley area decreasing

D2- More irrigated maize grain grown, barley area decreasing

D3- Barley not grown, soybeans begin to be irrigated

D4- Region becomes self sufficient, maize grain begins to be exported

D5- Increasing irrigation of soybeans and maize grain

N1- More soybeans irrigated, nonirrigated maize grain grown

N2- All soybeans irrigated, maize grain begins to be irrigated

N3- More maize grain irrigated
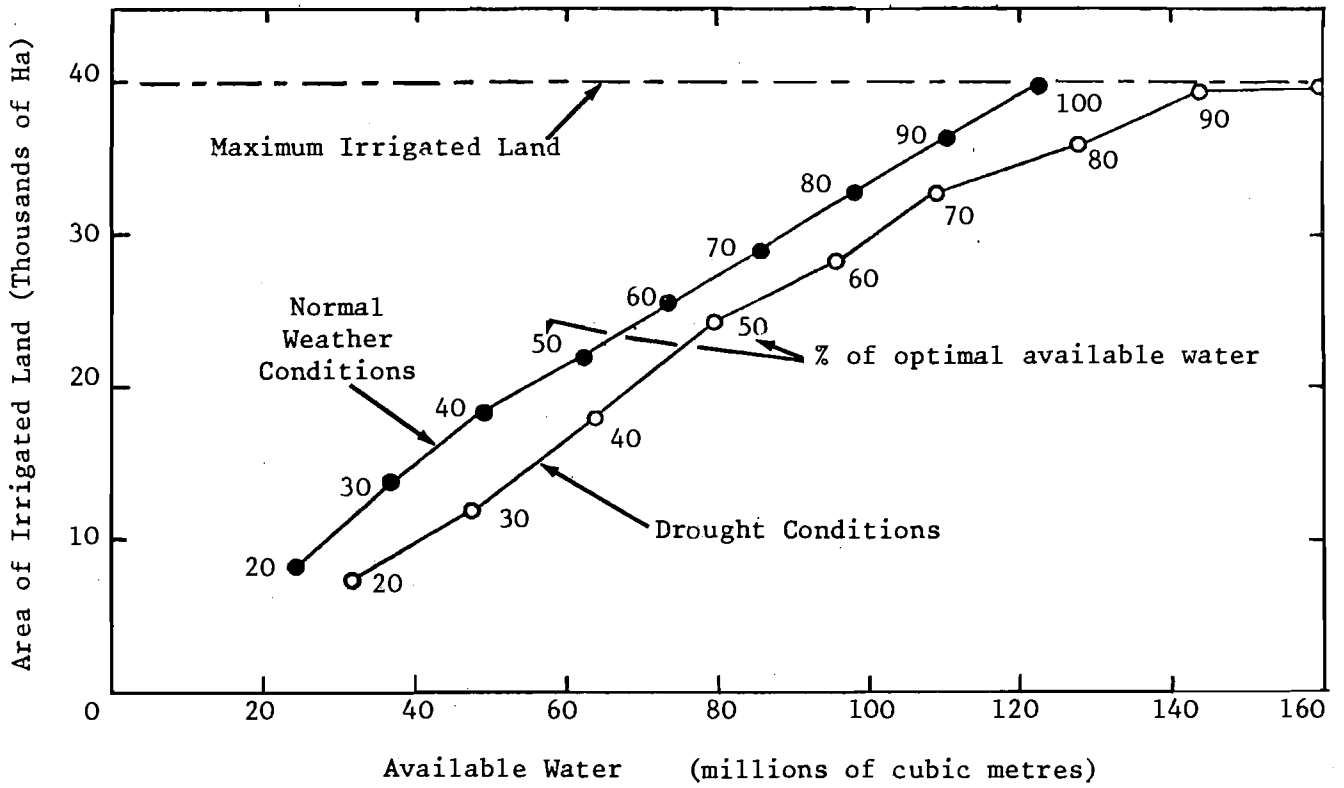
Figure 3.9 Area of Irrigated Land vs. Available Water
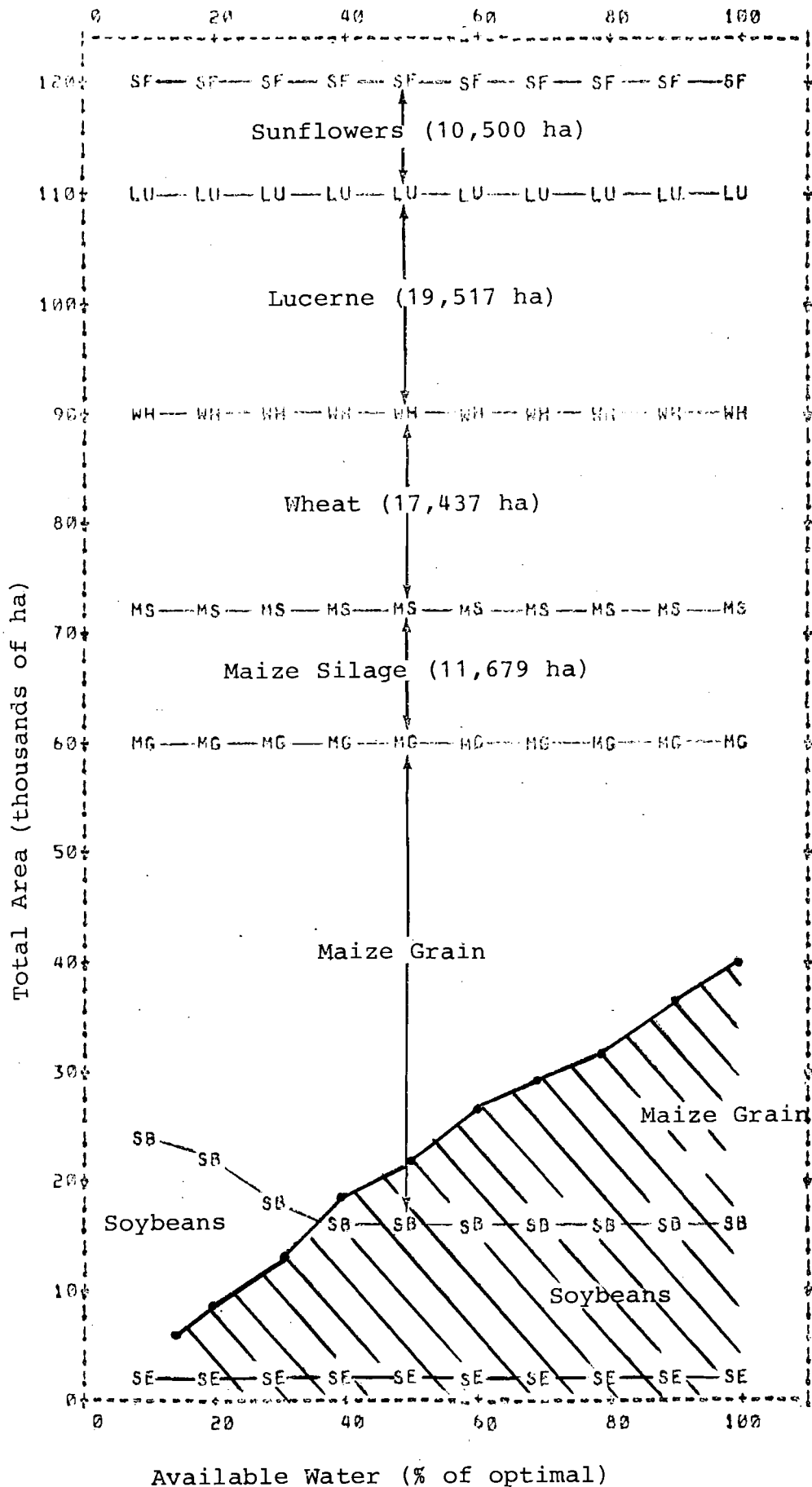
Fig 3.10 Crop Distribution vs. Available Water (Normal Weather)
(shaded portion is irrigated area)

Available Water (% of optimal)
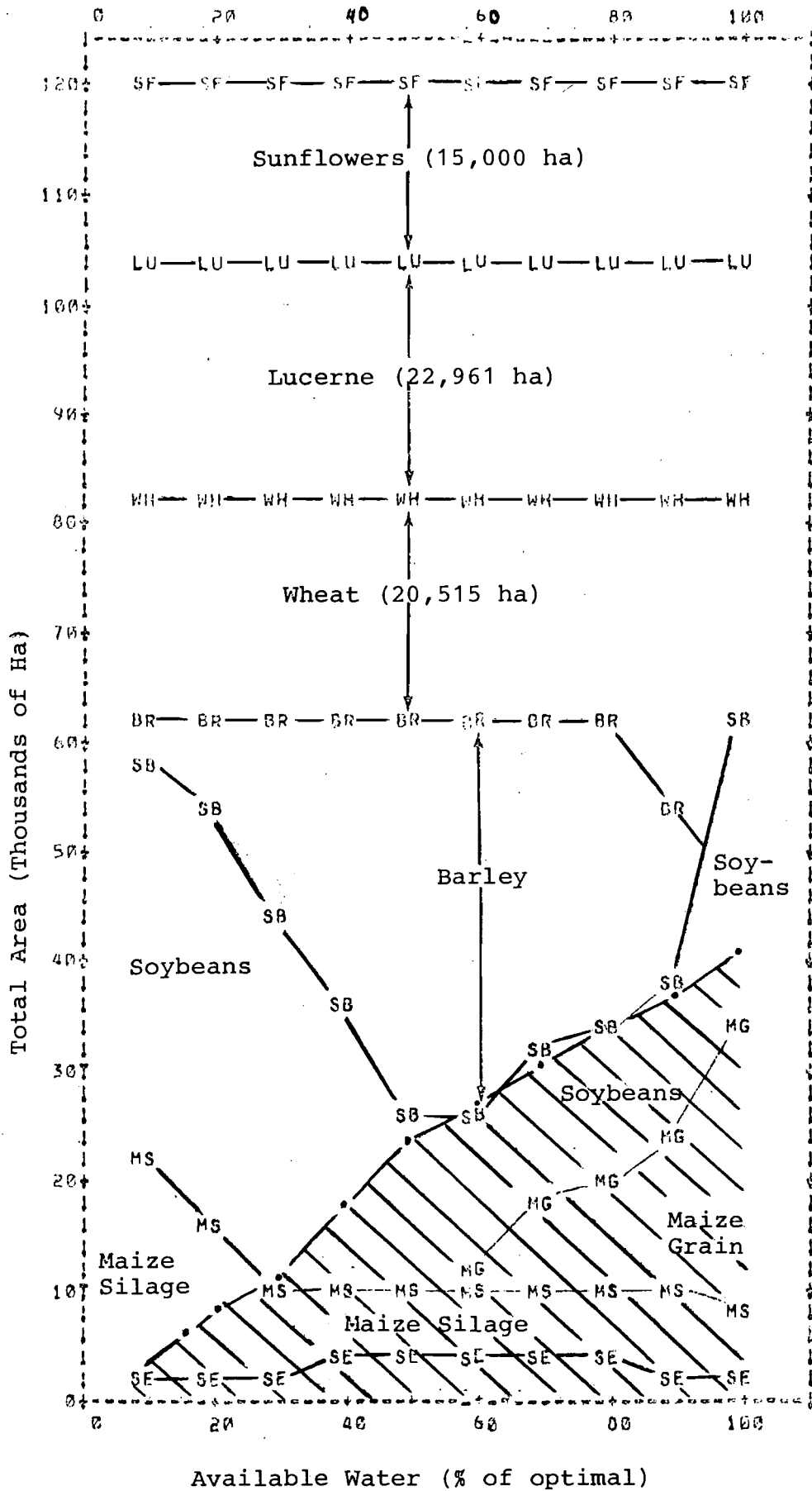
Fig. 3.11 Crop Distribution vs. Available Water (Drought)
(shaded portion is irrigated area)
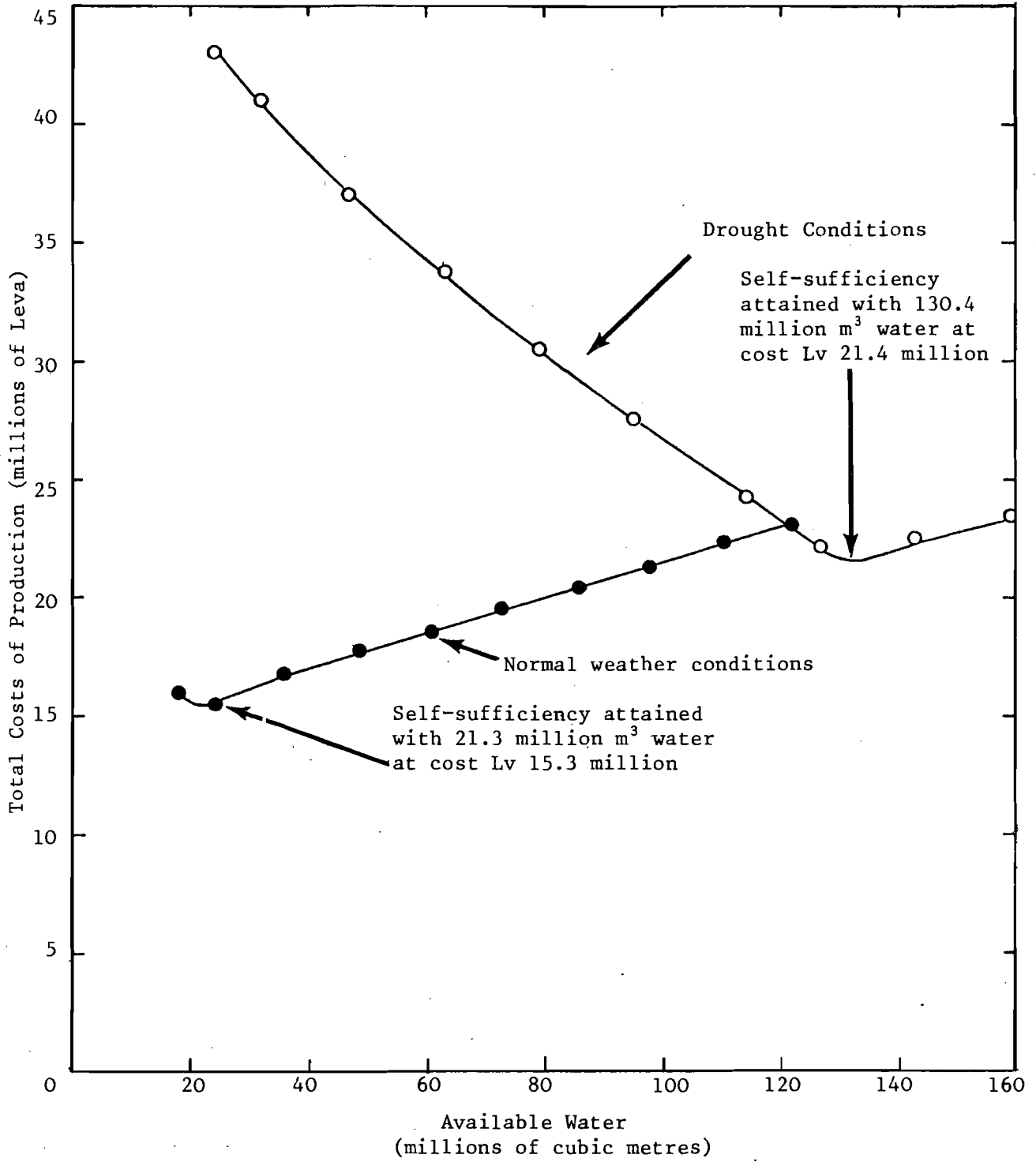
Figure 3.12   Production Costs vs. Available Water
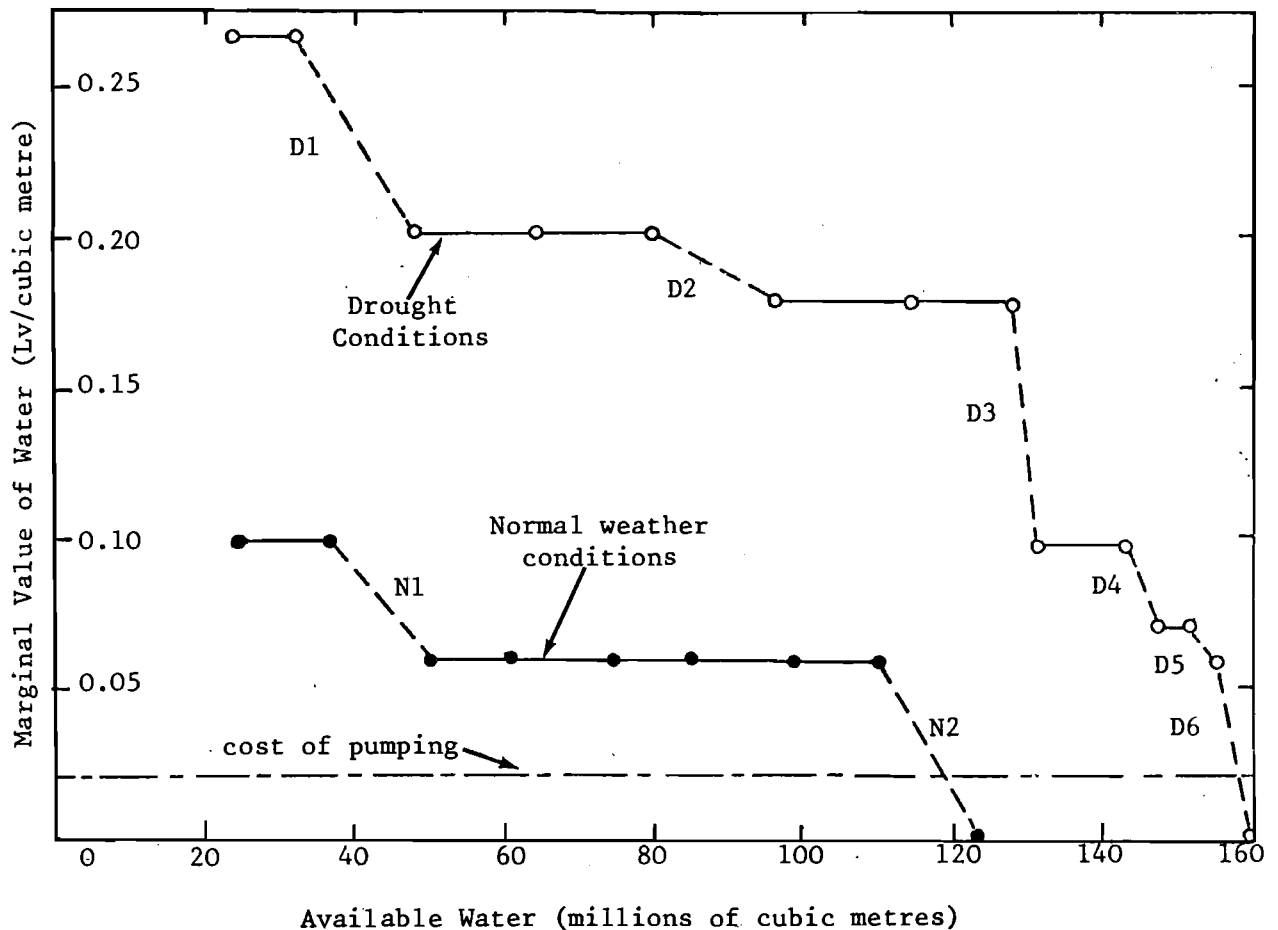
Figure 3.13. Demand Curves for Water

Explanation of Regions of Demand Curves:

D1- Soybeans begin to be irrigated

D2- Irrigated maize grain begins to be grown

D3- Region reaches self-sufficiency, export of wheat begins

D4- Nonirrigated soybeans begin to be grown

D5- No more barley grown, export of maize begins, exports of wheat decrease

D6- Exports of wheat cease

N1- Irrigated maize grain begins to be grown

N2- Irrigated area becomes limiting factor

4. CONCLUSIONS

The development of land and water for irrigation in the Drustar agricultural-industrial complex in 1980 is investigated for both normal weather and drought conditions. The major results are:

a) 33,000 ha of irrigated land and 135 million cubic metres per year of water are needed for the complex to be self-sufficient in drought conditions. At this level of development, 100,000 tons of maize grain could be exported from the complex under normal weather conditions.

b) The total costs of crop production are minimized at the point when the complex is just self-sufficient.

c) The marginal values of land and water developed for irrigation are always greater than their unit costs of supply in the range of development considered.

d) The optimal distribution of crops to be grown on both irrigated and nonirrigated land is determined for all cases investigated.

These results are preliminary and should only be interpreted as being indicative of the kind of questions the model can answer. However, we consider that the data and structure of the model could be improved and extended through further discussion with Bulgarian experts to make the model sufficiently reliable for actual decision-making. Improvements in the data could include:

- Crop yields without irrigation for various weather conditions.
- The relation between crop yields and water applied by irrigation.
- Costs and technology of crop production, especially for irrigation.

Extensions to the structure of the model could involve:

- Breaking down the complex on the basis of soil type into sub-regions which have different crop yields and water requirements.
- Introducing the livestock of the complex into the model and considering different diets for them.

- Taking account of other crops which could be grown in the complex.
- Adding the dynamics of change from year to year, such as crop rotations and grain storage.
- Incorporating the facilities needed for water supply, such as dams, pumps, and channels.

REFERENCES

Carter, H., C. Csaki, A. Propoi, *Planning Long Range Agricultural Investment Projects: A Dynamic Linear Programming Approach,* IIASA RM-77-38, June 1977.

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Ministry of Information and Communications, *Statisticheski godishnik* (Statistical Yearbook) for Peoples Republic of Bulgaria, Sofia 1975.

Propoi, A., *Dynamic Linear Programming Models for Livestock Farms,* IIASA RM-77-29, June 1977.

Appendix 1

TABLES OF COMPUTATIONAL RESULTS

The following four tables give the detailed data produced by SWIM computer printouts for each of the series of computer runs carried out: varying the amount of irrigated land, and the amount of water, both under normal weather conditions and drought conditions. A glossary of the terms used in the printouts is included to aid in the interpretation of the results.

GLOSSARY OF TERMS

	UNIT	
PW	$m^3 \times 10^6$	Amount of irrigation water
DLPW	Lv/m^3	Marginal value of water
NL	Ha	Total irrigated land required
DLNL	Lv/Ha	Marginal value of irrigated land
ALUI	Ha	Irrigated land for growing lucerne
ALUN	Ha	Nonirrigated land for growing lucerne
AMSI	Ha	Irrigated land for growing maize silage
AMSN	Ha	Nonirrigated land for growing maize silage
AMGI	Ha	Irrigated land for growing maize grain
AMGN	Ha	Nonirrigated land for growing maize grain
AWHI	Ha	Irrigated land for growing wheat
AWHN	Ha	Nonirrigated land for growing wheat
ABRI	Ha	Irrigated land for growing barley
ABRN	Ha	Nonirrigated land for growing barley
ASBI	Ha	Irrigated land for growing soybeans
ASBN	Ha	Nonirrigated land for growing soybeans
ASFI	Ha	Irrigated land for growing sunflowers
ASFN	Ha	Nonirrigated land for growing sunflowers
AS	Ha	Irrigated land for seeds
IMAZ	Tn	Maize grain import
EMAZ	Tn	Maize grain export
EWHT	Tn	Wheat export
EBRL	Tn	Barley export

UNIT

TAPR	$m^3 \times 10^6$	Total irrigation water in April
TMAY	$m^3 \times 10^6$	Total irrigation water in May
TJUN	$m^3 \times 10^6$	Total irrigation water in June
TJUL	$m^3 \times 10^6$	Total irrigation water in July
TAUG	$m^3 \times 10^6$	Total irrigation water in August
IREQ	-	Number of irrigation sprinklers
AMN	Tn	Ammonium sulphate fertilizer
SPH	Tn	Super phosphate fertilizer
POT	Tn	Potassium sulphate fertilizer
FUL	litres	Fuel
TRH	Hrs	Tractor hours
CJH	Hrs	Combine June-July hours
CHS	Hrs	Combine August-October hours
TRS	-	Number of tractors
CMB	-	Number of combines
SCB	-	Number of silage combines
TEXB	$Lv \times 10^6$	Value of exports
COST	$Lv \times 10^6$	Total cost of production
OBJ	$Lv \times 10^6$	Value of exports minus cost of production

I I A S A PDF 11/45 COMPUTER

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.............................................
:  SILISTRA AGRICULTURAL-INDUSTRIAL COMPLEX  :
:           WATER DEMAND STUDY               :
.............................................
```

YEAR: 1980 WEATHER: NORMAL
VARYING THE AREA OF IRRIGATED LAND WITH UNCONSTRAINED WATER

AREA (HA)	10000	15000	20000	25000	30000	35000	40000	45000	50000	120000

Table A.1 Results of Varying Irrigated Land (Normal Weather)

I I A S A   PDP 11/45 COMPUTER

•••
• SILISTRA AGRICULTURAL-INDUSTRIAL COMPLEX •
•   WATER DEMAND STUDY   •
•••

YEAR: 1980   WEATHER: DROUGHT
VARYING THE AREA OF IRRIGATED LAND   WITH UNCONSTRAINED WATER AND MAIZE IMPORTS ALLOWED

Table A1.2   Results of Varying Irrigated Land (Drought)

I I A S A   PDP 11/05 COMPUTER

****
* SILISTRA AGRICULTURAL-INDUSTRIAL COMPLEX *
* WATER DEMAND STUDY   *
****

YEAR: 1980   WEATHER: NORMAL
VARYING THE WATER WITH CONSTRAINED AREA OF IRRIGATED LAND = 40000

% OPT WATER	15%	20%	30%	40%	50%	60%	70%	80%	90%	100%
PW										
DLPW										
NL										
DLNL										
ALUI										
ALUN										
AMSI										
AMSN										
AMGI										
AMGN										
AWHI										
AWHN										
ABRI										
ABRN										
ASBI										
ASBN										
ABFI										
ABFN										
AB										
IMAZ										
EMAZ										
EWHT										
EBRL										
TAPR										
TMAY										
TJUN										
TJUL										
TAUG										
IRED										
AMN										
BPH										
PDT										
FUL										
TMH										
CJH										
CHS										
TRS										
CPB										
SCB										
TEXR										
CCBT										
OBJ										

Table A1.3 Results of Varying Available Water (Normal Weather)

I I A S A   PDP 11/45 COMPUTER

```
**********************************
*                                *
* SILISTRA AGRICULTURAL-INDUSTRIAL COMPLEX *
*        WATER DEMAND STUDY       *
*                                *
**********************************
```

YEAR: 1980   WEATHER: DROUGHT
VARYING THE WATER WITH CONSTRAINED AREA OF IRRIGATED LAND = 40000 AND MAIZE IMPORTS ALLOWED

X OPT WATER	15%	20%	30%	40%	50%	60%	70%	80%	90%	100%
PW	23,000	31,052	47,778	63,784	79,630	95,556	114,400	127,418	143,332	159,260
OLPW	-0,268	-0,268	-0,281	-0,281	-0,281	-0,172	-0,177	-0,177	-0,177	0,000
NL	5293,765	7489,250	11966,542	17996,756	24814,971	28436,172	32922,000	35980,984	39656,687	40000,000
DLNL	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	-355,311
ALUI	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
ALUN	22960,785	22960,785	22960,785	22960,785	22960,785	22960,785	22960,785	22960,785	22960,785	22960,785
AMBI	1525,673	3427,883	6540,000	6540,000	6540,000	6540,000	6540,000	6540,000	6540,000	6540,000
AMSN	17908,300	11114,705	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
AMGI	0,000	0,000	0,000	0,000	0,000	2002,216	7466,618	10608,290	14665,684	20742,400
AMGN	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
AMHI	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
AMHN	20514,787	20514,787	20514,787	20514,787	20514,787	20514,787	20514,787	20514,787	27371,270	20514,787
ABRI	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
ABRN	3309,100	8067,219	17314,746	26073,504	34032,422	34665,336	37224,500	27143,525	16611,061	5214,543
ABBI	0,000	0,000	1046,156	6795,120	12544,064	14267,407	14267,407	14267,427	14267,407	23124,510
ABBN	36533,336	36533,336	33043,223	19860,168	4277,117	0,000	0,000	0,000	0,000	0,000
ABPI	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
A0FN	15000,000	15000,000	15000,000	15000,000	15000,000	15000,000	15000,000	15000,000	15000,000	15000,000
A0	3760,091	3961,367	4360,387	4655,636	4930,686	4880,560	4504,568	4505,202	4243,075	3502,964
IMAZ	16436,000	150000,000	124090,000	98749,117	73400,707	49735,359	22401,467	3734,446	0,000	0,000
EMAZ	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	36605,466
EWWT	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	10649,650	0,000
EBRL	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
TAPR	2,469	2,566	2,758	2,939	3,121	3,118	3,225	2,961	2,027	2,399
TMAY	7,232	7,695	8,947	9,265	9,534	10,271	11,373	12,126	12,978	15,011
TJUN	6,818	9,517	12,537	15,787	19,017	22,176	25,894	28,436	31,591	34,535
TJUL	2,718	5,186	10,203	15,519	20,635	26,045	32,186	36,381	41,594	46,466
TAUG	3,448	6,608	13,263	28,193	27,123	33,947	42,003	47,586	50,345	62,630
IREQ	29,293	65,013	145,654	256,834	366,414	452,133	542,120	603,565	679,930	702,743
AMN	13932,470	12979,130	11708,733	13244,646	14792,603	16151,395	17675,602	18716,620	20153,666	22069,943
BPH	25100,637	25474,812	26290,572	27680,982	29391,232	30092,641	30515,463	30004,208	30065,205	29607,301
PDT	9100,947	8566,318	7520,183	7421,122	7314,861	7422,945	7656,014	7816,541	8019,286	8605,662
FUL	6,586	6,442	6,333	6,316	6,299	6,330	6,400	6,456	6,526	6,700
TPH	222020,000	199200,000	192090,000	190790,000	186600,000	189098,000	190790,000	191950,000	193228,000	202332,000
CJH	6700,905	19403,020	13769,920	16950,137	20146,350	20093,188	17347,596	17347,596	16009,567	7467,953
CHS	15594,260	15594,260	15147,111	12069,039	10232,566	11804,068	13729,676	15528,436	17763,684	27272,721
TRS	70	75	60	57	45	47	56	61	68	103
CMB	38	38	29	22	19	16	25	30	36	65
SCB	50	86	27	27	27	27	27	27	27	27
TEXB	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	2,126	4,362
COST	43,117	46,905	36,915	33,713	30,511	27,583	24,237	21,952	22,333	23,487
OBJ	43,117	46,905	36,915	33,713	30,511	27,583	24,237	21,952	22,227	16,125

Table A1.4   Results of Varying Available Water (Drought,

Appendix 2

MATHEMATICAL DESCRIPTION OF THE MODEL

This section formalizes the verbal description of the model discussed in Section 2. Following Fig. 2.1 we have designated all input, production process, and output variables by x, y and Z respectively. The further subdivision of these variables is explained below.

A2.1 Objective Function

The objective function which has been adopted for Silistra agricultural-industrial comples maximizes the difference between benefit from additional amount of crops production and cost of the total crop production in the region, e.g.

$$OB = \max \left\{ \sum_{i=1}^{7} p_i^E z_i^E - \left[\sum_{j=1}^{m} p_j x_j + \sum_{i=1}^{7} \sum_{k=1}^{2} c_k^i y_k^i + \sum_{i=1}^{7} c_i (Z_i + z_i^E) + \sum_{i=1}^{7} p_i^I z_i^I \right] \right\} \quad (1)$$

where z_i^E - is amount of i crop (Tn) produced for export to other regions/countries; i=1,...,7; i=1 (lucerne), i=2 (maize silage), i=3 (maize grain), i=4 (wheat), i=5 (barley), i=6 (soybeans), i=7 (sunflower).

p_i^E - is export price of i crop (Lv/Tn); i=1,...,7;

x_j - is amount of j input (Tn,ℓ,m^3,etc) required for the total crop production in the complex; j=1,...,m.

p_j - is price of j input (Lv/Tn, Lv/ℓ, Lv/m^3, etc); j=1,...,m.

y_k^i - is amount of land (ha) irrigated k=1, or non-irrigated k=2 needed for production of crop i; i=1,...,7.

c_k^i - is cost (Lv/Ha) of producing i crop on irrigated (k=1) or on nonirrigated (k=2) area; this cost includes all fixed and variable costs related to field cultivation activities that have not been included in the costs of the input resources.

z_i - is amount of production (Tn) from i crop produced in the complex to meet population's and live-stock requirements.

z_i^I - is amount of production (Tn) imported from other regions to meet the complex requirements.

p_i^I - is imported price (Lv/Tn) of crop i.

c_i - is cost (Lv/Tn) associated with processing of crop yield (transportation to storages and grain-drying).

A2.2   Constraints

A2.2.1   Physical Constraints

A2.2.1.1   Arable Land

The amount of arable land available for growing crops is constrained by the following inequality:

$$\sum_{i=1}^{7} \sum_{k=1}^{2} y_k^i + \sum_{i=1}^{7} y_{ks}^i \leq A - A_N \tag{2}$$

where y_{ks}^i - is area (Ha) required for producing seeds for i crop; the index k=1 because seeds are assumed to be always irrigated

A - is total amount of arable land (Ha) available

A_N - is amount of arable land (Ha) needed for crops serving only population needs, e.g. tobacco, dry beans, flax, vegetables, vineyards, and orchards.

A2.2.1.2   Irrigated Land

This constraint takes care for the rate of irrigation land development in SWIM.

$$\sum_{i=1}^{7} y_1^i + \sum_{i=1}^{7} y_{ks}^i \leq I \tag{3}$$

where I is total irrigation land available

k=1 (seeds are irrigated)

A2.2.1.3   Water Availability

The total amount of water available for irrigation (PW) is split into two parts, crop irrigation and seeds irrigation.

$$\sum_{i=1}^{7} w_i(t)\, y_k^i + \sum_{i=1}^{7} w_i(t)\, a_i\, y_{ks}^i - W(t) = 0 \quad ; \ t=1,2,3,4,5; \ k=1 \qquad (4)$$

$$\sum_{t=1}^{5} W(t) \le PW \qquad (5)$$

where $w_i(t)$ – is amount of water (m^3/Ha) needed for optimum growth of crop i at time t; t refers to vegetation season; t=1 (April), t=2 (May), t=3 (June), t=4 (July), and t=5 (August).

a_i – is ratio between seeding rate (Tn/Ha) and crop yield of seed areas (Tn/Ha).

$W(t)$ – is a slack variable

PW – is total amount of water available for irrigation purposes (m^3).

A2.2.2   Production Requirement Constraints

This set of constraints spells out all crop production requirements for both population and livestock.

A2.2.2.1   Substitutional Crops

Some of the crops needed for livestock production can be substituted one for another according to their content of digestible nutrients and digestible protein.

A2.2.2.1.1   Substitution of Maize Grain and Barley

$$d_3 z_3 + d_5 z_5 \ge M \qquad (6)$$

where Z_3 and Z_5 - are amount of maize grain (Tn) and barley (Tn), respectively produced for meeting the requirements of maize grain M (Tn)

d_3 and d_5 - are substitutional coefficients for maize grain and barley.

A2.2.2.1.2   Substitution of Soybean and Sunflower

$$d_6 Z_6 + d_7 Z_7 \geq SM \tag{7}$$

where Z_6 and Z_7 - are amount of soybean (Tn) and sunflower (Tn), respectively produced for meeting the requirements of soybean meal SM (Tn); d_6 and d_7 take care of the ratio of substitution between soybean and sunflower.

A2.2.2.2   Nonsubstitutional Crops

These crops can not be substituted one for another either because of the difference in nutrients and protein or because of population food requirements. The following crops are nonsubstitutional: lucerne, maize silage, wheat, as well as part of sunflower production to produce oil. The constraints for these crops, taken into account in SWIM are as follows:

$$Z_1 \geq L \tag{8}$$

$$Z_2 \geq MS \tag{9}$$

$$d_B Z_4 \geq WB \tag{10}$$

$$d_F Z_4 \geq WF \tag{11}$$

$$d_s Z_7 \geq OL \tag{12}$$

where z_1 - is amount of lucerne (Tn) produced to meet the requirements L (Tn).

z_2 - is amount of maize silage (Tn) produced to meet the requirements MS(Tn).

z_4 - is amount of wheat (Tn) produced to meet the requirements of wheat bran WB(Tn) and flour WF(Tn).

d_B - is amount of bran (Tn) produced from one ton of wheat.

d_F - is amount of flour (Tn) produced from one ton of wheat; note that $d_B + d_F < 1$ because of losses associated with flour and bran production.

z_7 - is amount of sunflower produced (Tn).

OL - is total amount of oil needed for population (Tn).

d_W - indicates the oil content (Tn) in one ton of sunflower production; note that $d_s + d_7 < 1$ since amounts of oil and sunflower meal can not **exceed** the total sunflower production.

A2.2.3 Material Balance Constraints

The material balance equations, while not being actual constraints, take into account various inputs for and outputs from crop production. The structure of SWIM allows these inputs and outputs to be constrained when necessary.

A2.2.3.1 Seeds Requirements

$$-x_j + \sum_{i=2}^{3} \sum_{k=1}^{2} s_{kj}^i y_k^i = 0 \quad ; \quad j = 1, 2, \ldots, 6 \qquad (13)$$
$$i = j \quad \text{if } j=1$$
$$i = 2,3 \text{ if } j=2$$
$$i = j+1 \text{ if } j>2$$

where x_j - is amount of seeds (Tn) required to produce crop j; j=1 (lucerne); j=2 (maize silage & maize grain) j=3 (wheat); j=4 (barley); j=5 (soybean); j=6 (sunflower).

y_k^i - is amount of land (Ha) occupied by i crop when being irrigated (k=1) or nonirrigated (k=2)

s_{kj}^{i} - is crop j seeding rate (Tn/Ha) required to produce crop i on irrigated (k=1) or on non-irrigated (k=2) land (the subscripts i and j do not coincide because some of the seeds can be used to produce 2 crops, like maize grain and maize silage)

A2.2.3.2   Fertilizer Requirements

There are three essential type of fertilizers being used in Silistra agricultural-industrial complex: ammonium sulphate, super phosphate, and potassium sulphate. The following fertilizer balance constraints are included in SWIM:

$$-x_j + \sum_{i=1}^{7} \sum_{k=1}^{2} f_{kj}^{i} \, y_k^{i} = \bar{x}_j \quad ; \; j = 7,8,9 \qquad (14)$$

where x_j - is amount of j fertilizer (Tn) required in the complex.

$\bar{x}_j$ - is amount of manure (Tn) which can substitute j fertilizer

f_{kj}^{i} - is fertilizer rate (Tn/Ha) of j fertilizer for crop i when being irrigated (k=1) or nonirrigated (k=2).

A2.2.3.3   Fuel Requirements

Fuel is required for operating tractors, various combines and grain processing equipment. The total amount of fuel required, x_{10}, is determined by the following equation.

$$-x_{10} + \sum_{i=1}^{7} \sum_{k=1}^{2} u_k^{i} \, y_k^{i} = 0 \qquad (15)$$

where u_k^{i} - is fuel rate (ℓ/Ha) for production of crop i on irrigated (k=1) or nonirrigated (k=1) land.

A2.2.3.4   Labor Requirements

The labor is actually the machine-hrs. of field work needed (assuming 1 operator/machine). In principal, all machine-hrs. could be lumped together to obtain the total number of hrs. required. In this study however we separate machine-hrs. required for tractors, combines (June-July) and combines (August-October). The latter two can be operated by people coming outside from the region.

$$-x_{11} + \sum_{i=1}^{7} \sum_{k=1}^{2} t_k^i \, y_k^i = 0 \qquad\qquad (16)$$

where t_k^i - is amount of tractor-hrs/Ha needed for field activities on y_k^i crop area when being irrigated (k=1) or nonirrigated (k=2) x_{11} is total amount of tractor-hrs. for the whole crop area.

$$-x_{12} + \sum_{i=1}^{7} \sum_{k=1}^{2} CJ_k^i \, y_k^i = 0 \qquad\qquad (17)$$

where CJ_k^i -is amount of combine-hrs/Ha on June & July required for harvesting of y_k^i crop area.
x_{12} -is total amount of combine-hrs. on June & July.

$$-x_{13} + \sum_{i=1}^{7} \sum_{k=1}^{2} CA_k^i \, y_k^i = 0 \qquad\qquad (18)$$

where CA_k^i -is amount of combine-hrs/Ha in August-October requested for harvesting of y_k^i crop area.
x_{13} -is total amount of combine-hrs in August-October.

A2.2.3.5   Machinery Requirements

To convert the machine-hrs. already specified in 2.2.3.4 into a more meaningful number, which is the number of machines needed, an estimate has to be made about the critical time in the combination of activities on all crops when all tractors or combines are being pressed into use.

A2.2.3.5.1 Tractor Requirements

$$-x_{14} + \frac{1}{T_t} \sum_{i=1}^{7} \sum_{k=1}^{2} m_k^i \, y_k^i = 0 \tag{19}$$

where m_k^i - is number of machine-hrs/Ha for crop i (irrigated, k=1, or nonirrigated, k=) over the critical period. In our case this period is in March & April (see Table A3.4).

T_t - is total time available over the critical period (hrs); $T_t = (D-D_w)w_t$, where D is number of calendar days in the critical period; D_w is number of days taken off due to holidays or bad weather conditions in this period; w_t is working hrs/day.

x_{14} -is total number of tractors needed for crop production.

A2.2.3.5.2 Combine Requirements

$$-x_{15} + \frac{1}{T_c} \sum_{i=1}^{7} \sum_{k=1}^{2} mc_k^i \, y_k^i = 0 \tag{20}$$

where mc_k^i -is number of machine-hrs/Ha for harvesting of crop i (excluding maize silage) over the critical period. As it can be seen from Table A3.4 this period is in June-July.

T_c - is total time (hrs) available over the critical period; T_c is determined in the same way like in (19).

x_{15} -is total number of combines needed for crop harvesting (excluding maize silage)

A2.2.3.5.3 Silage Chopper Requirements

$$-x_{16} + \frac{1}{T_{sc}} \sum_{k=1}^{2} ms_k^2 \, y_k^2 = 0 \tag{21}$$

where ms_k^2 -is number of machine-hrs/Ha for harvesting maize silage over the critical period (September);

T_{sc} - is total time available (hrs) over the critical period.

x_{16} - is number of silage choppers required.

A2.2.3.5.4 <u>Irrigation Equipment Requirements</u>

To evaluate the number of irrigation equipment one has to identify the productivity of this equipment (Ha/sprinkler) as well as the time table of crop irrigation. The latter is needed to avoid excessive investment for an equipment, e.g. to account for the fact that this equipment can be moved from one place to another over the vegetation season to irrigate different crops.

The information given in figure 2.2 can serve as a guideline to determine the number of irrigation equipment. It is obvious from this figure that the major irrigation activities are associated with maize silage, maize grain and soya. Wheat and barley can be combined and made complementary to maize and soya. On the other hand sunflower is complementary to lucerne. All these relationships can be formalized as follows.

$$\frac{1}{S_p} \left[Y_1^1 + Y_1^2 + Y_1^3 + Y_1^6 \right] + E^{4,5} + E^7 = TE \tag{22}$$

where S_p - is productivity of the irrigation equipment (Ha/sprinkler).

Y_1^1 , Y_1^2, Y_1^3, Y_1^6 - are irrigated areas of lucerne, maize silage, maize grain, and soybeans respectively

$E^{4,5}$ - is irrigation equipment extra needed for wheat and barley

E^7 - is irrigation equipment extra needed for sunflowers.

TE - is total number of irrigation equipment needed

The variables $E^{4,5}$ and E^7 are determined by the equations (23) and (24).

The equation (23) take into account complementarity of sunflowers and lucerne irrigation equipment. The next one accounts for complementarity of wheat and barley with maize and soybeans.

$$\frac{1}{S_p} \left[y_1^1 - y_1^7 \right] + E^7 - D^7 = 0 \tag{23}$$

$$\frac{1}{S_p} \left[y_1^2 + y_1^3 + y_1^6 - y_1^4 - y_1^5 \right] + E^{4,5} - D^{4,5} = 0 \tag{24}$$

where $D^7 \geq 0$ - is a dummy variable, e.g. number of irrigation equipment extra needed for sunflowers, E^7, is equal to 0 if $y_1^7 \geq y_1^1$ and $E^7 = \frac{1}{S_p} [y_1^1 - y_1^7]$ if $y_1^7 > y_1^1$; in other words either E^7 or D^7 are equal to zero.

$E^{4,5} \geq 0$ - is number of irrigation equipment extra needed for wheat and barley.

$D^{4,5} \geq 0$ - is a dummy variable with the same properties like D^7.

A2.2.4   Exports, Import and Crop Yield Production

The yield of each crop is influenced by many factors like irrigated water, weather, cultivation practice, etc. To allow for variations in the yield, meeting at the same time crop requirements in the complex, the following constraints are adopted.

$$z_i^I - z_i^E - z_i + \sum_{k=1}^{2} \ell_k^i \, y_k^i = 0 \tag{25}$$

where ℓ_k^i - is yield of i crop (Tn/Ha) grown on irrigated (k=1) or on nonirrigated (k=2) area.

z_i - is total amount (Tn) from i crop available in the complex.

z_i^E - is amount of crop i (Tn) for export to other regions/countries.

z_i^I - is amount of crop i (Tn) imported from other regions in the complex.

Appendix 3

TABLES OF INPUT RESOURCES

The following tables give the data on input resources of seeds, fertilizer, fuel and labor in SWIM.

Crops		Seeding Rate	Seed Crop Yield	Cost of Seeds	a_i †	Model Designation		
1		2	3.	4	5	6	7	8
	Irrigated/ nonirrig.	Tn/Ha	Tn/Ha	Lv/Tn	—	i	k	j
Lucerne	irr	0.020	0.2	5300	0.1	1	1	1
	non	0.020	0.2	5300	0.1		2	
Maize Silage	irr	0.019	8.6	700	0.0022	2	1	2
	non	0.0175	8.6	700	0.0020		2	
Maize Grain	irr	0.0175	8.6	700	0.0020	3	1	2
	non	0.0155	8.6	700	0.0018		2	
Wheat	irr	0.12	4.8	185	0.025	4	1	3
	non	0.10	4.8	185	0.021		2	
Barley	irr	0.22	4.2	160	0.0523	5	1	4
	non	0.20	4.2	160	0.0476		2	
Soybeans	irr	0.055	3.0	725	0.0183	6	1	5
	non	0.050	3.0	725	0.0167		2	
Sunflowers	irr	0.0165	2.6	365	0.0063	7	1	6
	non	0.015	2.6	365	0.0058		2	

Table A3.1 Seeds Requirements

Notes: † a_i = Column (2) ÷ Column (3)

CROPS	Irrigated/nonirrig.	N removed (kg/Ha)	N needed (kg/Ha)	Ammonium sulphate (Tn/Ha)	P removed (kg/Ha)	P needed (kg/Ha)	Super Phosphate (Tn/Ha)	K removed (kg/Ha)	K needed (kg/Ha)	Potassium Sulphate (Tn/Ha)	Designation in the Model (i)	Designation in the Model (k)
		2	3	4	5	6	7	8	9	10	11	12
											i	k
Lucerne	irr	*-	-	-	70	90	0.45	280	224	0.5034	1	1
	non	-	-	-	40	60	0.30	170	136	0.3056		2
Maize Silage	irr	235	282	0.8294	85	105	0.525	220	176	0.3955	2	1
	non	140	168	0.4941	48	68	0.34	125	100	0.2247		2
Maize Grain	irr	140	168	0.4941	65	85	0.425	45	36	0.0809	3	1
	non	80	96	0.2824	40	60	0.30	25	20	0.0449		2
Wheat	irr	66	79.2	0.2329	48	68	0.34	22	17.6	0.0396	4	1
	non	55	66	0.1941	40	60	0.30	18	14.4	0.0324		2
Barley	irr	60	72	0.2118	60	80	0.40	22	17.6	0.0396	5	1
	non	50	60	0.1765	50	70	0.35	18	14.4	0.0324		2
Soybeans	irr	*-	-	-	43	63	0.315	65	52	0.1169	6	1
	non	-	-	-	25	45	0.225	40	32	0.0719		2
Sunflowers	Irr	144	172.8	0.5082	48	58	0.34	48	38.4	0.0863	7	1
	non	120	144	0.4235	40	60	0.30	40	32	0.0719		2
Designation in the model				$j=7$ P_7			$j=8$ P_8			$j=9$ P_9		

Table A3.2 Fertilizer Requirements

Notes:- * these crops add N but we can not account for this without crop rotations.

1		Plowing	Cultivation	Planting	Harvesting (incl. straw)	Total Fuel	Designation in the Model u_k^1	
		2	3	4	5	6	7	8
		1/Ha	1/Ha	1/Ha	1/Ha	1/Ha	i	k
Lucerne	irr	6.6	1.54	1.23	52.65	62.02	1	1
	non	6.6	1.54	1.23	75.18	84.55		2
Maize Silage	irr	19.8	26.56	4.35	13.62	64.30	2	1
	non	19.8	26.56	4.35	19.47	70.18		2
Maize Grain	irr	19.8	26.56	4.35	9.45	60.16	3	1
	non	19.8	26.56	4.35	13.50	64.21		2
Wheat	irr	19.8	4.62	3.70	10.06	38.18	4	1
	non	19.8	4.62	3.70	12.58	40.70		2
Barley	irr	19.8	4.62	3.70	10.06	38.18	5	1
	non	19.8	4.62	3.70	12.58	40.70		2
Soybeans	irr	10.98	29.26	4.35	7.34	51.93	6	1
	non	10.98	29.26	4.35	8.15	52.74		2
Sunflowers	irr	19.8	14.63	4.35	8.15	46.93	7	1
	non	19.8	14.63	4.35	10.19	48.97		2

Table A3.3 Fuel Requirements

Notes: Price of fuel P_{10}, assumed to be 0.072 Lv/1

	Plowing	Cultivation	Planting	Harvest	Total	June-July	Aug-Oct	Designation in the Model	
								i	k
irrigated / nonirrig.	man hr/Ha	man hr/Ha	man hr/Ha	man hr/Ha	man hr/Ha	man hr/Ha	man hr/Ha		
Lucerne irr	0.183	0.0496	0.0493	3.00	3.28			1	1
non	0.183	0.0496	0.0493	2.10	2.38				2
Maize Silage irr	0.55	0.92	0.174	0.649	2.293			2	1
non	0.55	0.92	0.174	0.454	2.098				2
Maize Grain irr	0.55	0.92	0.174		1.644		0.562	3	1
non	0.55	0.92	0.174		1.644		0.394		2
Wheat irr	0.55	0.149	0.148	0.614	1.46	0.455		4	1
non	0.55	0.149	0.148	0.491	1.288	0.364			2
Barley irr	0.55	0.149	0.148	0.614	1.46	0.455		5	1
non	0.55	0.149	0.148	0.491	1.338	0.364			2
Soybeans irr	0.305	1.053	0.174		1.532		0.326	6	1
non	0.305	1.053	0.174		1.532		0.293		2
Sunflowers irr	0.55	0.618	0.174		1.342		0.408	7	1
non	0.55	0.618	0.174		1.342		0.326		2
Designation in the Model					t_k^i	CJ_k^i	CA_k^j		

Table section spanning columns: Tractor-hours (Plowing, Cultivation, Planting, Harvest, Total); Combine-hours (June-July, Aug-Oct).

Table A3.4 Labor Requirements

Appendix 4

TABLES OF PRODUCTION COSTS

For each crop, the following tables show all production costs associated with field cultivation activities. The costs are either attached to the land area on a cost/ha basis or to the input resources on a cost/unit amount basis. The fixed costs attached to land are depreciated capital investments (machinery purchase). The total cost attached to land (e.g 70.51 in table A4.1) is the unit cost used in the linear programming for the crop area decision variable (c_k^i in equation 1). The total land and resource cost (e.g 159.02 in table A4.1) is the total production cost per ha.

		SEEDS	FERTILIZER	CHEMICALS	MACHINERY	LABOR	IRRIGATION	TOTAL COSTS
Costs Attached to Land								
Fixed Costs Lv/Ha					17.60			
Var. Costs Lv/Ha			3.00	31.55	15.54	2.82		
Tot. Costs Lv/Ha			3.00	31.55	33.14	2.82		70.51
Costs Attached to Resources								
Seeds	Tn/Ha	0.020						
	Lv/Tn	1767.5						
Ammonium Sulphate	Tn/Ha							
	Lv/Tn							
Super-phosphate	Tn/Ha		0.30					
	Lv/Tn		58.00					
Potassium Sulphate	Tn/Ha		0.3056					
	Lv/Tn		86.75					
Fuel	ℓ/Ha				62.03			
	Lv/ℓ				0.072			
Operator-Hours	Hr/Ha					2.389		
	Lv/Hr					2.00		
Water	m³/Ha							
	Lv/m³							
Resource Cost Lv/Ha		35.35	43.91		4.47	4.78		88.51
Land & Resource Cost Lv/Ha		35.35	46.91	31.55	37.61	7.60		159.02

A4.1 Nonirrigated Lucerne Production Costs

		SEEDS	FERTILIZER	CHEMICALS	MACHINERY	LABOR	IRRIGATION	TOTAL COSTS
Costs Attached to Land	Fixed Costs Lv/Ha				22.80		103.25	
	Var. Costs Lv/Ha		3.00	31.55	21.24	2.82	19.75	
	Tot. Costs Lv/Ha		3.00	31.55	44.04	2.82	123.00	204.41
Costs Attached to Resources	Seeds Tn/Ha	0.020						
	Seeds Lv/Tn	1767.5						
	Ammonium Sulphate Tn/Ha							
	Ammonium Sulphate Lv/Tn							
	Super-phosphate Tn/Ha		0.45					
	Super-phosphate Lv/Tn		58.00					
	Potassium Sulphate Tn/Ha		0.5034					
	Potassium Sulphate Lv/Tn		86.75					
	Fuel ℓ/Ha				84.56			
	Fuel Lv/ℓ				0.072			
	Operator-Hours Hr/Ha					3.292		
	Operator-Hours Lv/Hr					2.00		
	Water m³/Ha						54 00	
	Water Lv/m³						0.022	
Resource Cost Lv/Ha		35.35	69.77		6.09	6.58	118.80	236.59
Land & Resource Cost Lv/Ha		35.35	72.77	31.55	50.13	9.40	241.80	441.00

A4.2 Irrigated Lucerne Production Costs

		SEEDS	FERTILIZER	CHEMICALS	MACHINERY	LABOR	IRRIGATION	TOTAL COSTS
Costs Attached to Land	Fixed Costs Lv/Ha				19.15			
	Var. Costs Lv/Ha		6.00	30.60	18.77	2.82		
	Tot. Costs Lv/Ha		6.00	30.60	37.92	2.82		77.34
Costs Attached to Resources	Seeds — Tn/Ha	0.0175						
	Seeds — Lv/Tn	700.00						
	Ammonium Sulphate — Tn/Ha		0.4941					
	Ammonium Sulphate — Lv/Tn		107.10					
	Super-phosphate — Tn/Ha		0.34					
	Super-phosphate — Lv/Tn		58.00					
	Potassium Sulphate — Tn/Ha		0.2247					
	Potassium Sulphate — Lv/Tn		86.75					
	Fuel — ℓ/Ha				64.34			
	Fuel — Lv/ℓ				0.072			
	Operator-Hours — Hr/Ha					2.098		
	Operator-Hours — Lv/Hr					2.00		
	Water — m³/Ha							
	Water — Lv/m³							
	Resource Cost Lv/Ha	12.25	92.13	30.60	4.63	4.20		113.21
	Land & Resource Cost Lv/Ha	12.25	98.13	30.60	42.55	7.02		190.55

A4.3 Nonirrigated Maize Silage Production Costs

		Unit	SEEDS	FERTILIZER	CHEMICALS	MACHINERY	LABOR	IRRIGATION	TOTAL COSTS
Costs Attached to Land	Fixed Costs Lv/Ha					22.00		103.25	
	Var. Costs Lv/Ha			6.00	30.60	22.32	2.82	19.75	
	Tot. Costs Lv/Ha			6.00	30.60	44.32	2.82	123.00	206.74
Costs Attached to Resources	Seeds	Tn/Ha	0.019						
		Lv/Tn	700.00						
	Ammonium Sulphate	Tn/Ha		0.8294					
		Lv/Tn		107.10					
	Super-phosphate	Tn/Ha		0.525					
		Lv/Tn		58.00					
	Potassium Sulphate	Tn/Ha		0.3955					
		Lv/Tn		86.75					
	Fuel	ℓ/Ha				70.18			
		Lv/ℓ				0.072			
	Operator-Hours	Hr/Ha					2.293		
		Lv/Hr					2.00		
	Water	m³/Ha						34.00	
		Lv/m³						0.022	
Resource Cost Lv/Ha			13.30	153.59		5.05	4.59	74.80	251.33
Land & Resource Cost Lv/Ha			13.30	159.59	30.60	49.37	7.41	197.80	458.07

A4.4 Irrigated Maize Silage Production Costs

		SEEDS	FERTILIZER	CHEMICALS	MACHINERY	LABOR	IRRIGATION	TOTAL COSTS
Costs Attached to Land	Fixed Costs Lv/Ha				18.70			
	Var. Costs Lv/Ha		6.00	22.55	18.13	2.82		
	Tot. Costs Lv/Ha		6.00	22.55	36.83	2.82		68.2
Costs Attached to Resources	Seeds Tn/Ha	0.0155						
	Seeds Lv/Tn	700.00						
	Ammonium Sulphate Tn/Ha		0.2824					
	Ammonium Sulphate Lv/Tn		107.10					
	Super-phosphate Tn/Ha		0.30					
	Super-phosphate Lv/Tn		58.00					
	Potassium Sulphate Tn/Ha		0.0449					
	Potassium Sulphate Lv/Tn		86.75					
	Fuel ℓ/Ha				60.17			
	Fuel Lv/ℓ				0.072			
	Operator-Hours Hr/Ha					2.038		
	Operator-Hours Lv/Hr					2.00		
	Water m³/Ha							
	Water Lv/m³							
Resource Cost Lv/Ha		10.85	51.54	22.55	4.33	4.08		70.80
Land & Resource Cost Lv/Ha		10.85	57.54	22.55	41.16	6.90		139.00

A4.5 Nonirrigated Maize Grain Production Costs

		SEEDS	FERTILIZER	CHEMICALS	MACHINERY	LABOR	IRRIGATION	TOTAL COSTS
Costs Attached to Land	Fixed Costs Lv/Ha				21.35		103.25	
	Var. Costs Lv/Ha		6.00	22.55	21.39	2.82	19.75	
	Tot. Costs Lv/Ha		6.00	22.55	42.74	2.82	123.00	197.11
Costs Attached to Resources	Seeds Tn/Ha	0.0175						
	Lv/Tn	700.00						
	Ammonium Sulphate Tn/Ha		0.4941					
	Lv/Tn		107.10					
	Super-phosphate Tn/Ha		0.425					
	Lv/Tn		58.00					
	Potassium Sulphate Tn/Ha		0.0809					
	Lv/Tn		86.75					
	Fuel ℓ/Ha				64.22			
	Lv/ℓ				0.072			
	Operator-Hours Hr/Ha					2.206		
	Lv/Hr					2.00		
	Water m³/Ha						3.400	
	Lv/m³						0.022	
Resource Cost Lv/Ha		12.25	84.59		4.62	4.41	74.80	180.67
Land & Resource Cost Lv/Ha		12.25	90.59	22.55	47.36	7.23	197.80	377.78

A4.6 Irrigated Maize Grain Production Costs

			SEEDS	FERTILIZER	CHEMICALS	MACHINERY	LABOR	IRRIGATION	TOTAL COSTS
Costs Attached to Land	Fixed Costs Lv/Ha					13.35			
	Var. Costs Lv/Ha			3.00	6.65	12.64	2.82		
	Tot. Costs Lv/Ha			3.00	6.65	25.99	2.82		38.46
Costs Attached to Resources	Seeds	Tn/Ha	0.1						
		Lv/Tn	185.00						
	Ammonium Sulphate	Tn/Ha		0.1941					
		Lv/Tn		107.10					
	Super-phosphate	Tn/Ha		0.3					
		Lv/Tn		58.00					
	Potassium Sulphate	Tn/Ha		0.0324					
		Lv/Tn		86.75					
	Fuel	ℓ/Ha				38.18			
		Lv/ℓ				0.072			
	Operator-Hours	Hr/Ha					1.211		
		Lv/Hr					2.00		
	Water	m³/Ha							
		Lv/m³							
Resource Cost Lv/Ha			18.50	41.00		2.75	2.42		64.67
Land & Resource Cost Lv/Ha			18.50	44.00	6.65	28.74	5.24		103.13

A4.7 Nonirrigated Wheat Production Costs

Item	Unit	SEEDS	FERTILIZER	CHEMICALS	MACHINERY	LABOR	IRRIGATION	TOTAL COSTS
Costs Attached to Land								
Fixed Costs Lv/Ha					14.54		50.00	
Var. Costs Lv/Ha			3.00	6.65	14.11	2.82	19.75	
Tot. Costs Lv/Ha			3.00	6.65	28.65	2.82	69.75	110.87
Costs Attached to Resources								
Seeds	Tn/Ha	0.1						
	Lv/Tn	185						
Ammonium Sulphate	Tn/Ha		0.2329					
	Lv/Tn		107.10					
Super-phosphate	Tn/Ha		0.34					
	Lv/Tn		58.00					
Potassium Sulphate	Tn/Ha		0.0396					
	Lv/Tn		86.75					
Fuel	ℓ/Ha				40.69			
	Lv/ℓ				0.072			
Operator-Hours	Hr/Ha					1.302		
	Lv/Hr					2.00		
Water	m³/Ha						900	
	Lv/m³						0.022	
Resource Cost Lv/Ha		18.5	48.10	6.65	2.93	2.60	19.80	91.93
Land & Resource Cost Lv/Ha		18.5	51.10	6.65	31.58	5.42	89.55	202.80

A4.8 Irrigated Wheat Production Costs

		SEEDS	FERTILIZER	CHEMICALS	MACHINERY	LABOR	IRRIGATION	TOTAL COSTS
Costs Attached to Land								
Fixed Costs Lv/Ha					13.35			
Var. Costs Lv/Ha			3.00	6.65	12.64	2.82		
Tot. Costs Lv/Ha			3.00	6.65	25.99	2.82		38.46
Seeds	Tn/Ha	0.2						
	Lv/Tn	160						
Ammonium Sulphate	Tn/Ha		0.1765					
	Lv/Tn		107.10					
Costs Attached to Resources Super-phosphate	Tn/Ha		0.35					
	Lv/Tn		58.00					
Potassium Sulphate	Tn/Ha		0.0324					
	Lv/Tn		86.75					
Fuel	ℓ/Ha				38.18			
	Lv/ℓ				0.072			
Operator-Hours	Hr/Ha					1.211		
	Lv/Hr					2.00		
Water	m³/Ha							
	Lv/m³							
Resource Cost Lv/Ha		32.00	42.01		2.75	2.42		79.18
Land & Resource Cost Lv/Ha		32.00	45.01	6.65	28.74	5.24		117.64

A4.9 Nonirrigated Barley Production Costs

			SEEDS	FERTILIZER	CHEMICALS	MACHINERY	LABOR	IRRIGATION	TOTAL COSTS
Costs Attached to Land	Fixed Costs Lv/Ha					14.54		50.00	
	Var. Costs Lv/Ha			3.00	6.65	14.11	2.82	19.75	
	Tot. Costs Lv/Ha			3.00	6.65	28.65	2.82	69.75	110.87
Costs Attached to Resources	Seeds	Tn/Ha	0.22						
		Lv/Tn	160						
	Ammonium Sulphate	Tn/Ha		0.2118					
		Lv/Tn		107.10					
	Super-phosphate	Tn/Ha		0.4					
		Lv/Tn		58.00					
	Potassium Sulphate	Tn/Ha		0.0396					
		Lv/Tn		86.75					
	Fuel	ℓ/Ha				40.69			
		Lv/ℓ				0.072			
	Operator-Hours	Hr/Ha					1.302		
		Lv/Hr					2.00		
	Water	m³/Ha						900	
		Lv/m³						0.022	
Resource Cost Lv/Ha			35.20	49.31	6.65	2.93	2.60	19.80	109.84
Land & Resource Cost Lv/Ha			35.20	52.31	6.65	31.58	5.42	39.55	220.71

A4.10 Irrigated Barley Production Costs

		SEEDS	FERTILIZER	CHEMICALS	MACHINERY	LABOR	IRRIGATION	TOTAL COSTS
Costs Attached to Land Fixed Costs Lv/Ha					13.64			
Var. Costs Lv/Ha				28.00	12.05	2.82		
Tot. Costs Lv/Ha				28.00	25.69	2.82		56.51
Costs Attached to Resources Seeds	Tn/Ha	0.050						
Seeds	Lv/Tn	725.00						
Ammonium Sulphate	Tn/Ha							
	Lv/Tn							
Super-phosphate	Tn/Ha		0.225					
	Lv/Tn		58.00					
Potassium Sulphate	Tn/Ha		0.0719					
	Lv/Tn		86.75					
Fuel	ℓ/Ha				51.93			
	Lv/ℓ				0.072			
Operator-Hours	Hr/Ha					1.825		
	Lv/Hr					2.00		
Water	m³/Ha							
	Lv/m³							
Resource Cost Lv/Ha		36.25	19.29	28.00	3.74	3.65		62.93
Land & Resource Cost Lv/Ha		36.25	19.29	28.00	29.43	6.47		119.44

A4.11 Nonirrigated Soybean Production Costs

			SEEDS	FERTILIZER	CHEMICALS	MACHINERY	LABOR	IRRIGATION	TOTAL COSTS
Costs Attached to Land	Fixed Costs Lv/Ha					14.12		103.25	
	Var. Costs Lv/Ha				28.00	12.64	2.82	19.75	
	Tot. Costs Lv/Ha				28.00	26.76	2.82	123.00	180.58
Costs Attached to Resources	Seeds	Tn/Ha	0.055						
		Lv/Tn	725.00						
	Ammonium Sulphate	Tn/Ha							
		Lv/Tn							
	Super-phosphate	Tn/Ha		0.315					
		Lv/Tn		58.00					
	Potassium Sulphate	Tn/Ha		0.1169					
		Lv/Tn		86.75					
	Fuel	ℓ/Ha				52.74			
		Lv/ℓ				0.072			
	Operator-Hours	Hr/Ha					1.858		
		Lv/Hr					2.00		
	Water	m³/Ha						2300	
		Lv/m³						0.022	
Resource Cost Lv/Ha			39.88	28.41	28.00	3.80	3.72	50.60	126.41
Land & Resource Cost Lv/Ha			39.88	28.41	28.00	30.56	6.54	173.60	306.99

A4.12 Irrigated Soybean Production Costs.

		SEEDS	FERTILIZER	CHEMICALS	MACHINERY	LABOR	IRRIGATION	TOTAL COSTS
Costs Attached to Land	Fixed Costs Lv/Ha				15.37			
	Var. Costs Lv/Ha		6.00	10.00	14.10	2.82		
	Tot. Costs Lv/Ha		6.00	10.00	29.47	2.82		48.29
Seeds	Tn/Ha	0.015						
	Lv/Tn	365.00						
Ammonium Sulphate	Tn/Ha		0.4235					
	Lv/Tn		107.10					
Super-phosphate	Tn/Ha		0.300					
	Lv/Tn		58.00					
Potassium Sulphate	Tn/Ha		0.0719					
	Lv/Tn		86.75					
Costs Attached to Resources — Fuel	ℓ/Ha				46.93			
	Lv/ℓ				0.072			
Operator-Hours	Hr/Ha					1.67		
	Lv/Hr					2.00		
Water	m³/Ha							
	Lv/m³							
Resource Cost Lv/Ha		5.48	68.99		3.38	3.34		81.19
Land & Resource Cost Lv/Ha		5.48	74.99	10.00	32.85	6.16		129.48

A4.13 Nonirrigated Sunflower Production Costs

	Units	SEEDS	FERTILIZER	CHEMICALS	MACHINERY	LABOR	IRRIGATION	TOTAL COSTS
Costs Attached to Land								
Fixed Costs Lv/Ha					16.33		50.00	
Var. Costs Lv/Ha			6.00	10.00	15.26	2.82	19.75	
Tot. Costs Lv/Ha			6.00	10.00	31.59	2.82	69.75	120.16
Costs Attached to Resources								
Seeds	Tn/Ha	0.0165						
Seeds	Lv/Tn	365.00						
Ammonium Sulphate	Tn/Ha		0.5082					
Ammonium Sulphate	Lv/Tn		107.10					
Super-phosphate	Tn/Ha		0.340					
Super-phosphate	Lv/Tn		58.00					
Potassium Sulphate	Tn/Ha		0.0863					
Potassium Sulphate	Lv/Tn		86.75					
Fuel	ℓ/Ha				48.97			
Fuel	Lv/ℓ				0.072			
Operator-Hours	Hr/Ha					1.75		
Operator-Hours	Lv/Hr					2.00		
Water	m³/Ha						1290	
Water	Lv/m³						0.022	
Resource Cost Lv/Ha		6.02	81.63		3.53	3.50	28.38	123.06
Land & Resource Cost Lv/Ha		6.02	87.63	10.00	35.12	6.32	98.13	243.22

A4.14 Irrigated Sunflower Production Costs

Appendix 5

COMPUTER DATA STRUCTURE

The computational results were obtained using a linear programming system, LPS/11, available on IIASA PDP11/45 computer. To run the system one has to specify the LP matrix, RHS, and upper and/or lower bounds. Their values are produced on the base of mathematical description of the model (Appendix 2) and the Tables of Input Resources and Crop Production costs specified in Appendixes 3 and 4.

This appendix has an aim to specify the LP matrix, RHS, and bounds in a way that they can be reproduced in any computer having a LP system. To facilitate this aim a Glossary of Terms as well as the LP matrix are enclosed.

A.5 Glossary of terms

A.5.1 Description of Decision Variables (Columns)

UNIT

ALUI	Ha	Irrigated land for growing lucerne
ALUN	Ha	Nonirrigated land for growing lucerne
AMSI	Ha	Irrigated land for growing maize silage
AMSN	Ha	Nonirrigated land for growing maize silage
AMGI	Ha	Irrigated land for growing maize grain
AMGN	Ha	Nonirrigated land for growing maize grain
AWHI	Ha	Irrigated land for growing wheat
AWHN	Ha	Nonirrigated land for growing wheat
ABRI	Ha	Irrigated land for growing barley
ABRN	Ha	Nonirrigated land for growing barley
ASBI	Ha	Irrigated land for growing soybeans
ASBN	Ha	Nonirrigated land for growing soybeans
ASFI	Ha	Irrigated land for growing sunflowers
ASFN	Ha	Nonirrigated land for growing sunflowers
AS	Ha	Irrigated land for seeds
NL	Ha	Total irrigated land required
LUC	Tn	Amount of lucerne produced
MSL	Tn	Amount of maize silage produced
MGR	Tn	Amount of maize grain produced
WHT	Tn	Amount of wheat produced
BRL	Tn	Amount of barley produced
SOY	Tn	Amount of soybeans produced
SFL	Tn	Amount of sunflowers produced

	UNIT	
SLUC	Tn	Total amount of lucerne seeds required
SMZ	Tn	Total amount of maize seeds required
SWT	Tn	Total amount of wheat seeds required
SBR	Tn	Total amount of barley seeds required
SSY	Tn	Total amount of soybean seeds required
SSF	Tn	Total amount of sunflower seeds required
AMN	Tn	Ammonia sulphate fertilizer
SPH	Tn	Super phosphate fertilizer
POT	Tn	Potassium sulphate fertilizer
FUL	lit.	Fuel
TRH	Hrs	Tractor hours
CJH	Hrs	Combine June-July hours
CSH	Hrs	Combine August-October hours
TRS	–	Number of tractors
CMB	–	Number of combines
SCB	–	Number of silage choppers
PW	m^3	Amount of irrigation water
OIL	Tn	Sunflower oil
FLO	Tn	Flour
EMAZ	Tn	Maize grain export
IMAZ	Tn	Maize grain import
EWHT	Tn	Wheat export
EBRL	Tn	Barley export
IREQ	–	Number of irrigation sprinklers
IRSF	–	No. of irrigation sprinklers extra for sunflowers
DSFL	–	Dummy variable for sunflowers
IRWB	–	Number of irrigation equipment extra for wheat and barley

	UNIT	
DWB	Tn	Dummy variable for wheat and barley
TEXB	Lv	Total export benefits
IRAP	m^3	Crop irrigation water in April
IRMY	m^3	Crop irrigation water in May
IRJN	m^3	Crop irrigation water in June
IRJL	m^3	Crop irrigation water in July
IRAG	m^3	Crop irrigation water in August
APRS	m^3	Seed irrigation water in April
MAYS	m^3	Seed irrigation water in May
JUNS	m^3	Seed irrigation water in June
JULS	m^3	Seed irrigation water in July
AUGS	m^3	Seed irrigation water in August
TAPR	m^3	Total irrigation water in April
TMAY	m^3	Total irrigation water in May
TJUNE	m^3	Total irrigation water in June
TJULY	m^3	Total irrigation water in July
TAUG	m^3	Total irrigation water in August
TCOST	Lv	Total cost of production

A.5.2 Description of Rows (Constraints)

UNIT

OBJECT	Lv	Objective function
SEL	Tn	Lucerne seed balance
SEM	Tn	Maize seed balance
SEW	Tn	Wheat seed balance
SEB	Tn	Barley seed balance
SES	Tn	Soybean seed balance
SEF	Tn	Sunflower seed balance
FAM	Tn	Ammonium sulphate balance
FSP	Tn	Super phosphate balance
FPO	Tn	Potassium sulphate balance
RFL	lit.	Fuel balance
RLT	Hrs	Tractor hour balance
RLC	–	Combines (June-July) balance
RLS	–	Combines (August-October) balance
MTR	–	Balance of number of tractors
MCJ	–	Balance of number of combines
MCS	–	Balance of number of silage combines
SAR	Ha	Seed area balance
NLB	Ha	Irrigated land balance
CYL	Tn	Lucerne land yield balance
CYM	Tn	Maize silage yield balance
CYG	Tn	Maize grain yield balance
CYW	Tn	Wheat yield balance

UNIT

CYB	Tn	Barley yield balance
CYS	Tn	Soybean yield balance
CYF	Tn	Sunflower yield balance
ALD	Ha	Arable land balance
FRW	Tn	Wheat bran constraint
FRS	Tn	Constraint on substitution of soybeans & sunflowers
FRG	Tn	Constraint on substitution of maize grain & barley
SOL	Tn	Sunflower oil constraint
WFL	Tn	Wheat flour constraint
EXB	Lv	Export benefit balance
COST	Lv	Cost of production balance
EQIR1	-	Total irrigation equipment balance
EQIR2	-	Irrigation equipment balance for lucerne & sunflower
EQIR3	-	Irrigation equipment balance for maize & soybeans
TIRAP	m^3	Crop water irrigation balance in April
TIRMY	m^3	Crop water irrigation balance in May
TIRJN	m^3	Crop water irrigation balance in June
TIRJL	m^3	Crop water irrigation balance in July
TIRAG	m^3	Crop water irrigation balance in August
SIRAP	m^3	Seed water irrigation balance in April
SIRMY	m^3	Seed water irrigation balance in May
SIRJN	m^3	Seed water irrigation balance in June
SIRJL	m^3	Seed water irrigation balance in July
SIRAG	m^3	Seed water irrigation balance in August
APRIL	m^3	Total water irrigation balance in April
MAY	m^3	Total water irrigation balance in May
JUNE	m^3	Total water irrigation balance in June

UNIT

JULY	m^3	Total water irrigation balance in July
AUGT	m^3	Total water irrigation balance in August
GTOT	m^3	Total water irrigation balance over vegetation season

BOUND SET: OLIM (OLIM is the name of the bound set)

LOLUC	Tn	Lower limit of lucerne production
LOMSL	Tn	Lower limit of maize silage production
LOOIL	Tn	Lower limit of sunflower oil production
LOFLO	Tn	Lower limit of flour production
UPNL	Ha	Upper limit of irrigated land available
UPPW	m^3	Upper limit of irrigation water available

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COLUMNS 1 TO 18

A5.3 Linear Programming Matrix

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COLUMNS   11 TO 2?

	OBJECT	ABBI	ABBN	ABFI	ABFN	AS	NL	LUC	MSL	MCR	N-T
1	OBJECT	-160.53000	-56.51000	-120.16000	-46.29000						
2	SEL										
3	SEM										
4	SEN										
5	SEO										
6	BEB	0.85500	7.85000	7.81500	8.01500						
7	SEF										
8	FAM										
9	FSP	8.31500	8.22500	8.58520	8.42350						
10	FPO	8.11650	8.07190	8.34000	8.30000						
11	RFL	52.74000	51.53000	8.86630	8.07190						
12	RLT	1.53200	1.53200	46.97000	45.93000						
13	RLC			1.34200	1.34200						
14	RLB	8.32000	8.29300	8.40000	8.32000						
15	MTR	8.34200	8.34200	8.14000	8.14000						
16	MCJ	8.32600	8.29300								
17	MCB										
18	BAR	8.01830	8.01670	8.08630	8.08500	-1.00000					
19	NLB	1.00000		1.00000		1.00000	-1.00000				
20	CYL							-1.00000			
21	CYM										
22	CYG										
24	CYH								-1.00000	-1.00000	-1.00000
25	CYS	2.78000	1.50000	2.20000	2.00000						
26	CYF	1.00000	1.00000	-1.00000	1.00000	1.00000					
27	ALD										
28	FRW										
29	FRB										
30	FRG									1.00000	2.10000
31	BOL										
32	NFL										
33	EXO	100.53000	56.51000	120.16000	46.29000						
34	COST	8.01920									
35	EQIR1										
36	EQIR2	-8.01920		8.01920							
37	EQIR3										
38	TIRAP	488.00000		498.00000							
39	TIRMY	790.00000		850.00000							
40	TIRJN	1032.00000									
41	TIRJL										
42	TIRAG										
43	BIRAP										
44	BIRMY										
45	BIRJN	8.75000	7.94000	3.86000	2.02000						
46	BIRJL	10.48000	13.21000	5.10000	4.66000						
47	BIRAG	18.66000	17.21000								
48	APRIL										
49	MAY										
50	JUNE										
51	JULY										
52	AUG										
53	GTOT										

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COLUMNS 21 TO 38

	BRL	SOV	SPL	SLUC	SMZ	SMT	SBR	SSV	SSF	AMN
1 OBJECT				-5300.0000	-700.0000	-165.0000	-160.0000	-725.0000	-365.0000	-107.1000
2 SEL				-1.00000						
3 SEM					-1.00000					
4 SEA						-1.00000				
5 SEB							-1.00000			
6 SE3								-1.00000		
7 SEF									-1.00000	-1.00000
8 FAM										
9 FSP										
10 FPO										
11 RPL										
12 RLT										
13 RLC										
14 RLS										
15 MTR										
16 MCJ										
17 MC3										
18 SHR										
19 NLR										
20 CVL										
21 CVM										
22 CVG										
23 CVH										
24 CVR	-1.00000	-1.00000	-1.00000							
25 CVS										
26 CVF										
27 ALO										
28 FRW										
29 FRS										
30 PRG	1.10000	0.75000	0.41000							
31 SOL			0.00000							
32 WPL										
33 EXH										
34 COST				5300.0000	700.0000	185.0000	160.0000	725.0000	365.0000	107.1000
35 EQIR1										
36 EQIR2										
37 EQIR3										
38 TIRAP										
39 TIRMY										
40 TIRJN										
41 TIRJL										
42 TIRAG										
43 SIRAP										
44 SIRMY										
45 SIRJN										
46 SIRJL										
47 SIRAG										
48 APRTL										
49 MAY										
50 JUNE										
51 JULY										
52 AUGT										
53 GTOT										

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COLUMNS   51 TO 48

	SEM	PST	FJL	TRM	CJM	CSM	TRS	CMB	SCB	PN
1 OBJECT	-54,00000	-36,75000	-2,07200	-2,00000	-2,00000	-2,00000				-2,02200
2 SEL										
3 SEM										
4 SEM										
5 SES										
6 SEM										
7 SEM										
8 FAM	-1,00000									
9 FSP		-1,00000								
10 FPN			-1,00000	-1,00000						
11 RFL					-1,00000	-1,00000				
12 RLT							-278,00000			
13 BLC								-350,00000		
14 RLS									-160,00000	
15 MTR										
16 MCJ										
17 MCS										
18 SAB										
19 NLR										
20 CVL										
21 CVM										
22 CVG										
23 CVY										
24 CVR										
25 CVP										
26 CVP										
27 ALD										
28 FRM										
29 FRS										
30 FRC										
31 SOL										
32 RFL										
33 EXA										
34 COST	54,00000	36,75000	2,07200	2,00000	2,00000	2,00000			0,02200	
35 EQTH1										
36 FQIR2										
37 EQTHS										
38 TIRAP										
39 TIRMY										
40 TIRJN										
41 TIRJL										
42 TIRAG										
43 SIRAP										
44 SIRMY										
45 SIRJN										
46 SIRJL										
47 SIRAG										
48 APRIL										
49 MAY										
50 JUNE										
51 JULY										
52 AUGT										
53 GTOT										-1,00000

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COLUMNS   41 TO 58

	OIL	FLC	EMAZ	IMAZ	EMHY	EBHL	IRLC	DSFL	
			113.00000	-170.00000	114.00000	101.00000		-5369.00000	5369.00000
1 DBJECT									
2 SEL									
3 SEH									
4 BEH									
5 BER									
6 SES									
7 SEF									
8 FAH									
9 FSP									
10 FPD									
11 RFL									
12 RLT									
13 RLC									
14 RLB									
15 MTR									
16 MCJ									
17 MCB									
18 BAR									
19 NLB									
20 CVL									
21 CVH									
22 CVG			-1.00000	1.00000					
23 CVH					-1.00000	-1.00000			
24 CVR									
25 CVB									
26 CVF									
27 ALD									
28 FRV									
29 FHB									
30 FRG									
31 SOL	-1.00000								
32 MFL		-1.00000							
33 EHB			113.00000	170.00000	114.00000	101.00000			
34 CDBT							-1.00000	5369.00000	5369.00000
35 EQIR1								1.00000	1.00000
36 EQIR2								-1.00000	1.00000
37 EQIR3								-1.00000
38 TIRAP									
39 TIRHV									
40 TIRJN									
41 TIRJL									
42 TIRAG									
43 BIRAP									
44 BIRHV									
45 BIRJN									
46 BIRJL									
47 BIRAG									
48 APRIL									
49 MAY									
50 JUNE									
51 JULY									
52 AUGT									
53 GYDY									

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COLUMNS 51 TO 60

	DMB	TEXB	IRAP	IRMV	IRJN	IRJL	IRAG	APKS	MAYS	JUN6
1 OBJECT										
2 SEL										
3 STM										
4 SEM										
5 SEB										
6 SES										
7 SEF										
8 FAM										
9 FSP										
10 FPO										
11 RFL										
12 RLT										
13 RLC										
14 RLB										
15 MTR										
16 MCJ										
17 MCR										
18 SAR										
19 NLR										
20 CVL										
21 CVM										
22 CVG										
23 CVH										
24 CVR										
25 CVB										
26 CVF										
27 ALD										
28 FRM										
29 FRS										
30 FRG										
31 BDL										
32 MFL										
33 EXB		-1.00000								
34 COST	1.00000									
35 EQIR1										
36 EQIR2										
37 EQIR3										
38 TIRAP			-1.00000							
39 TIRMV				-1.00000						
40 TIRJN					-1.00000					
41 TIRJL						-1.00000				
42 TIRAG							-1.00000			
43 SIRAP								-1.00000		
44 SIRMV									-1.00000	
45 SIRJN										-1.00000
46 SIRJL										
47 SIRAG										
48 APRIL			1.00000					1.00000		
49 MAY				1.00000					1.00000	
50 JUNE					1.00000					1.00000
51 JULY						1.00000	1.00000			
52 AUGT							1.00000			
53 GTOT			1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000

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COLUMNS 61 TO 66

	JULS	AUGS	TAPR	TMAY	TJUNE	TJULY	TAUG	TCOST
1 OBJECT								
2 SEL								
3 SEW								
4 SEW								
5 SEB								
6 SES								
7 SEF								
8 FAM								
9 FSP								
10 FPC								
11 RFL								
12 RLT								
13 RLC								
14 RLB								
15 MTR								
16 MCJ								
17 MCB								
18 SAR								
19 NLB								
20 CYL								
21 CYM								
22 CYG								
23 CYW								
24 CYB								
25 CYF								
26 CYF								
27 ALD								
28 FRM								
29 FRB								
30 FRG								
31 BOL								
32 MFL								
33 EHB								
34 COST								-1.00000
35 EQTR1								
36 FQTR2								
37 EQTR3								
38 TIRMP								
39 TIRMY								
40 TIRJN								
41 TIRJL								
42 TIRAG								
43 BKRAP								
44 BIRMY								
45 BIRJN								
46 BIRJL								
47 BIRAG	-1.00000	-1.00000	-1.00000	-1.00000	-1.00000	-1.00000	-1.00000	
48 APPIL								
49 MAY								
50 JUNE								
51 JULY	1.00000	1.00000						
52 AUGT	1.00000	1.00000						
53 GTOT								

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RGUND SET: DLTM

LC LUC   ....
LC MRL   ....
LO OTL   RAPP,PPPP
LC FLG   ....
UP ZN   ....
UP PM   ....

ROWS   COLUMNS   RHS-S   RANGES   BOUNDS   COEFS.   DENSITY
55   68   1   0   1   379   0.1052

39A TOTAL VALUES SPECIFIED,   0 COEFS ARE 0.0

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RHS   1 TO   1

                RHS

1 OBJECT
2 SEL
3 SEM
4 SEN
5 SES
6 SEG
7 SEF
8 FAM   7118.00000
9 FBP   8698.00000
10 FPC   6935.00000
11 RFL
12 RLT
13 RLC
14 RLB
15 HTR
16 MCJ
17 MCG
18 BAR
19 NLR
20 CVL
21 CVC
22 CVG
23 CVM
24 CVB
25 CVS
26 CVP
27 ALD   171600.00000
28 FRM   7865.00000
29 FRB   37300.00000
30 FRG   174100.00000
31 SOL
32 WFL
33 EHR
34 COST
35 EQTR1
36 EQTR2
37 EQTR3
38 TIRAP
39 TIRMY
40 TIRJN
41 TIRJL
42 TIRAG
43 SIRAP
44 SIRMY
45 SIRJN
46 SIRJL
47 SIRAG
48 APRIL
49 MAY
50 JUNE
51 JULY
52 AUGT
53 GTOT