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by

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INTRODUCTION

Agriculture remains the sustaining core of the bulk of China's 1 billion people. Some 70 percent of the population continues to produce the basic grains and other foods that nourish over 20 percent of the population of the world. Over the past three decades, self-sufficiency in foodstuffs has been a fundamental tenet of China's economic outlook. Development programs have proceeded on the assumption that its vast population cannot and must not become dependent on net imports of food grains (Malenbaum, 1982). However, the struggle to maintain food self-sufficiency has been great. There is restrained optimism regarding recent changes aimed at improving the economic efficiency of Chinese agriculture (CCP Central Committee, 1984). China is following a new strategy of greater specialization (through the "production responsibility system" and efforts to reform the economic structure of agriculture (Runsheng, 1984). In theory, crops will be grown where the conditions of soil and climate are most favorable. Production teams, the smallest farm level unit below brigades and communes, will have greater control over resources and decision-making and the freedom to sell products at "private" markets (Barker et al. 1982).

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However, for collectively owned communes, the Government will continue to use direct means, such as procurement quotas, and indirect techniques like credit control to manage production. For all farming systems, output targets and prices will still be set by the central government (Tuan and Crook, 1983).

Under this constraint, targets and prices may not reflect production costs and resource availability. A reallocation of resources to the best suited crops or crops mixes may be unlikely. The lack of labor mobility (due largely to few alternative jobs) may also become an increasingly serious source of inefficiency in agricultural production; although, there is the potential for households to engage in additional specialized contracts of production (Zili, Sp. 1984). Furthermore, pricing problems are evident. A surge in livestock production has resulted in overgrazed public lands and soil erosion (Pang and DeBoer, 1983). Some regions have profited and others have lost in real earnings because of insufficient farm production and losses in subsidies from the government. In some cases, households on state farms earn more than those on communes and vice-versa. Overall, there is no clear picture of actual opportunity costs for farm resources and optimal crop and livestock mixes for different regions of the country.

Without further remedial measures and/or improved information about the inefficiencies in farm production, further management decentralization may be thwarted before it gets off the ground. For now, some observers believe that recent policy changes will lead to a more rational allocation of resources, but that further improvement could be achieved if China were to adopt price and production planning based on Western concepts of comparative advantage (see Barker, Sisler and Rose, 1982). If anything, the effectiveness of policy

changes will depend on the ease with which technical and environmental constraints can be overcome.

This study develops a linear programming model for analysis of farm level production and the optimal pattern for resource allocation in Guyuan, a province in the northeastern part of China. Specifically, the model is used to determine the most efficient farm organization for the region and to estimate the "shadow prices"* of major inputs. The results are used to suggest ways to increase regional farm income and to assess policy options for promoting Guyuan's agricultural economy. For China, this is one of the first examples of linear programming applied to a regional analysis of farm efficiency.

THE SETTING

Guyuan is located in the Loess Plateau in the northeastern part of China. It is a relatively underdeveloped agricultural area with a serious problem of soil erosion and a rapidly growing population.

The land area of the region is 6,400 square kilometers, (i.e., 2,640.4 sq. miles), including cultivated land of 284,600 ha., forest 30,000 ha., natural pasture (in a poor condition) 253,000 ha., and other uses. The region has over 90 percent of its 506,900 people living in its rural sector. The population density of 79 persons per square kilometer, is less than those of other regions in China, however, a population growth of 2.7 percent per year puts heavy pressure on its limited land. Most land is

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*A shadow price technically implies an imputed price that is derived from the LP model. Its derivation is particularly important since input and product prices are not determined on a competitive basis matching supply and demand. In simple terms, the shadow price represents the opportunity cost of using the ith resource and is associated with the full utilization of the resource in the optimal solution of the LP model.

located between 1,500-1,800 meters in altitude. Of the cultivated land, there is lowland 165,940 ha., i.e., 58.3 percent of the total area; and highland 118,660 ha., i.e., 41.7 percent of the total area.

Poverty is extant in Guyuan with a low average annual income of about 100-150 yuan (i.e., $50-75) per capita and a very poor agricultural base. The annual average precipitation is 350-600 m.m., but it is difficult for the rainfall to be utilized efficiently, because of its uneven distribution within the year. Usually more than 60 percent of the rainfall concentrates in July, August, and September, during much of the harvesting period. Only 27 percent falls in April, May, and June, during the growing season. Sometimes it washes away large quantities of soil, worsening the erosion process. Other water resources are also very limited in the region. There are 65 sets of small reservoirs built for agricultural irrigation, but the average surface water flow is only three cubic meters per second.

The annual temperature, on average, is 6.3°C. The average temperature in the highest month (July), is 19°C, and in the lowest month (February), is -8.2°C. The growing season usually starts in May and ends in September. Damaging frosts tend to come early in the fall and late in the spring. Weather conditions are far from ideal.

In 1983, there were 36 communes in Guyuan. Each commune is divided into 7-15 brigades. Each brigade is divided into five or six production teams, the grassroot units as well as operating units of the commune. A production team usually consists of about 30 households, (approximately 200 persons), and owns about 114 ha. of cultivated land and other resources.

Communes account for most of China's agricultural enterprises. The communes have a type of socialist ownership in which the means of production such as equipment and land are collectively owned by farmers living within

commune boundaries. The production team, not the central Government is responsible for profit and losses and the Government bears no responsibility for compensating peasants for their farm work.

Until the mid-seventies, "direct planning" was used to regulate China's economic activity.* Agricultural production targets were formulated by the central Government and transmitted to basic production units, leaving little flexibility to these units to make economic decisions. This planning procedure was used to control the commune system during the Cultural Revolution (1966-1976) and is still being used to guide the state system of Government-owned farms.

"Indirect planning" is now implemented in the commune system. As before, production targets are approved by the central Government and are transmitted down the administrative hierarchy as far as the county level. But instead of requiring procurement quotas of production teams, the Government uses various economic measures such as procurement contracts, bonus systems, price policies, and credit and loans to adjust and guide production activities. Provision of marketing facilities and electricity are also used to guide farm leaders to make proper economic decisions.

Thus, Government plans, targets, and administrative orders continue to govern the Chinese agricultural economy, contrasting sharply with the U.S. farm economy where private farmers and business people monitor commodity markets, prices, and interest rates as they make production and marketing decisions. In China, it is difficult to come to any economically rational benefit-cost evaluation with respect to input uses, bearing in mind that the Chinese planning system is still very much dominated by physical targets.

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*For a detailed comparison of direct and indirect planning, see Tuan and Crook (1983).

Of more recent interest is the fact that at the local level, production teams have experimented with a wide variety of incentive schemes referred to as production-responsibility-systems. Different subsystems are used such as the production-responsibility scheme that is assigned to groups to labor. There are also the fractional contract-of-land; relative-to-production scheme; and the full-responsibility-to-household-systems, i.e., the "house contract system." Currently the last one has become the most prevalent type. Under such a system, each family is responsible for certain cultivated land or other items within the commune. The household negotiates with a production team to farm given parcels of cultivated land, to raise livestock, or to care for trees. They can deal with their own products at home or sell in the market after delivering a certain quantity of the output to fulfill the collective (team) obligations which are determined by the commune. The procurement rates differ according to different kinds of crops or animals.*

There are many rural consumer cooperatives in the region. Each commune has at least one cooperative to sell goods to or to buy farm products from. Usually about 60 percent of the grain products are consumed at home, 30 percent are sold to the government, through some special agencies, and less than 10 percent are sold in the marketplace. More than 80 percent of cash crops are sold to the government.

Some village markets operate in different places once a week or every 10 days, allowing the farmers to sell products at varying prices. But

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*According to Tuan and Crook (1983): "Other than required sales of agricultural commodities at fixed procurement prices, farmers are allowed to sell their remaining products to government purchasing stations at negotiated prices which range between the procurement and premium prices. Moreover, products grown or raised on private plots or privately produced by the commune members can be sold in small rural or town markets. The prices in these markets are negotiated between buyers and sellers within the limits set by the government" (p. 24).

generally, prices of farm products are fixed by the government in the state owned shops.

CURRENT PROBLEMS

The farmers' income in Guyuan is much lower than those in other regions of China, barely enough for food and to maintain the basic necessities of life.

The main agricultural problems of rural Guyuan are: (1) limited investment capital; (2) low crop yields; and (3) lack of knowledge and techniques of modern agriculture.

There is a branch of the National Agricultural Bank System in the region. A credit cooperative operates in each commune, providing loans for the farmers with low interest or without any interest. Farmers occasionally get subsidies from the government to meet the need of investment in agricultural production, even though the subsidy is very small relative to the need.

The crop yields, in general, are lower than the provincial or national average. For example, the average of 500 kg. per ha. of wheat is two-thirds less than the yield of that of the northeast region in which Guyuan is located; corn's average yield of 600 kg. per ha., i.e., 60 percent less than that of the region; millet's average yield is two-thirds lower than the regional average and oilseed's average yield is less than half that of the region.

Limited irrigation represents an important reason for the poor crop yields. There are only 15,000 ha. irrigated out of the 285,600 ha. of cultivated land. In addition, Guyuan has two different types of unirrigated land area, the lowland and the upland. Each area is different in terms of the

sun, soil and rainfall patterns and, hence, different cropping patterns and yields.

Another problem is low utilization of fertilizer. Farmers rarely use fertilizer in the fields. Crop residues and animal dung are used as fuel at home (especially in winter). Some manure is available for wheat, potato, corn, and millets in small quantities during the rest of the year. Most unirrigated crops do not receive any fertilizer at all. Lack of improved crop varieties and little attention to disease control are other important factors contributing to the low crop yields.

The Cultural Revolution not only compounded problems by exacting quotas in Guyuan, but also foresook the collection of data and research to determine the proper cropping and livestock patterns for the region (Blase et al. 1982). Development was hampered by policies of national self-reliance which limited specialization, fixed boundaries of communal farms, enforced immobility of labor, and transportation bottlenecks. Problems which have not been entirely resolved.

However, with the relaxation of policies since the mid-seventies, agricultural research has commenced and data has been collected to estimate the costs and returns to farm production in various regions of China. One such study is that of Feng-Shu Zhu (1981), which forms the basis for this study and analysis.

In this study, the principal objective is to test if resources are allocated in optimal combinations and to derive answers to the following questions:

- are the irrigated and unirrigated areas (both upland and lowland) producing the optimal combinations of crops?

- what are the socio-economic returns (shadow prices) of the resources employed?
- should more (or less) livestock be produced in the region of Guyuan? and
- are resources for crops being used optimally and/or what adjustments or improvements are recommended for Guyuan?

METHOD OF ANALYSIS

A linear programming model is formulated to determine the optimum resource allocation among a specified number of farm activities for the region of Guyuan. The model is formulated on the basis of one year and developed with the following mathematical construction.* The primal function is as follows:

$$\text{Max:} \quad Z = \sum_{j=1}^{22} C_j X_j \qquad j = 1, 2, \ldots, 22$$

$$\text{S.T.} \quad \sum_{j=1}^{22} a_{ij} X_j \leq b_i \qquad i = 1, 2, \ldots, 27$$

and $X_j \geq 0$,

where Z = The total farm income (yuan = \$0.53)

C_j = The farm income from one unit of jth activity

X_j = The level of activity of jth process

a_{ij} = The technical coefficient relating the fraction of the ith resource used in one unit of jth activity

b_i = The quantity available of ith resource.

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*For a similar application, see Andrews *et al*. 1976.

Zhu's study (1981) has identified 22 kinds of production activity for irrigated/unirrigated land as well as lowland/upland conditions. Crops that are fertilized are also identified separately. The production activities are as follows:*

X_1 area of wheat irrigated

X_2 area of oilseed irrigated

X_3 area of corn irrigated

X_4 area of millet A irrigated

X_5 area of wheat unirrigated

X_6 area of oilseed unirrigated

X_7 area of potato unirrigated

X_8 area of millet A**/ unirrigated

X_9 area of millet B**/ unirrigated

X_{10} area of oats unirrigated

X_{11} area of alfalfa unirrigated

X_{12} area of barley unirrigated

X_{13} area of oilseed unirrigated in upland

X_{14} area of oats unirrigated in upland

X_{15} area of grass unirrigated in upland

X_{16} area of wheat unirrigated, fertilizer added

X_{17} area of oilseed unirrigated, fertilizer added

X_{18} area of millet A unirrigated, fertilizer added

X_{19} area of oats unirrigated, fertilizer added

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*Land area in hectares.

**Millet A and millet B are different varieties.

X_{20} number of cow

X_{21} number of sheep (and goats)

X_{22} number of pigs

It is assumed that there are 27 resource constraints covering available labor, land, and capital. There are an estimated 164,000 laborers (males and females) in Guyuan. It is assumed that each laborer can work on the farm for 25 days per month and nine months per year. So, in total, we assume 36,900,000 man-days available. The list of resource constraints for each of the activities is as follows:*

b_1 $X_1 + X_2 + X_3 + X_4 \leq 15{,}000$ (irrigated land)

b_2 $X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} \leq 150{,}940$ (unirrigated land)

b_3 $X_{13} + X_{14} + X_{15} \leq 118{,}660$ (upland)

b_4 $X_1 \geq 4{,}500$ (LL, i.e., lower limit, of wheat irrigated)

b_5 $X_2 \leq 3{,}000$ (UL, i.e., upper limit, of oilseed irrigated)

b_6 $X_3 \geq 1{,}500$ (LL of corn irrigated)

b_7 $X_4 \geq 3{,}000$ (LL of millet A irrigated)

b_8 $X_5 \geq 30{,}000$ (UL of oilseed unirrigated)

b_9 $X_6 \leq 30{,}000$ (UL of oilseed unirrigated)

b_{10} $X_7 \geq 15{,}000$ (LL of potato unirrigated)

b_{11} $X_8 \geq 5{,}000$ (LL of millet A unirrigated)

b_{12} $X_9 \leq 15{,}000$ (UL of millet B unirrigated)

b_{13} $X_{10} \geq 7{,}000$ (LL of oats unirrigated)

b_{14} $X_{11} \geq 22{,}000$ (LL of alfalfa unirrigated)

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*Note that LL is the "lower limit" and UL the "upper limit" of resource constraint.

b_{15} $X_{12} \geq 0$ (UL of barley unirrigated)

b_{16} $X_1 + X_2 + X_3 + X_4 \leq 2{,}500{,}000$ (UL of labor for irrigated land)

b_{17} $X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} \leq 25{,}000{,}000$ (UL of labor for unirrigated land)

b_{18} $X_{13} + X_{14} + X_{15} \leq 9{,}400{,}000$ (UL of labor in upland)

b_{19} $X_1 + X_2 + X_9 + X_{10} + X_{12} + X_{14} + X_{15} + X_{16} + X_{17} + X_{18} + X_{19} + X_{20} + X_{21} + X_{22} \leq 4{,}000{,}000$ (UL of labor for May)

b_{20} $X_1 + X_2 + X_3 + \ldots X_{22} \leq 4{,}000{,}000$ (UL of labor in June)

b_{21} $X_1 + X_2 + X_3 + \ldots X_{22} \leq 4{,}000{,}000$ (UL of labor in August)

b_{22} $X_3 + X_4 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{13} + X_{14} + X_{15} + X_{17} + X_{18} + X_{19} + X_{20} + X_{21} + X_{22} \leq 4{,}000{,}000$ (UL of labor in September)

b_{23} $X_{16} + X_{17} + X_{18} + X_{19} + X_{20} + X_{21} + X_{22} \leq 1{,}000{,}000$ (UL of capital)

b24 $-.6\ X_{11} + X_{20} \leq 0$ (Alfalfa for cow)

b25 $.67\ X_{22} \leq 253{,}000$ (UL of sheep)

b26 $-.02\ X_7 + X_{23} \leq 100{,}000$ (UL of pigs)

b27 $-X_{19} + X_{22} \leq 0$ (Oats for cow)

Table 1 of this report summarizes the format used in this model.

THE RESULTS

The Primal Solution

The linear programming problem outlined above was solved under the objective function for profit maximization. The sum of farm income to be maximized in Guyuan is 82,803,386 yuan. Table 1 shows a summary of the net return per activity where we have row Z-C. The optimal contribution of each activity to the region's income is as follows:

Table 1. Schematic Picture of the L.P. Matrix

	Activities																						Constraints
	Irrigated Land				Unirrigated Land								Upland			Unirrig. Land Fer.				Livestock			
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}	X_{20}	X_{21}	X_{22}	
Irrigated Land	1	1	1	1																			$\leq$ 15,000 b_1
Unirrigated Land					1	1	1	1	1	1	1	1				1	1	1	1				$\leq$ 150,940 b_2
Upland													1	1	1								$\leq$ 118,660 b_3
Wheat Irrig.	1																						$\geq$ 4,500 b_4
Oilseed Irrig.		1																					$\leq$ 3,000 b_5
Corn Irrig.			1																				$\geq$ 1,500 b_6
Millet A Irrig.				1																			$\geq$ 3,000 b_7
Wheat Unirrig.					1																		$\geq$ 30,000 b_8
Oilseed Unirrig.						1																	$\leq$ 30,000 b_9
Potato Unirrig.							1																$\geq$ 15,000 b_{10}
Millet A Unirrig.								1															$\geq$ 5,000 b_{11}
Millet B Unirrig.									1														$\leq$ 15,000 b_{12}
Oats Unirrig.										1													$\geq$ 7,000 b_{13}
Alfalfa Unirrig.											1												$\geq$ 22,000 b_{14}
Barley Unirrig.												1											$\geq$ 0 b_{15}
Labor per unit	120	120	150	180																			$\leq$2,500,000 b_{16}
Labor per unit					110	90	138	160	70	70	100	100				120	100	175	80				$\leq$2,500,000 b_{17}
Labor per unit													70	50	50								$\leq$9,400,000 b_{18}
Labor in May	20	15	0	0	20	10	0	0	0	10	0	20	0	15	8	20	10	0	10	60	1	3	$\leq$4,000,000 b_{19}
Labor in June	15	15	20	20	5	5	30	15	10	5	5	5	15	5	8	8	5	15	8	60	1	3	$\leq$4,000,000 b_{20}
Labor in August	20	20	5	20	10	15	10	5	5	5	5	20	5	5	8	20	5	8	8	60	1	3	$\leq$4,000,000 b_{21}
Labor in Sept.	0	0	20	20	0	0	30	20	15	15	15	0	15	15	8	0	15	20	15	60	1	3	$\leq$4,000,000 b_{22}
Capital																30	30	20	20	250		2	$\leq$1,000,000 b_{23}
Alfalfa for cow											-.6									1			$\leq$ 0 b_{24}
Pasture																					.67		$\leq$ 253,000 b_{25}
Potato for pigs							-.02															1	$\leq$ 100,000 b_{26}
Oats for cow																			-1	1			$\leq$ 0 b_{27}
Ret. per unit (Z)	990	1045	888	400	528	570	490	300	180	160	200	440	190	80	250	660	760	432	200	1200	40	150	
Net return (Z-C)	530	715	490	150	237	392	154	75	60	100	140	126	40	10	150	310	460	85	150	800	30	80	

$$\text{Max } Z = 530\ X_1 + 715\ X_2 + 490\ X_3 + 150\ X_4 + 237\ X_5 + 392\ X_6 + 154\ X_7 + 75\ X_8 + 60\ X_9 + 100\ X_{10} + 140\ X_{11} + 126\ X_{12} + 40\ X_{13} + 10\ X_{14} + 150\ X_{15} + 310\ X_{16} + 460\ X_{17} + 85\ X_{18} + 150\ X_{19} + 800\ X_{20} + 30\ X_{21} + 80\ X_{22}.$$

The net values for each activity of this function are derived by subtracting costs of production for each activity in Guyuan (1981) from the Z values of Table 1. The average costs of production are provided in Table 2 and are derived from research conducted by the principal author in the region. The results show that the profitable (optimal) crops are oilseed, wheat, corn and millet A, which should be grown to the capacity of irrigated land as follows: 3,000 ha., 7,500 ha., 1,500 ha., and 3,000 ha., i.e., 20 percent, 50 percent, 10 percent and 20 percent of the total irrigated land area. On unirrigated land, the optimal combination of crops should be wheat, oilseed, potato, millet A, alfalfa and oats; grown to the capacity of the land as follows: 75,979 ha., 30,000 ha., 15,000 ha., 22,000 ha., and 2,960 ha.; i.e., 50.3 percent, 19.9 percent, 9.9 percent, 3.3 percent, 14.6 percent and 2.0 percent of the total unirrigated area, respectively. In general, these results are summarized in Table 3. It also shows several activities which should not be produced in the region given the assumptions indicated above.

With regard to the upland, grass (activity 15, Table 3) is the most profitable to be grown. Therefore, much feed would be provided to raise additional sheep and goats possibly to 470,000 head. We note, however, that the natural pasture appears to be "overgrazed" with nearly 380,000 sheep and goats (activity 21, Table 3) optimally identified for the region.

An optimal allocation in Guyuan would also include 2,960 cows and 100,329 pigs, (activities 20 and 22, Table 3).

Table 2. Yield and Cost of Main Kinds of Crops Produced in Guyuan (1983)

Items	Unit	Wheat		Oilseed		Potato Unirrigated	Millet Unirrigated
		Irrigated	Unirrigated	Irrigated	Unirrigated		
yield	kg/ha	3,000	1,650	1,100	600	7,000	1,800
price	yuan/kg	0.33	0.33	0.95	0.95	0.07	0.24
return	yuan/ha	990	528	1,045	570	490	432
cost: labor	yuan/ha	210	160	172	99	198	240
seed	yuan/ha	61	33	27	18	40	9
fertil.	yuan/ha	83	18	28	8	40	62
animal power	yuan/ha	90	72	87	47	56	28
machine	yuan/ha	8	NA	8	NA	NA	NA
misc.	yuan/ha	8	8	8	6	6	8
total	yuan/ha	460	291	330	178	340	347
profit	yuan/ha	530	237	715	392	150	85

Source: Zhu, 1981.

Table 3. Optimal Resource Allocation*

Activity		Optimal Land Resource	Obj. Gradient	Reduced Gradient
1. Wheat Irr	BS	7500.00000	530.00000	0.00000
2. Oilseed Irr	BS	3000.00000	715.00000	0.00000
3. Corn Irr	BS	1500.00000	490.00000	0.00000
4. Millet Irr	BS	3000.00000	150.00000	0.00000
5. Wheat Uni	BS	75979.47448	237.00000	0.00000
6. Oilseed Uni	BS	30000.00000	392.00000	0.00000
7. Potato Uni	BS	15000.00000	154.00000	0.00000
8. Millet Uni	BS	5000.00000	75.00000	0.00000
9. Millet B Uni	LL	0.00000	60.00000	-177.00000
10. Oat Uni	LL	0.00000	100.00000	-137.00000
11. Alfalfa Uni	BS	22000.00000	140.00000	0.00000
12. Barley Uni	BS	0.00000	126.00000	0.00000
13. Oilseed Uplan	LL	0.00000	40.00000	-110.00000
14. Oat Uplan	LL	0.00000	10.00000	-140.00000
15. Grass Uplan	BS	118660.00000	150.00000	0.00000
16. Wheat Fer	LL	0.00000	310.00000	-6.22222
17. Oilseed Fer	LL	0.00000	460.00000	-11.22222
18. Millet Fer	LL	0.00000	85.00000	-42.81481
19. Oats Fer	BS	2960.51852	150.00000	0.00000
20. Cow	BS	2960.51852	800.00000	0.00000
21. Sheep	BS	377611.93089	30.00000	0.00000
22. Pig	BS	100329.99999	80.00000	0.00000
23. RHS1	EQ	-1.00000	0.00000	-82803386.85293

*BS = basic solution
UL = upper limit
LL = lower limit
Irr = irrigated
Uni = unirrigated
Uplan = upland
Fer = fertilizer

In the optimal crop mix, wheat increases to 10,000 ha., alfalfa increases to 20,000 ha., grassland increases to 118,666 ha., oilseed decreases to 30,000 ha., millet decreases to 50,000 ha., oats decrease to 70,000 ha., and corn and potato stay at the same levels, compared with the actual crop mix.

The Dual Solution

The dual of the primal problem of maximizing profits for the region is to minimize the total cost or values imputed to all resources used in the crop and livestock production.* The dual problem is as follows:

$$\text{Min } P = \sum_{i=1}^{27} b_i Y_i \qquad i=1, 2, \ldots, 27$$

$$\text{S.T.} \quad \sum_{i=1}^{27} a_{ij} Y_i \geq c_j \qquad j=1, 2, \ldots, 22$$

$$\text{and } Y_i \geq 0$$

where P = The imputed value of the resources

b_i = The quantity available of the ith resource

a_{ij} = The ith resource or input used in the jth activity

Y_i = The shadow price (or the marginal value product)

c_j = The marginal revenue of the jth activity

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*There is direct correspondence between the primal and dual solutions. The primal is to maximize profits by finding the optimal output levels. This is tantamount to minimizing the total imputed value or opportunity cost of the resources used with the proviso that the opportunity cost of production of each output must be no less than the gross profit from that output. That is, the total gross profit must be imputed or allocated in its entirety to the resources in the region via the shadow prices.

The optimal value for the dual function is equal to 82,803,386 yuan. The minimum cost resource combination is as follows:

$$\begin{aligned}\text{Min } P = {} & 15{,}000\ Y_1 + 150{,}940\ Y_2 + 118{,}660\ Y_3 + 7{,}500\ Y_4 + 3{,}000\ Y_5 \\ & + 1{,}500\ Y_6 + 3{,}000\ Y_7 + 75{,}980\ Y_8 + 30{,}000\ Y_9 + 15{,}000\ Y_{10} \\ & + 5{,}000\ Y_{11} + 0\ Y_{12} + 2{,}960.52\ Y_{13} + 22{,}000\ Y_{14} + 0\ Y_{15} \\ & + 2{,}025{,}000\ Y_{16} + 1{,}634{,}584.37\ Y_{17} + 5{,}933{,}000\ Y_{18} \\ & + 3{,}469{,}810.48\ Y_{19} + 3{,}241{,}594.6\ Y_{20} + 3{,}936{,}389.45\ Y_{21} \\ & + 2{,}819{,}920.82\ Y_{22} + 1{,}000{,}000\ Y_{23} - 10{,}239.48\ Y_{24} \\ & + 253{,}000\ Y_{25} + 100{,}000\ Y_{26} + 0\ Y_{27}\end{aligned}$$

where

$Y_1 = 530$	$Y_2 = 237$	$Y_3 = 150$	$Y_4 = 0$
$Y_5 = 185$	$Y_6 = -38.5$	$Y_7 = -380$	$Y_8 = 0$
$Y_9 = 155$	$Y_{10} = -81.5$	$Y_{11} = -162$	$Y_{12} = 0$
$Y_{13} = 0$	$Y_{14} = -97$	$Y_{15} = -111$	$Y_{16} = 0$
$Y_{17} = 0$	$Y_{18} = 0$	$Y_{19} = 0$	$Y_{20} = 0$
$Y_{21} = 0$	$Y_{22} = 0$	$Y_{23} = 2.6$	$Y_{24} = 0$
$Y_{25} = 44.7$	$Y_{26} = 74.7$	$Y_{27} = 139.8$	

The dual solution shows, for example, that one unit of additional irrigated land would increase return by 530 yuan, one unit of additional unirrigated land would increase return by 237 yuan and one unit of upland would increase profit by 150 yuan. The entire list of Y_i values comes from the right hand column of Table 4. One more unit of irrigated or unirrigated oilseed, more units of capital invested, more cows, sheep and pigs would all increase economic returns to the region's resources. Any more units of unirrigated millet B, unirrigated oats, upland oilseed or oats, unirrigated wheat with much fertilizer, unirrigated oilseed with much fertilizer, and

Table 4. Resource Constraints and Dual Activity*

Constraints		AT	Activity	Slack Activity	Dual Activity**
	B_0	BS	82803386.85293	-82803386.85293	1.00000
Irr Land	B_1	UL	15000.00000	0.00000	-530.00000
Uni Land	B_2	UL	150940.00000	0.00000	-237.00000
Upland	B_3	UL	118660.00000	0.00000	-150.00000
Wheat Irr	B_4	BS	7500.00000	-3000.00000	0.00000
Oilseed Irr	B_5	UL	3000.00000	0.00000	-185.00000
Corn Irr	B_6	LL	1500.00000	0.00000	38.50563
Millet Irr	B_7	LL	3000.00000	0.00000	380.00000
Wheat Uni	B_8	BS	75979.47448	-45979.47448	0.00000
Oilseed Uni	B_9	UL	30000.00000	0.00000	-155.00000
Potato Uni	B_{10}	LL	15000.00000	0.00000	81.50563
Millet Uni	B_{11}	LL	5000.00000	0.00000	162.00000
Millet B Uni	B_{12}	BS	0.00000	15000.00000	0.00000
Oats Uni	B_{13}	BS	2960.51852	-2960.51852	0.00000
Alfalfa Uni	B_{14}	LL	22000.00000	0.00000	97.00000
Barley Uni	B_{15}	LL	0.00700	0.00000	111.00000
Labor Irr	B_{16}	BS	2025000.00000	475000.00000	0.00000
Labor Uni	B_{17}	BS	16364584.37444	8635415.62556	0.00000
Labor Uplan	B_{18}	BS	5933000.00000	3467000.00000	0.00000
May Labor	B_{19}	BS	3469810.48439	530189.51561	0.00000
June Labor	B_{20}	BS	3241594.59754	758405.40246	0.00000
August Labor	B_{21}	BS	3936389.44735	63610.55265	0.00000
September Labor	B_{22}	BS	2819920.81976	1180079.18024	0.00000
Capital	B_{23}	UL	1000000.00000	0.00000	-2.64074
Cow Alfalfa	B_{24}	BS	-10239.48201	10239.48201	0.00000
Manure	B_{25}	UL	253000.00000	0.00000	-44.77612
Pig Potato	B_{26}	UL	100000.00000	0.00000	-74.71852
Cow Oats	B_{27}	UL	0.00000	0.00000	-139.81481

*See footnotes to Table 3.
**Shadow Prices

unirrigated millet A with much fertilizer would all reduce the amount of expected return in different rates, respectively.

Because land cannot be sold among farmers in China, people do not know what the real price is. It is difficult to compare the shadow price with the actual price of land. The shadow price of man-days of labor is equal to zero, indicating that additional workers would not contribute to the amount of expected economic return. The shadow price of capital is 2.64 yuan, i.e., each additional unit of capital would increase economic returns by 2.64 yuan.

Thus, there is a labor surplus, especially out of the growing season. In the harvest season--August, there are 63,610 man-days of labor unused.

Capital is a limiting resource. The investment of 1 million yuan is at the upper limit (UL). If capital could be increased to at least 5 million, then the economic return to Guyuan would be maximized.

SUMMARY AND RECOMMENDATIONS

In this study, a programming methodology has been developed and applied to the region of Guyuan. The method determines the optimum production and maximum profit subject to certain contraints such as irrigated and unirrigated land area, man-days of labor available, especially with regard to growing season, harvesting season, and capital available. The model covers one year.

Analysis of the primal problem yielded an optimal solution for achieving a profit of 82,803,386 yuan from crop and livestock production. The optimal allocation of resources for these crops and livestock is derived from a set of shadow prices (imputed marginal values) using the dual solution. The dual problem is to minimize the total value imputed to all resources used in crop and livestock production which, in turn, yielded an optimal solution of 82,803,386 yuan.

The cost of labor was estimated according to the local standard of living of the farmer. Other data was collected directly or indirectly from the region during 1981 by the first author.

The results of the model provide several recommendations:

Expanded Irrigation Would be Profitable for the Region

Controlled water supply in the region is a major constraint. Zhu has shown (1981) that the irrigated area could be expanded to at least double the current area.* This study shows that resources are used optimally and crops yield highest returns under irrigated conditions. If irrigation was expanded we could imagine additional savings to the project if erosion was stopped. Sprinkler irrigation might also be a feasible alternative for the lowlands in Guyuan. It could possibly enhance the use of labor and land. Overall, our analysis shows that additional irrigated land to 15,000 ha. would increase the region's expected return by a sum of 4,400,000 yuan.

Additional Fertilizer Should be Utilized*

The marginal value product of additional fertilizer is high in the region studied. The data show that additional fertilizer would increase the crop returns by 10 to 50 percent, even more on unirrigated land for some crops.

Currently, the poor soil structure and fertility in the region seriously affects crop growth. The soil fertility has been minimally maintained with applications of organic material--primarily nightsoils, animal manures, crop residues etc. As mentioned before, the farmers' competing demands, especially for fuel, have diverted increasing amounts of organic material to nonfarm uses. Added fertilizer (with adequate water supply) may be the easiest, as

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*For an assessment at the macro-level, see Kueh, 1984.

well as the quickest, method to increase agricultural output and yields. Further study is needed also for Guyuan to find alternative sources of fuel and ways to enhance fertilizer use on crops.

Reforestation and Improvement of Grazing Land

Because of the shortage of vegetation cover in the area, there is serious soil erosion in Guyuan. Hence, low yields of crops occur. There is a large amount of submarginal agricultural land especially in the upland. The results of the model suggest that some land that has been cultivated in the uplands could be profitably returned to grassland for grazing purposes. Upland livestock could utilize marginal land area that could not support field crops. If additional land is returned to livestock production the returns to the region could be increased. According to the study, each ha. of grazing land yields a greater return by 150 yuan, compared to 10-40 yuan from cultivated upland farms.

To plant more and more trees and to expand grassland area would improve natural pasture and ameliorate the problem of erosion. This recommendation is in line with past policies of the government and is shown to be a profitable option for the region.

Accelerate the Diffusion of Better Crop and Animal Varieties

The data does not provide a direct suggestion for crop varieties or livestock types, but to the best of our knowledge, better varieties of crops and livestock could be beneficial for the region.

In recent years, more and more farmers in Guyuan have been trying to improve the quality of crops and animals, as well as gain new knowledge about better farming practices. The study suggests that the major characteristics of the favorable varieties should be high yields, short growing periods,

resistance to drought and diseases, and more fodder to feed farm livestock. Highest returns could come from improved wheat and alfalfa crops. The existing agricultural research institute, with the agricultural extension station, the extension units for husbandry and veterinary medicine, and the station of agricultural management, should continue their research and expand ties with farmers in an effort to add qualitative improvements in the region's farms.

To Develop the Rural Employment and Services

It is evident that the results of this research could be complemented by further study regarding other potential economic activities for the region's people. The zero shadow price for labor indicates the availability of excess "redundant" labor that can be employed in other ways, without lowering the region's production of crops and livestock. Beyond the crop and animal production, farmers could furthermore engage in processing farm products, in small industries, transportation, marketing and related business activities. Additional local centers could facilitate more public services, especially to provide more job opportunities for the surplus laborers. There are approximately 12 to 17 million man-days of surplus labor. This labor could contribute from 18 to 43 million yuan to Guyuan, if more fully utilized in remunerative activities. Labor continues to represent a tremendous resource with the potential for large economic returns. Unless development policies can be enacted to engage surplus labor within the countryside in productive activities outside farming, it is unlikely that farming alone will secure an adequate living for all of Guyuan's families.

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