Impact of nitrate fertilizer restrictions on Salt River Project and Roosevelt Water Conservation District growers.

IMPACT OF NITRATE FERTILIZER RESTRICTIONS ON SALT RIVER PROJECT AND ROOSEVELT WATER CONSERVATION DISTRICT GROWERS

by

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March 25 1974
Date

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ABSTRACT

Environmental pollution has become one of the most important of society's problems and the extent of this problem continues to grow every day. Society, through an extreme concern for pollution, is beginning to construct policies, laws, and institutions to deal with this problem. Unfortunately, in many cases, laws are being enacted, policies developed, and institutions built or modified to combat pollution without full knowledge of the parameters of the system upon which they must operate.

Several types of regulatory programs may be imposed by government to control farm pollution. For example, regulations may take the form of restrictions upon inputs used in production, land use, and waste disposal practices. All of these controls have potentially significant effects upon farm operation and costs of production. An important aspect of this problem is the probable economic impact of such restrictions upon the agricultural industry and upon individual producers.

This study investigates the economic impact of nitrate fertilizer restrictions on Arizona's Salt River Project and Roosevelt Water Conservation District growers. A procedure to identify this impact, incorporating

production functions and a linear programming formulation was utilized.

The integrated model is described, the results for the irrigation districts are presented, and tentative implications drawn. Limitations of the study and additional research possibilities are also outlined.

CHAPTER I

INTRODUCTION

Modern agriculture occupies an increasingly interdependent role with other sectors of an economy. In the United States, this close relationship results because of technological changes in farming and the commercialization of agriculture which has occurred in the past two decades. Industry provides many of the inputs which improve farm production and at the same time purchases farm commodities for processing into final food products. The farmer, for his part, has become dependent upon new technology and has rearranged his input mix to include more and more new inputs.

One result of the supportive relationship between industry and agriculture has been an increase in total farm output and a reduced level of traditionally important agricultural factors of production. For example, the farm labor force in 1968 was less than half the level of 1950, mechanical power and machinery are up about one-third and fertilizer and liming material inputs have increased by over three times in the past twenty years. Total estimated physical inputs have risen only about ten per cent since 1950, yet output has climbed over forty per cent indicating the increased efficiency of production. As farms continue to

grow larger, become more capital intensive, and employ increasing quantities of inputs from other sectors, the interdependence between the agricultural and industrial sectors will be accentuated.

Fertilizer is a major farm input purchased from the industrial sector. The use of fertilizer has increased at a seven and one-half per cent compound annual growth since 1950. During the 1960's the consumption of plant nutrients exceeded this rate, reaching 12-13 per cent increases in 1966 and 1967. In 1968, total plant nutrient consumption increased 7 per cent over 1967. In more specific terms, the total of all fertilizer materials consumed in the U. S. reached 38.5 million tons in 1968, more than double the tonnage used in 1950. Plant nutrient consumption reached almost 15 million tons or four times the nutrient consumption of 1950 (Fertilizer Trends, 1969).

Nitrogen consumption in the United States is increasing more rapidly than the other primary plant nutrients (phosphorus and potash). Total consumption is now almost 7 million tons with 4.8 million applied as direct applications material. In 1968, direct application accounted for over 555,000 of the 667,000 ton increase in nitrogen consumption above 1967 consumption.

Consumption of nitrate fertilizers in Arizona also increased more rapidly than the other plant nutrients. Total consumption is now almost 85 thousand tons with 79

thousand tons applied as direct application materials. These materials account for over 25 hundred of the 29 hundred ton increase in nitrogen production between 1967 and 1968 (Fertilizer Summary Data, 1968). This increased use of fertilizers, nitrogen in particular, has contributed to a larger supply of food produced at a lower real cost to consumers.

As long as the goals of the nation regarding the agricultural sector remain those of production efficiency and lower food costs, the interaction of the agricultural sector with related industries had been successful. Moreover, the increased use of new and more productive inputs coincided closely with the farmer's desire to increase his income and the consumer's desire for lower food costs. Under these circumstances, the unrestricted use of new inputs was accepted by both agriculturalists and the public at large as a means to achieve these ends. However, in part due to the success that has been achieved in this area, the same public now turns its attention to the side-effects associated with the unrestricted use of these new inputs. Considerable attention has focused on items such as pesticide residues in milk, growth stimulant residues in beef, effects of insecticides on bird populations, and herbicide effects on fish in streams and reservoirs. The recent bans on the growth stimulant "DES" and "DDT" are specific examples. Contemporary concern with deteriorating

environmental quality has also focused public attention upon the ramifications of heavy use of inorganic fertilizers. Regulation of fertilizer use is, therefore, a likely possibility.

The principal danger associated with fertilizer utilization is a potential harmful effect upon public health. If excess amounts of nitrates percolate through the soil to the water table or collect in lakes and reservoirs, the source of drinking water may become contaminated and unfit for human and animal consumption. When man or animals ingest too much nitrate nitrogen, the blood cannot supply cells with adequate oxygen and a condition similar to asphyxiation occurs. Also, farm animals have been observed to have high abortion rates, diarrhea, decreased appetite, and reduced production performance when fed too much nitrate nitrogen (Collected Papers Regarding Nitrates in Agricultural Waste Water, 1969).

In laboratory experiments, it has been found that bacteria can convert "nitrates" to "nitrites," which are raw materials for cancer-causing chemicals. Nitrates react with two common nutrients, creatine and a related chemical creatinine, to create a known corcinogen. Creatine is found in muscle tissue and is a normal constituent of meat. Cells convert creatine to creatinine, which is found in meat, milk, and blood as well as grain, certain vegetables, and crab meat. There is good reason, therefore, to be concerned

about the quality of groundwater, which may eventually be a source of drinking water (Clark, Thilly, and Tannenbaum, 1971).

Recent studies have linked nitrogen in water supplies to agricultural activity. Farms in the San Joaquin Valley of California have been found to contribute as much as 109 pounds of nitrogen per acre to the local water drainage system (Wadleigh, 1970). St. Louis scientists from the Center for Biology of Natural Systems at Washington University attempted to find out how much of the nitrogen chemicals (nitrates) found in man-made Lake Decatur, the drinking water reservoir for Decatur, Illinois, came from nitrogen fertilizers. They concluded that at least 55 per cent of the nitrogen chemicals discovered in the lake in the spring of 1970, the period when fertilizers are applied to the corn crop, came from fertilizers being washed into the watershed (Kohl, Shearer, and Commoner, 1971).

A study now underway by the Agricultural Research Service is measuring the nitrogen level in field drains of the Imperial Valley of California, a valley with large acreages of truck crops. High levels of nitrogen are applied to many of the Imperial Valley soils, in some instances as much as 800 pounds per acre. Preliminary results indicate that nitrate residues may attain rather high levels at shallow soil depths; but at lower depths most of the nitrate disappears (Wadleigh, 1970). These results

suggest that denitrification results when nitrogen reaches the water table. Denitrification occurs in soils where there is (1) lack of free oxygen (anaerobic conditions), (2) food for bacteria (crop residues), and (3) nitrate (from fertilizer and natural sources). Under anaerobic conditions free oxygen is lacking for bacterial metabolism so microbes break down the nitrate (NO_3), using part of the osygen in the molecule for respiration. The part of the molecule that is left disperses as nitrogen gas and gaseous oxides of nitrogen. It is hoped that the ARS study will help set guidelines for depths of tile drainage systems.

The Problem

Although evidence exists to show that fertilizer can contribute to the levels of nitrate found in surface and underground water supplies, it should be recognized that fertilizers are not the only possible source of this nitrate. Natural sources such as rainfall and symbiotic nitrate produced from the association of two dissimilar organisms are also potential contributors to the nitrogen found in soil-water environments. Rainfall or snow, in non-industrial regions, adds a few pounds of nitrogen and sulphur each year. Some kinds of microorganisms living in the soil are able to take nitrogen gas from the air and incorporate it into organic nitrogen compounds. Manure, compost, sewage, and other plant or animal residues all

contain some of the eseential plant nutrients which originally came from the soil. Thus, there are many sources of the nitrate which could contaminate ground and surface water supplies. Few attempts have been made to determine the contribution of each source to changes in water quality. As a result, there is no general agreement on the actual relationship between fertilizer usage and the concentration of nitrates found in water.

If nitrate nitrogen was found to be polluting water in Arizona, with agreement on the pollution-nitrate relationship, what would be the procedure for establishing publicly acceptable levels of nitrates or tolerance levels? In past cases of farm pollutants (i.e., pesticides, herbicides, and growth stimulants), the procedure followed was to establish tolerance levels to minimize any potential side-effects on the environment, wildlife, or human population. These tolerance levels have often represented a compromise between the conflicting goals of improved farm production efficiency and public health standards. Residue tolerance levels for chemical use are usually established only after long and arduous evaluation of all aspects of their use, and these include economic considerations as well as human well-being. To preclude or limit the use of an agricultural input as important as nitrate fertilizer may raise the cost of food and reduce human well-being as much as allowing the unlimited use of the chemical. Moreover, any regulatory

scheme will have to take into account the particular physical and economic characteristics of agricultural regions as well as the incidence of alternative impacts. A balance must be struck between over-use which may be harmful and elimination of its use which could also have serious detrimental consequences.

As pointed out, there is conflicting evidence pertaining to application levels of nitrogen fertilizers which cause harmful side effects. The process of gathering the data necessary to indicate the degree of nitrate pollution to be expected with alternative rates of fertilizer use, under various climatic and soil conditions, may be time-consuming. In addition, there may be a considerable time lag between experimental results and the establishment of the conclusive evidence necessary for general agreement on tolerance levels. In the meantime, the emotional fervor which surrounds questions of environmental quality could result in public action to assure that real or suspected hazards to public health are removed. It is conceivable that legislation at state and federal levels could be enacted at any time to limit or reduce the amount of nitrate fertilizers which farmers may use.

In a haste to "do something," laws, or regulations, controlling fertilizer use might be implemented without full knowledge of the resulting physical and economic consequences. Undesirable effects include increased costs of

farm production, reduced food output, and unworkable laws and costly litigation. These in turn could have a serious impact on consumer food costs, farm and agricultural sector income, as well as farm management and resource utilization practices. The type of crops grown could shift from high nitrate using crops to low nitrate users. A realignment of production factors and changes in output and costs could easily decrease net farm incomes. Under these conditions, it is conceivable that some growers could be forced out of business. The degree to which legislation would adversely affect growers and perhaps the producers' commodities in related economic sectors depends upon the nature of the laws governing the restrictions. It becomes critical to have economic information which will aid in the establishment of fertilizer restriction policies, should they be needed.

Research Objectives

The agricultural area adjacent to metropolitan Phoenix, Arizona is a case in point where public concern may encourage restrictions on nitrate fertilizer use. This situation arises due to an intensified farm sector operating in close proximity to a rapidly growing metropolitan area. In the Phoenix area, it is possible that the water resources of the city are polluted by the nitrate fertilizers from the agricultural sector. There are two major irrigation districts that service the agricultural sector, the Salt River

Project (SRP) and the Roosevelt Water Conservation District (RWCD).

The principal objective of this study is to measure the probable short run economic consequences of alternative nitrate fertilizer restrictions on Salt River Project and Roosevelt Water Conservation District growers. Two forms of fertilizer restrictions will be examined: (1) rate limits on a per acre basis, and (2) application limits on a total farm basis. Although total farm restrictions cannot control per acre nitrogen concentrations, they can restrict a region to prescribed fertilizer usage; therefore, this approach is examined as a policy alternative to per acre limits. In order to determine possible land-fertilizer substitutes, special cases were analyzed where land diversion for government payments was not carried out. This latter approach will provide insight as to how farmers, faced with fertilizer restrictions, might use their resources if more land were available for cultivation.

Method of Analysis

Linear programming is the method of analysis chosen. This method can reflect comprehensive changes in farm resource use, enterprise combinations, and net income as nitrate fertilizer is restricted to different rates and amounts. In addition, the optimal linear programming

solution provides marginal value products of the resources that are totally used by the model.

This study of farmer adjustments is based upon linear programming models of representative farm size groups. These groups will be discussed in more detail in Chapter III. Construction of the model involved the development of an objective function, resource restrictions, and technical coefficients. Net returns over variable costs for the crop enterprises are required in order to develop the objective function. It is the net revenue over variable costs which is maximized when the optimal solution is reached. Resource restrictions are the quantities of resources available to the farm size groups. Technical coefficients specify the resource requirements for growing the crops in the model. Both primary and secondary data will be used to develop the components of the linear programming model.

Constant levels of technology and prices are assumed. Furthermore, imports and exports of agricultural commodities with respect to Arizona are also assumed to remain constant in this study.

The plan of the thesis is as follows: the linear programming model and related resource restrictions are presented in Chapter II. Chapter III contains a discussion of the production resources used in the model, crop calendars of operation, nitrogen response functions, and typical crop

budgets used to develop data for the objective function. Chapter IV contains the results from the linear programming models. Finally, in Chapter V the conclusions reached using the linear programming results are discussed. Also, recommendations as to data requirements and additional physical and economic research needed to provide input data for future studies of this nature will be made.

CHAPTER II

COSTS AND RETURNS

In this chapter costs and returns to representative Maricopa County farmers in the SRP and RWCD are developed. Initial material deals with basic terminology followed by a brief definition of the production resources involved. A discussion of nitrate fertilizer response functions and net returns over variable and fixed costs concludes the material presented in this chapter.

Net Returns over Variable Costs

A linear programming approach to this problem requires that net revenue per acre for each crop grown be calculated for each process (activity) used to produce the crop. Alternative nitrate fertilization rates become distinctive production processes and, hence, represent separate crop enterprise activities. It is assumed that crop enterprise, barley-sorghum (BARSOR), barley (BAR), early-plant-sorghum (EPS), late-plant-sorghum (LPS), wheat (WHE), and potatoes (POT) is grown with four different fertilizer rates. Alfalfa hay and alfalfa hay-pasture (AL and ALPH), respectively are produced only one way each, since AL and ALPH do not require nitrate fertilization. Cotton is

produced in eight ways; solid plant (COT SL) and skip-row plant (COT SK), with four fertilizer rates for each.

Data on net returns for each activity were obtained by (1) developing a calendar of operations for each crop, (2) calculating variable costs for each crop activity in the calendar, (3) adding non-calendar variable costs, (4) computing gross income figures for each crop enterprise activity, and (5) subtracting the sum of the variable costs from the gross income. A detailed description of steps, along with a discussion of the procedures used to obtain fixed costs, is presented in this chapter.

Farm Sizes

Within the SRP and the RWCD, costs and returns per acre vary because of economies of size. Average farm sizes were calculated by first stratifying farm size data into four broad categories and then dividing the number of farms in each category into the aggregate acreage of that class (see Table 1). Each average farm may be considered representative of farms in each size category. L-P models are developed for each of the farm size ranges on the basis of the representative farms in the two producing regions. Solutions are then aggregated for each size category. The net revenue over variable cost figure for each crop enterprise in each model reflects economies due to size and any peculiarities of production, such as special land preparation

Table 1. Representative Farm Sizes[a]

Group Classification	Crop Acreage Range	Total Number of Farms	Aggregate Cropland Acreage	No. of Farms in Sample[b]	Representative Farm Size[c] (Acres)
Salt River Farm Model Sizes:					
I	30-199.9	205	20,505	15	100
II	200-599.9	97	39,290	26	400
III	600-1,199.9	39	34,660	26	900
IV	1,200 & Above	21	37,835	17	1,800
Roosevelt Water Conservation District Farm Model Sizes:					
I	30-199.9	90	9,000	6	100
II	200 & Above	45	18,000	6	400

[a]Mack (1969).

[b]Farm samples made by Mack (1969).

[c]Average size of farm in each group. A separate L-P model is developed for each group based upon the average farm size for that group.

particular to that size group. The models are referred to as Size Groups I through IV for the SRP and Size Groups I and II for the RWCD.

Production Resources

Production resources utilized in each of the farm size groups within the SRP and RWCD areas are summarized in this section. A more detailed description of these resources, including resource base, enterprise combinations, and costs and returns of each activity enterprise, is developed in a University of Arizona, Department of Agricultural Economics, file report series (Mack, 1969).[1]

Land

Although land quality may vary throughout the study area, the degree and extent of variance is not significant. Therefore, land is assumed to be homogeneous in its productive capacity. Management of the land, on the other hand, is often a relative variable when considering land productivity because good land management practices may convert poor land into a highly productive resource, whereas poor management may ruin highly productive land. (For

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1. The analytical format and certain basic empirical data employed in this study are adapted from a linear programming analysis of farmers' response to water scarcity in the SRP-RWCD areas by Mack (1969) in a Ph.D. dissertation. The file report cited contains data not available in the dissertation itself.

additional comments regarding the management factor, see page 22.)

Irrigation Facilities

The file report (Mack, 1969) provides data on a representative farm model basis with respect to wells, pumps, and ditches. Representative facilities and their costs calculated on a widespread farm basis can be found in Table 8 of that report. These values are utilized here (Tables 3-10, pp. 20, 34, 37-47).

Fertilizer

Fertilizer was applied through an optimum source (see below) in the dry form, with the cost of the fertilizer computed on the basis of price per pound of nitrate nitrogen actually applied. The percentage of nitrogen available in each source was determined, and a price per pound of N for each source was calculated. The cost of the filler was not included in this price. Thus, for each level of fertilizer examined, the fertilizer cost was altered to reflect the different amounts applied.

Through interviews with agricultural biologists, an optimum nitrate fertilizer source was determined for each crop enterprise, the optimum source being that which provides nitrate fertilizer in a form that is most easily assimilated by the crop in question. Table 2 lists crop

Table 2. Optimum Nitrate Nitrogen Fertilizer Source and Price per Pound of Nitrogen for Various Crop Enterprises[a]

Crop Enterprise	Fertilizer Source	Cost/lb. of N
Cotton	Urea	1.6¢
Barley	Urea	1.6¢
Grain Sorghum	Anhydrous Ammonia (NH_3)	2.9¢
Wheat	Urea	1.6¢
Potatoes	16-48-0	1.2¢
Alfalfa	Treble Superphosphate	.74¢/lb. P

[a]Source: Johnson (1971).

enterprise, optimum fertilizer source, and the price per pound of nitrate nitrogen.

The effects of four different rates of nitrate nitrogen fertilizer for each crop (except for alfalfa) are observed. Response functions for each crop enterprise, which permitted derivation of approximate yields associated with each of the four fertilizer rates were developed and will be discussed later in this chapter.

Buildings

Most farms have shop buildings on the premises; however, their size, condition, and age vary considerably from one operation to another. Labor and management housing was typically present on farms in the larger size groups.

In addition, farms in the largest size typically included an office building, but a wide variation in value was reported. A complete summary of buildings by size group and their corresponding values can be found in Table 8 of the Departmental file report.

Water Availability

Water availability varies between irrigation districts and among representative farms. In the Salt River Project, water is available under five different arrangements, viz., assessment water (ASES WA), normal flow water (NF WA), stored and developed water (SD WA), project pump water (PRO WA), and private pump water (PTE WA).[2] Project water (PRO WA) is available on an equal share basis in the Roosevelt Water Conservation District. The only limitation on project water is a three acre-foot maximum per acre during the prorate period (Mack, 1969).[3] Table 3 contains a summary of water sources and water costs.

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2. Assessment water is defined as that water up to two acre-feet, delivered upon request to all project lands once the basic assessment has been made; normal flow water is water delivered upon demand to land having normal flow rights; stored and developed water is allocated by the district to its customers depending on availability, but has typically amounted to one acre-foot per project acre; project pump water is pumped water available from the SRP; private pump water is that water which is pumped through privately owned wells.

3. The prorate period is a period of time from March 1 to October 1 when surface flows are low and during which period RWCD users are restricted to a prorated share of available water supplies.

Table 3. Water Costs by Source for the SRP and RWCD

Area and Water Source	Cost per Acre Foot[a]
Salt River Project:	
Assessment Water	--
Normal Flow Water	1.75
Stored and Developed Water	1.75
Project Pump Water	7.50
Private Pump Water	6.44
Roosevelt Water Conservation District:	
Project Water	8.50[b]

[a]Source: The Salt River Project (1970).

[b]Source: Mack (1969).

Water availability and its effect upon farm operation can be easily observed in the results of the linear programming models of Chapter IV. Data pertaining to water supplies and costs are entered into the L-P models in such a way that the water availability characteristics particular to the two water projects and various farm sizes will be reflected in the resource allocation optimally obtained.

Machinery Inventory

Tables 9 through 12 of the file report provide a detailed machinery inventory and cost schedule which is utilized here in this report. It is assumed that if a

machine is in inventory and if a farm operation calls for that machine, the farmer does the operation himself. If the machine is not in the inventory, the operation is done on a custom basis. It is also assumed that inventories and costs of machinery remain constant over time.

Custom Operations

It was found that operations which required expensive tillage and harvesting equipment were carried out by the smaller farms on a custom basis. If a machine is part of the farm inventory, then an activity using such machinery is not customized. A complete listing of custom operations and their associated costs is contained in Table 10 of the file report.

Labor

The supply function for all classes of labor is assumed to be perfectly price elastic, that is, any and all quantities of labor or number of laborers can be hired at a constant wage rate.

A discussion of the various classes of labor is presented on page 19 and in Table 14 of the file report.

Capital

It is assumed that farm operators may obtain as much capital as they need at constant interest rates. In reality, however, individual farm operators may be able to

obtain increasing amounts of operating capital only at increasing costs. This would not be the case with regard to large groups of farm operators. An average efficiency in obtaining capital is assumed (Mack, 1969).

Management

As can be expected, many levels of management are found at any one time in any sector of the economy. But in the long run, the less efficient manager will be forced to improve or be driven out of the industry. In this analysis, management ability is assumed to be homogeneous within each size group as well as between groups.

Crop Rotation

Rotational cropping practices in this study are based on crop complementarity and disease and insect control recommendations of the United States Department of Agriculture. The rotation most commonly used and approved by agronomists is a cotton-barley or wheat-sorghum cropping pattern. Also, fallow ground may enter into the rotation as an acceptable disease or insect control measure in a rotation. In either case, cotton is the primary recipient of crop rotation benefits.

In order to insure an adequate amount of rotational land for agronomic purposes, cotton allotments for each of the six farm groups were limited to less than the total amount of land available for cultivation in each group. If

cotton allotments were not so restricted, the linear programming model would allocate all available resources to the cotton enterprise, since cotton has a higher net revenue over variable cost figure than the other crops. Similar limits were constructed for other enterprises. Thus, both cotton allotment restrictions and crop limits were needed to insure that the resource allocation models utilized (1) provide sufficient land for recommended crop rotations and (2) reflect historical cropping patterns which, in turn, reflect farmers' preferences for certain crops. This preference being derived from market conditions and the relationship between cropping requirements and farmers' resources.

Calendars of Operation

From the farm survey made by Mack (1969) little variance was found among farms as to operations performed and physical inputs used in production of identical crops. Consequently, for the representative farm models, the calendars of operations are identical for individual crops. Integrated into these calendars are the representative farm budgets which are composed of inputs, operations, and equipment necessary to perform each task. The calendars and unit budgets for each crop for each farm size model are presented in the file report. As indicated, the report was considered a source of primary data for this study.

Response Functions for Nitrate Fertilizer

Part of the difference between costs and net returns (see Tables 5-10, pp. 37-47) for different nitrate fertilizer usage is due to shifts along a production function. A production function expresses the physical relationship between output and a set of inputs. In this study, output is in terms of crop yields per acre and the major variable input is the quantity of nitrate fertilizer applied per acre. Some inputs (e.g., land, labor, seed varieties) are assumed to remain constant while other inputs (viz., phosphorus and potash) are allowed to change, in a complementary fashion, with alternate levels of N.

Given a production function and input and output prices, the profit-maximizing farmer can determine the economically optimum rate of fertilizer use for any crop and at any point in time. Ceteris paribus, the higher the fertilizer cost per acre the less fertilizer he will apply per acre. The production function and price data can also illustrate farm conditions if fertilizer is restricted to particular per acre usage levels. In the case of such restrictions, the grower must make adjustments. If, for example, under restricted fertilizer conditions the grower is producing uneconomic yields, he must cut costs or through some means other than increased fertilization increase gross revenue. If the per acre fertilizer limits were above the most efficient level the grower would be free to operate

optimally. On the other hand, with a total farm or regional fertilizer restriction each grower would apply fertilizer optimally among the crops in his operation by considering the relative production functions, input and output prices, and the total amount of fertilizer available. Under a regional fertilizer limit, farmers would still be free to vary per acre application rates. Since the quantity of fertilizer used per acre is sensitive to fertilizer cost and the resulting net revenue (output prices constant), fertilizer production functions become essential for making reliable projections of farmer adjustments to possible limits upon fertilizer use.

It is usually quite difficult to obtain a completely specified production function for a particular crop. There are several reasons for this being true. First, due to the nature of their formulation, typical crop response data are difficult to adapt to economic analysis. These data are often collected by physical scientists who have no particular interest in economic analysis and who are not familiar with the way in which economists try to use physical data of this type. Also, most of the data is taken from experimental plots, subject to experimental conditions which are not usually representative of production under field conditions. Another problem is that existing production function data are not continuous in nature. One or two points may be known, but an extrapolation of these, or a fit between them,

must be made to make the function continuous. In addition, the accuracy of basic response relationships is dependent upon the timing of fertilizer application and the ability to control other factors, such as soil, weather, insects, seed variety, location, etc. Without experimental control, yield variations are difficult to explain.

In order to utilize existing data a composite of different fertilizer crop response relationships was made. The composite included data from a USDA survey report entitled Crop Yield Response to Fertilizer in the United States (Ibach and Adams, 1968), the file report (Mack, 1969), and crop response data from Arizona Experimental Station annual reports on soil fertility and soil research for Maricopa County which spanned approximately ten years. These composite response data were used to construct fertilizer production functions for crops grown in the SRP and RWCD areas. Extrapolation of data points was based upon consultations with researchers in the Departments of Agronomy, Agricultural Chemistry and Soils, at The University of Arizona, Agricultural Experiment Station. Timing of fertilizer application in experiments was assumed to be the same as outlined in the calendars of operations.

Figures 1 through 5 illustrate fertilizer response functions for the various crops considered in this analysis.

Primary data used in forming the functions for the various crop enterprises examined were obtained from

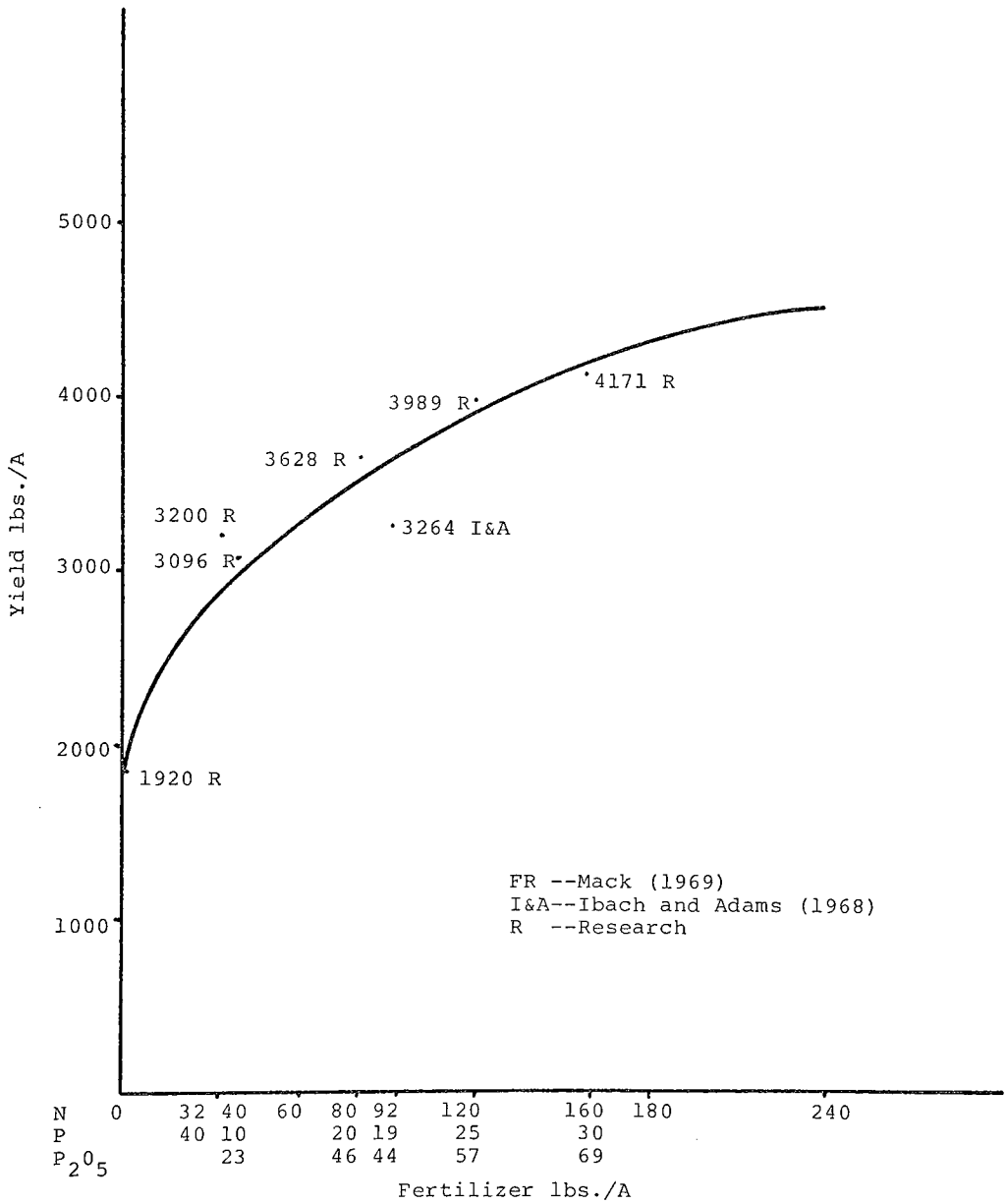

Figure 1. Response Function for Barley

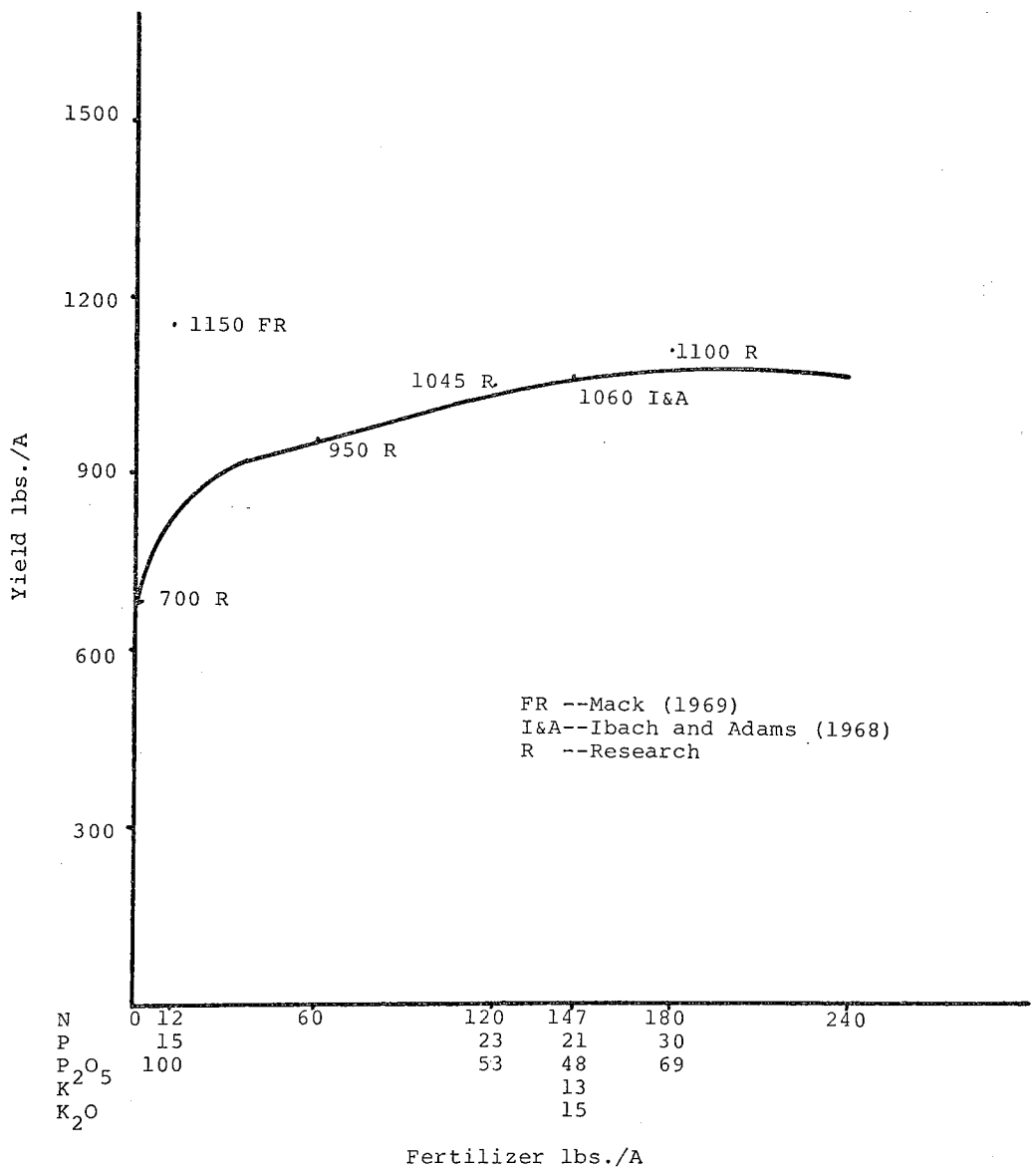

Figure 2. Response Function for Cotton

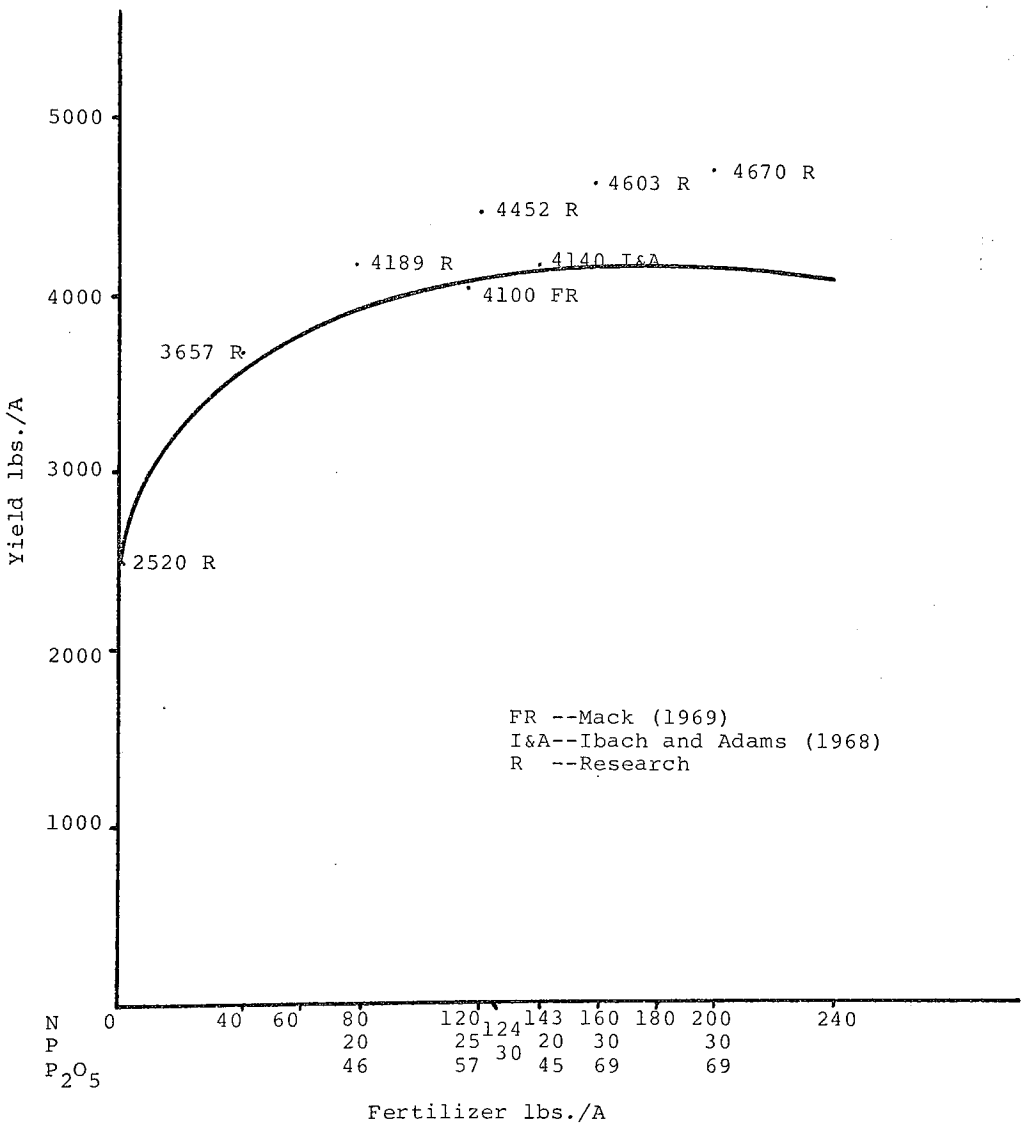

Figure 3. Response Function for Grain Sorghum

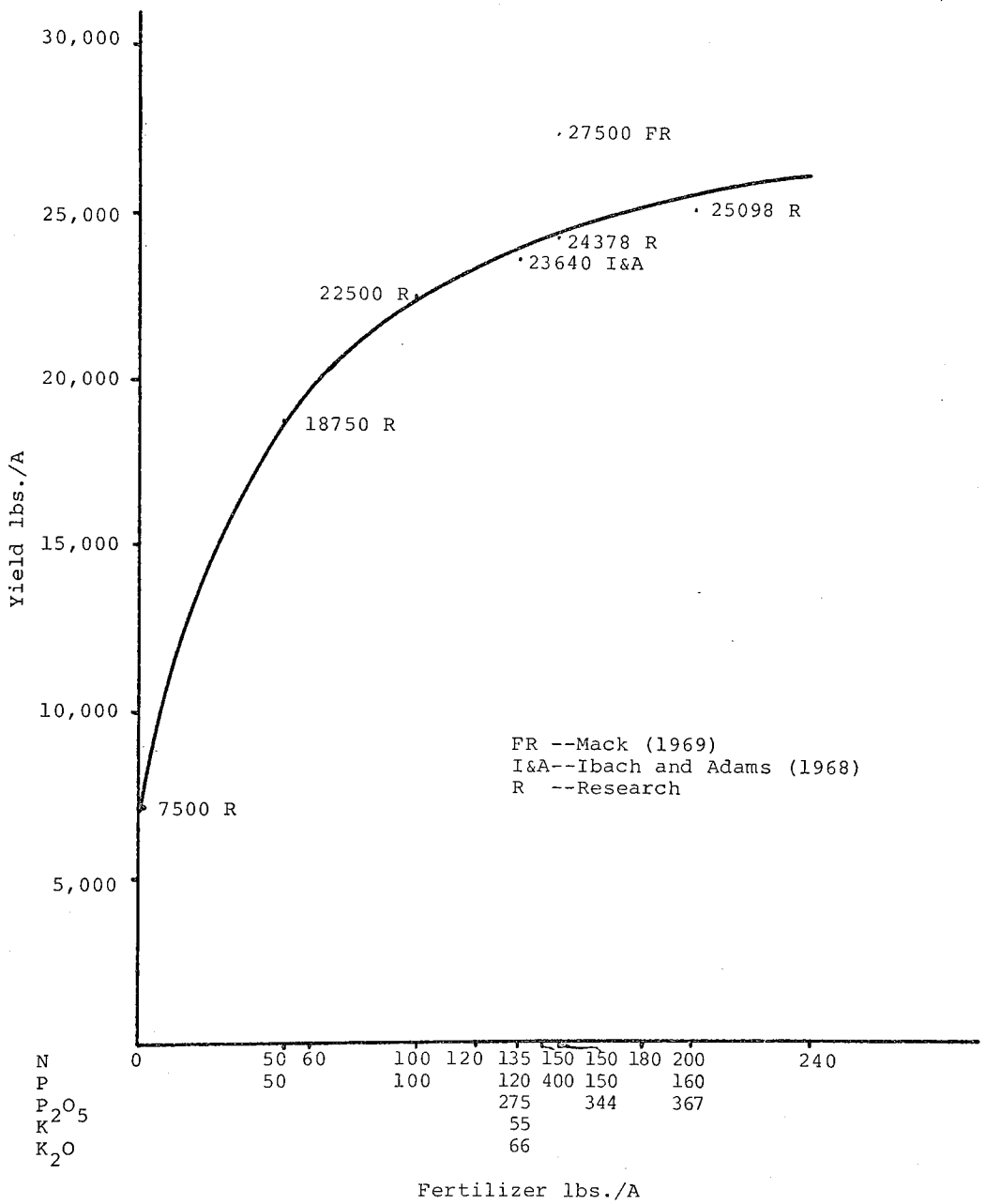

Figure 4. Response Function for Potatoes

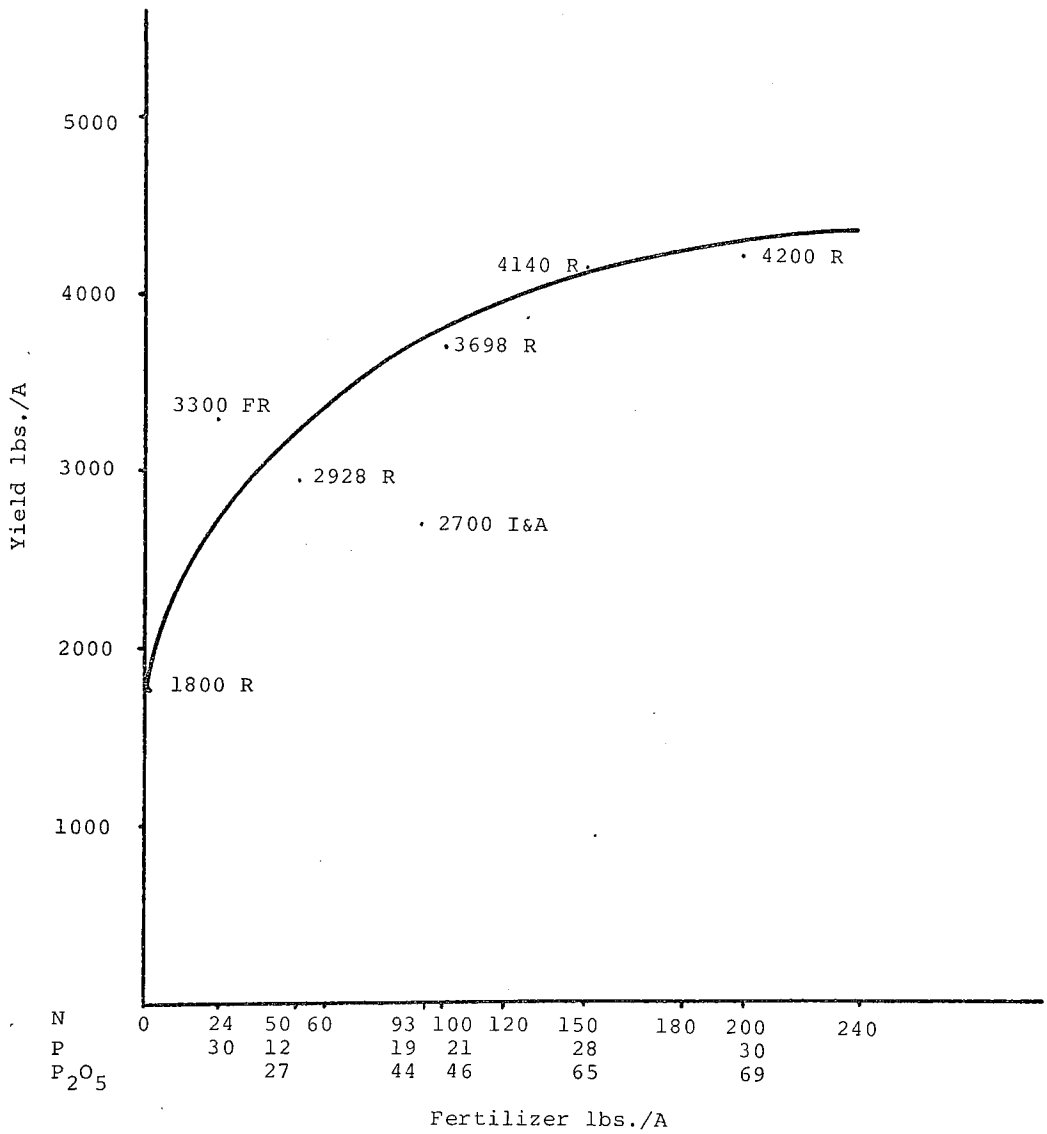

Figure 5. Response Function for Wheat

FR--Mack (1969); I&A--Ibach and Adams (1968); R--Research

nitrogen response trials at various locations in Maricopa County from 1959-1965. Since the SRP and RWCD service large agricultural areas in Maricopa County, it is assumed that the response data which are relevant to Maricopa County also apply for the SRP and RWCD areas. The weather during the years for which these response data were compiled was normal for the seasons in which the study crops were grown. Irrigation was supplied to the crops at average or medium levels.

The fertilizer treatments were conducted under field test plot conditions with the treatment levels ranging from 0 to 400 pounds per acre of nitrogen fertilizer. Dealing with the same crop, at the start of the experiments each year the assumption was made that weather, soil moisture, and nitrogen levels were comparable to those of previous experiments. The plots were treated identically except for the variance of fertilizer treatment levels.

The variety of cotton used was Acala 44-10. The majority of the studies concerning barley, grain sorghum, and wheat used the varieties Arivat, R.S. 610, and Ramona 50, respectively. In each experiment the crops are assumed to have been raised with the same agronomic techniques and management ability.

Data from Mack's file report and the Ibach and Adams (1968) report were used to check the credibility of the response functions developed from the primary data. Thus,

each response function is a composite of primary and secondary data.

The response relationships for the different crops with respect to nitrate fertilizer are crucial in determining the net revenue for each fertilizer rate. These net revenue figures make up the objective function of the analytical model (which will be discussed in more depth in Chapter III). Due to a shortage of response data, some crops such as sugar beets, lettuce, carrots, and onions were not included in the analysis.

Crop Yields, Product Prices, and Gross Returns

As indicated, expected crop yields with alternative fertilizer rates were calculated from a composite of data. Four output levels for each enterprise are listed in Tables 5-10 (pp. 37-47). Each output level is the anticipated yield based upon the four different fertilizer rates listed in Column 1 and the response functions of Figures 1-5.

Product prices were taken from Arizona Agricultural Statistics 1971 (1971). Where applicable, government price support payments are included as a separate item in computing gross returns. Table 4 presents a summary of yields, product prices, government payments, and gross returns.

Table 4. Per Acre Crop Yields, Prices, and Gross Returns, SRP[a] and RWCD[b]

Crop	Nitrate Rate	Yield	Unit	Dollars/ Unit	Product Revenue	Govt. Payment	Gross Returns
Cotton-Solid Plant	60	960	lb.	.31	297.60	144.00	441.60
	120	1,040	lb.	.31	322.40	156.00	478.40
	150	1,070	lb.	.31	331.70	160.60	492.20
	180	1,085	lb.	.31	336.35	162.75	499.10
Cotton-Skip Row	60	1,075	lb.	.31	333.25	161.25	494.50
	120	1,165	lb.	.31	361.15	174.75	535.90
	150	1,198	lb.	.31	371.38	179.70	551.08
	180	1,215	lb.	.31	376.65	182.25	558.90
a. Alfalfa Hay	--	6.5	tn.	31.00	201.50	--	201.50
Hay & Pasture	--	25	day	.05/hd	12.50	--	214.00
b. Alfalfa Hay	--	4.5	tn.	31.00	139.50	--	139.50
Hay & Pasture	--	25	day	.05/hd	12.50	--	152.00
Barley	60	32.50	cwt.	2.50	81.25	--	81.25
	120	39.00	cwt.	2.50	97.50	--	97.50
	150	42.80	cwt.	2.50	107.00	--	107.00
	180	42.90	cwt.	2.50	107.25	--	107.25
Grain Sorghum	60	39.50	cwt.	2.46	98.75	--	98.75
	120	44.50	cwt.	2.46	111.25	--	111.25
	150	46.00	cwt.	2.46	115.00	--	115.00
	180	46.50	cwt.	2.46	116.25	--	116.25
Barley-Grain Sorghum	--	--		--	180.00	--	180.00
	--	--		--	208.75	--	208.75
	--	--		--	222.00	--	222.00
	--	--		--	223.50	--	223.50

Table 4.--Continued

Crop	Nitrate Rate	Yield	Unit	Dollars/ Unit	Product Revenue	Govt. Payment	Gross Returns
Wheat	60	30.05	cwt.	2.33	70.02	--	70.02
	120	38.00	cwt.	2.33	88.54	--	88.54
	150	41.40	cwt.	2.33	96.46	--	96.46
	180	42.00	cwt.	2.33	97.86	--	97.86
Potatoes	60	197.50	cwt.	3.15	620.55	--	620.55
	120	233.50	cwt.	3.15	735.53	--	735.53
	150	243.78	cwt.	3.15	767.91	--	767.91
	180	252.50	cwt.	3.15	795.38	--	795.38

[a]Salt River Project.

[b]Roosevelt Water Conservation District.

Tables of Net Returns over Variable Costs

Tables 5 through 10 not only summarize calendar costs, but also list other non-calendar variable costs, gross returns and net returns over variable costs for the four farm sizes in the SRP, the two farm sizes in the RWCD, and the five fertilizer rates of the crop production functions. Calendar costs come directly from the calendar of operations. Other variable costs are thus not directly associated with any particular operation but judged to be more nearly like variable costs than fixed costs.

Fixed Costs

Fixed costs are those outlays that are incurred regardless of the level of production. These costs cannot be varied in the short run. However, in the long run fixed costs become subject to change. In this study, we are dealing with farms having a prescribed set of fixed resources; therefore, fixed costs will exist. These fixed costs were included in the "Total Operating Costs" in Tables 5 through 10.

An opportunity cost for real estate is not included among the fixed costs, because buyers of land, upon which land values depend, will be available as long as agriculture produces a net return to land. Also, we are concerned with agriculture as an aggregate rather than with farms as individual entities. On an aggregate basis, farm land has

Table 5. Nitrate Fertilizer Rates, Crop Yields, Costs, and Returns, SRP-I (100 ac. farm)

Crop	Nitrate Rates lb./ac.	Yield Units/ac.	Total Variable Costs $/ac.	Total Operating Costs $/ac.	Gross Returns $/ac.	Net Returns Over Total Operating Costs $/ac.
Cotton SLD	60	960 lbs.	189.30	240.30	441.60	201.30
	120	1,040 lbs.	190.27	241.30	478.40	237.10
	150	1,070 lbs.	190.75	241.79	492.20	250.41
	180	1,085 lbs.	191.25	242.31	499.10	256.79
Cotton SKP	60	1,075 lbs.	238.60	275.40	494.50	219.10
	120	1,165 lbs.	239.57	276.40	535.90	259.50
	150	1,198 lbs.	240.05	276.89	551.08	274.19
	180	1,215 lbs.	240.55	277.40	558.90	281.50
Alfalfa	0	6.5 tns.	96.28	112.52	201.50	88.98
Hay Pasture	0	25 days	--	112.52	214.00	101.48
Barley	60	3,250 lbs.	33.62	39.26	81.25	41.99
	120	3,900 lbs.	34.59	40.24	97.50	57.26
	150	4,280 lbs.	35.07	40.73	107.00	66.27
	180	4,290 lbs.	35.57	41.24	107.25	66.01
Grain Sorghum	60	3,950 lbs.	48.04	55.69	98.75	43.06
	120	4,450 lbs.	49.78	57.45	111.25	53.80
	150	4,600 lbs.	50.65	58.33	115.00	56.67
	180	4,650 lbs.	51.52	59.21	116.25	57.04
Bar-Sorg.	60	--	81.66	93.82	180.00	86.18
	120	--	84.37	96.53	208.75	112.22
	150	--	85.72	97.89	222.00	124.11
	180	--	87.09	99.27	223.50	124.23

Table 5.--Continued

Crop	Nitrate Rates lb./ac.	Yield Units/ac.	Total Variable Costs $/ac.	Total Operating Costs $/ac.	Gross Returns $/ac.	Net Returns Over Total Operating Costs $/ac.
Wheat	60	3,005 lbs.	34.37	40.03	70.02	29.99
	120	3,800 lbs.	35.34	41.01	88.54	47.53
	150	4,140 lbs.	35.82	41.50	96.46	54.96
	180	4,200 lbs.	36.32	42.01	97.86	55.85

Table 6. Nitrate Fertilizer Rates, Crop Yields, Costs, and Returns, SRP-II (400 ac. farm)

Crop	Nitrate Rates lb./ac.	Yield Units/ac.	Total Variable Costs $/ac.	Total Operating Costs $/ac.	Gross Returns $/ac.	Net Returns Over Total Operating Costs $/ac.
Cotton SLD	60	960 lbs.	153.32	195.58	441.60	246.02
	120	1,040 lbs.	154.29	196.58	478.40	281.82
	150	1,070 lbs.	154.77	197.07	492.20	295.13
	180	1,085 lbs.	155.27	197.58	499.10	301.52
Cotton SKP	60	1,074 lbs.	189.95	219.43	494.50	275.07
	120	1,165 lbs.	190.82	220.33	535.90	315.57
	150	1,198 lbs.	191.30	220.82	551.00	330.26
	180	1,215 lbs.	191.80	221.34	558.90	337.56
Alfalfa	0	6.5 tns.	95.46	110.57	201.50	90.93
Hay & Pasture	0	25 days	--	110.57	214.50	103.93
Barley	60	3,250 lbs.	30.42	35.79	81.25	45.46
	120	3,900 lbs.	31.39	36.77	97.50	60.73
	150	4,280 lbs.	31.87	37.26	107.00	69.74
	180	4,290 lbs.	32.37	37.77	107.25	69.48
Grain	60	3,950 lbs.	52.13	59.67	98.75	39.08
Sorghum	120	4,450 lbs.	53.87	61.44	111.25	49.81
	150	4,600 lbs.	54.74	62.32	115.00	52.68
	180	4,650 lbs.	55.61	63.20	116.25	53.05
Bar-Sorg.	60	--	73.75	87.60	180.00	92.40
	120	--	76.46	90.39	208.75	118.36
	150	--	77.81	91.78	222.00	130.22
	180	--	79.18	93.19	223.50	130.31

Table 6.--Continued

Crop	Nitrate Rates lb./ac.	Yield Units/ac.	Total Variable Costs $/ac.	Total Operating Costs $/ac.	Gross Returns $/ac.	Net Returns Over Total Operating Costs $/ac.
Wheat	60	3,005 lbs.	31.17	36.64	70.02	33.38
	120	3,800 lbs.	32.14	37.63	88.54	50.91
	150	4,140 lbs.	32.62	38.11	96.46	58.35
	180	4,200 lbs.	33.12	38.62	97.86	59.24
Potatoes	60	19,750 lbs.	457.26	514.80	620.55	105.75
	120	23,350 lbs.	457.59	515.14	735.53	200.39
	150	24,378 lbs.	457.76	515.31	767.91	252.60
	180	25,250 lbs.	457.92	515.48	795.38	279.80

Table 7. Nitrate Fertilizer Rates, Crop Yields, Costs, and Returns, SRP-III (900 ac. farm)

Crop	Nitrate Rates lb./ac.	Yield Units/ac.	Total Variable Costs $/ac.	Total Operating Costs $/ac.	Gross Returns $/ac.	Net Returns Over Total Operating Costs $/ac.
Cotton SLD	60	960 lbs.	147.31	177.77	441.60	263.83
	120	1,040 lbs.	148.28	178.77	478.40	299.63
	150	1,070 lbs.	148.76	179.26	492.20	312.94
	180	1,085 lbs.	149.26	179.78	499.10	319.32
Cotton SKP	60	1,075 lbs.	180.58	218.45	494.50	276.05
	120	1,165 lbs.	181.55	219.45	535.80	316.45
	150	1,198 lbs.	182.03	219.94	551.08	331.14
	180	1,215 lbs.	182.53	216.46	558.90	342.44
Alfalfa Hay	0	6.5 tns.	70.54	86.12	201.50	115.38
& Pasture	0	25 days	--	--	214.00	127.88
Barley	60	3,250 lbs.	28.53	36.89	81.25	44.36
	120	3,900 lbs.	29.50	37.87	97.50	59.63
	150	3,280 lbs.	29.98	38.36	107.00	68.64
	180	4,290 lbs.	30.48	38.86	107.25	68.39
Grain	60	3,950 lbs.	53.60	53.64	98.75	45.11
	120	4,450 lbs.	45.34	55.40	111.25	55.85
	150	4,600 lbs.	46.21	56.29	115.00	58.71
	180	4,650 lbs.	47.08	57.17	116.25	59.08
Bar-Sorg.	60	--	73.75	92.50	180.00	87.50
	120	--	76.46	95.29	208.75	113.46
	150	--	77.81	96.68	222.00	125.32
	180	--	79.18	98.09	223.50	125.41

Table 7.--Continued

Crop	Nitrate Rates lb./ac.	Yield Units/ac.	Total Variable Costs $/ac.	Total Operating Costs $/ac.	Gross Returns $/ac.	Net Returns Over Total Operating Costs $/ac.
Wheat	60	3,005 lbs.	29.28	37.80	70.02	32.22
	120	3,800 lbs.	30.25	38.78	88.54	49.76
	150	4,140 lbs.	30.73	39.27	96.46	57.19
	180	4,200 lbs.	31.23	39.77	97.86	59.09
Potatoes	60	19,750 lbs.	455.52	532.22	620.55	88.33
	120	23,350 lbs.	455.85	532.55	735.35	202.80
	150	24,378 lbs.	456.02	532.72	767.91	235.19
	180	25,250 lbs.	456.18	532.89	795.38	262.49

Table 8. Nitrate Fertilizer Rates, Crop Yields, Costs, and Returns, SRP-IV (1800 ac. farm)

Crop	Nitrate Rates lb./ac.	Yield Units/ac.	Total Variable Costs $/ac.	Total Operating Costs $/ac.	Gross Returns $/ac.	Net Returns Over Total Operating Costs $/ac.
Cotton	60	960 lbs.	147.73	172.27	441.60	269.33
	120	1,040 lbs.	148.70	173.27	478.40	305.13
	150	1,070 lbs.	149.18	173.76	492.20	318.44
	180	1,085 lbs.	149.68	174.28	499.10	324.82
Cotton SKP	60	1,075 lbs.	180.20	210.33	494.50	284.17
	120	1,165 lbs.	181.17	211.33	535.90	324.57
	150	1,198 lbs.	181.65	211.83	551.08	339.25
	180	1,215 lbs.	182.15	212.35	558.90	346.56
Alfalfa Hay	0	6.5 tns.	65.64	77.65	201.50	123.85
& Pasture	0	25 days	--	--	214.00	136.35
Barley	60	3,250 lbs.	28.38	34.08	81.25	47.17
	120	3,900 lbs.	29.35	35.08	97.50	62.42
	150	3,280 lbs.	29.83	35.57	107.00	71.43
	180	4,290 lbs.	30.33	36.07	107.25	71.18
Grain	60	3,950 lbs.	53.19	51.05	98.75	47.70
	120	4,450 lbs.	44.93	52.82	111.25	58.43
	150	4,600 lbs.	45.80	53.71	115.00	61.29
	180	4,650 lbs.	46.67	54.59	116.25	61.66
Bar-Sorg.	60	--	72.50	87.05	180.00	92.95
	120	--	75.21	89.84	208.75	118.91
	150	--	76.56	91.23	222.00	130.77
	180	--	77.93	92.64	223.50	130.86

Table 8.--Continued

Crop	Nitrate Rates lb./ac.	Yield Units/ac.	Total Variable Costs $/ac.	Total Operating Costs $/ac.	Gross Returns $/ac.	Net Returns Over Total Operating Costs $/ac.
Wheat	60	3,005 lbs.	29.13	34.96	70.02	35.06
	120	3,800 lbs.	30.10	35.94	88.54	52.60
	150	4,140 lbs.	30.58	36.43	96.46	60.03
	180	4,200 lbs.	31.09	36.94	97.86	60.92

Table 9. Nitrate Fertilizer Rates, Crop Yields, Costs, and Returns, RWCD-I (100 ac. farm)

Crop	Nitrate Rates lb./ac.	Yield Units/ac.	Total Variable Costs $/ac.	Total Operating Costs $/ac.	Gross Returns $/ac.	Net Returns Over Total Operating Costs $/ac.
Cotton SLD	60	960 lbs.	189.30	240.30	441.60	201.30
	120	1,040 lbs.	190.27	241.30	478.40	237.10
	150	1,070 lbs.	190.75	241.79	492.20	250.41
	180	1,085 lbs.	191.25	242.31	499.10	256.79
Cotton SKP	60	1,075 lbs.	238.60	275.40	494.50	219.10
	120	1,165 lbs.	239.57	276.40	535.90	259.50
	150	1,198 lbs.	240.05	276.89	551.08	274.18
	180	1,215 lbs.	240.55	277.40	558.90	281.50
Alfalfa Hay	0	4.5 tns.	78.51	90.78	139.50	48.72
& Pasture	0	25 days	--	--	152.00	61.22
Barley	60	3,250 lbs.	33.62	39.26	81.25	41.99
	120	3,900 lbs.	34.50	40.24	97.50	37.26
	150	4,280 lbs.	35.07	40.73	107.00	66.27
	180	4,290 lbs.	35.57	41.24	107.25	66.01
Grain	60	3,950 lbs.	48.04	55.69	98.75	43.06
	120	4,450 lbs.	49.78	57.45	111.25	53.00
	150	4,600 lbs.	50.65	58.33	115.00	56.67
	180	4,650 lbs.	51.52	59.21	116.25	57.04
Bar-Sorg.	60	--	81.66	93.82	180.00	86.18
	120	--	84.37	96.53	208.75	112.22
	150	--	85.72	97.69	222.00	124.11
	180	--	87.09	99.27	223.50	124.23

Table 9.--Continued

Crop	Nitrate Rates lb./ac.	Yield Units/ac.	Total Variable Costs $/ac.	Total Operating Costs $/ac.	Gross Returns $/ac.	Net Returns Over Total Operating Costs $/ac.
Wheat	60	3,005 lbs.	34.37	40.03	70.02	29.99
	120	3,800 lbs.	35.34	41.01	88.54	47.53
	150	4,140 lbs.	35.82	41.50	96.46	54.96
	180	4,200 lbs.	36.32	42.01	97.86	55.85

Table 10. Nitrate Fertilizer Rates, Crop Yields, Costs, and Returns, RWCD-II (400 ac. farm)

Crop	Nitrate Rates lb./ac.	Yield Units/ac.	Total Variable Costs $/ac.	Total Operating Costs $/ac.	Gross Returns $/ac.	Net Returns Over Total Operating Costs $/ac.
Cotton SLD	60	960 lbs.	153.32	195.58	441.60	246.02
	120	1,040 lbs.	154.29	196.58	478.40	281.82
	150	1,070 lbs.	154.77	197.07	492.20	295.13
	180	1,085 lbs.	155.27	197.58	499.10	301.52
Cotton SKP	60	1,075 lbs.	189.95	219.43	494.50	275.07
	120	1,165 lbs.	190.82	220.33	535.90	315.57
	150	1,198 lbs.	191.30	220.82	551.08	330.26
	180	1,215 lbs.	191.80	221.34	558.90	337.56
Alfalfa Hay	0	4.5 tns.	77.69	89.84	139.50	49.66
& Pasture	0	25 days	--	--	152.00	62.16
Barley	60	3,250 lbs.	30.42	35.79	81.25	45.46
	120	3,900 lbs.	31.39	36.77	97.50	60.73
	150	4,280 lbs.	31.87	37.26	107.00	69.74
	180	4,290 lbs.	32.37	37.77	107.25	69.48
Grain	60	3,950 lbs.	52.13	59.67	98.75	39.08
Sorghum	120	4,450 lbs.	53.87	61.44	111.25	49.81
	150	4,600 lbs.	54.74	62.32	115.00	52.68
	180	4,650 lbs.	55.61	63.20	116.25	53.05
Bar-Sorg.	60	--	73.75	87.60	180.00	92.40
	120	--	76.46	90.39	208.75	118.36
	150	--	77.81	91.78	222.00	130.22
	180	--	79.18	93.19	223.50	130.31

Table 10.--Continued

Crop	Nitrate Rates lb./ac.	Yield Units/ac.	Total Variable Costs $/ac.	Total Operating Costs $/ac.	Gross Returns $/ac.	Net Returns Over Total Operating Costs $/ac.
Wheat	60	3,005 lbs.	31.17	36.64	70.02	33.38
	120	3,800 lbs.	32.14	37.63	88.54	50.91
	150	4,140 lbs.	32.62	38.11	96.46	58.35
	180	4,200 lbs.	33.12	38.62	97.86	59.24
Potatoes	60	19,750 lbs.	457.26	514.80	620.55	105.75
	120	23,350 lbs.	457.59	515.14	735.53	220.39
	150	24,378 lbs.	457.76	515.31	767.91	252.60
	180	25,250 lbs.	457.92	515.48	795.38	279.90

the same value; therefore, no opportunity cost is considered.

Fixed costs for each representative farm are contained in Mack (1969, Table 12).

Summary

With restrictions on nitrate nitrogen fertilization, Maricopa County farmers in the SRP and RWCD can be expected to react to these restrictions in terms of what, how, and how much to produce. It is important to determine as closely as possible the relevant costs and returns these farmers face in order to be able to predict what actions they might take under such circumstances. The resources defined in this chapter, as well as the costs and returns of production, are key inputs in the linear programming formulation of the problem. In Chapter III, we describe the linear programming model which uses the cost and return figures developed in this chapter as a basis for predicting input use, crop enterprise adjustments, and income as nitrate nitrogen utilization is limited.

CHAPTER III

THE LINEAR PROGRAMMING MODEL

Linear Programming and Its Processes

Linear programming is a mathematical technique for solving a set of linear equations which describe an objective, the technical relationship among the variables. The problem to be solved in linear programming is that of either maximizing or minimizing the value of the (linear) objective function subject to the set of linear constraints. The general form of a maximizing problem may be expressed symbolically as follows:

$$\text{Maximize} \qquad Z = \sum_{j=1}^{n} C_j X_j$$

$$\text{Subject to:} \qquad \sum_{j=1}^{n} A_{ij} X_j \leq b_i \quad (\text{for } i = 1,2,\ldots,m)$$

$$X_j \geq 0 \quad (\text{for } j = 1,2,\ldots,n)$$

In these expressions, the C_j's, b_i's, and A_{ij}'s are known parameters. The C_j's are the net return coefficients for each alternative process (X_j), the b_i's describe the supply of resources available, and the A_{ij}'s illustrate the technical coefficients of production. Given the C_j, b_i, and the A_i's, the solution of a linear programming problem

involves the determination of values for each unknown variable X_j such that the value of Z is maximized within the constraints imposed by the inequalities (Thompson, 1967).

There are several assumptions which are implicit in this linear programming procedure. These assumptions are: (1) additivity and linearity, (2) divisibility, (3) finiteness, (4) single-value expectations, and (5) profit maximization. Thus, a linear programming model consists of the following five parts: (1) an objective function which is to be maximized (or minimized, depending on the type of problem) and which yields the returns to each activity at the maximum (or minimum) value of the objective function; (2) real activities available to the producing unit; (3) disposal activities allowing non-use of productive resources; (4) artificial activities providing for required (e.g., institutionally imposed) solutions and computational conveniences; and (5) restrictions which specify the upper bounds of or limits on resources available in the model.

An easy way to understand the linear programming procedure is to visualize it in a matrix formulation. Burdak (1970) explained the meaning of the rows and columns of the matrices as follows:

> Each row of coefficients is an equation in itself. In matrix form, the variables (number of acres and number of acres-feet) have been left out of the equations and only the constraints (coefficients) of the equation are given. Thus, the coefficients

> which define a matrix are nothing more than the constants of a group of equations which set forth the problem. In order to maximize the objective function, one must find the values which simultaneously satisfy all the equations in the matrix and allow the highest attainable value for the objective function (p. 63).

The net revenue row constitutes the objective function. This gives the net revenue over variable costs for each acre of the revenue producing activity. For the water activities, the entries are the variable costs of one acre-foot of water. Finally, restrictions for the different areas are shown in the right-hand columns.

Components of the SRP and RWCD L-P Models

The objective of this L-P model is to obtain maximum net income from the alternatives of producing field crops in the SRP and RWCD with limitations of fertilizer, land, capital, and other factors SRP and RWCD farmers typically face. The solution to the model represents estimates of resource use, cropping patterns, crop output and farm income for typical farmers in the SRP and RWCD based upon alternate nitrate nitrogen rates per acre and levels of total use for each size group.

The Objective Function

An objective function is developed for each of the farm sizes assumed to represent farms in each irrigation district. Thus, there are six basic models (four for the SRP and two for the RWCD). These functions contain net

revenue coefficients for all enterprise activities on each model farm. Nitrate nitrogen fertilizer is available at four different rates of application: 60, 120, 150, and 180 pounds per acre. The reasons for choosing these four rates will be discussed later in this chapter. Each crop enterprise had a net revenue figure for each of the individual rates. As the rates changed, yields and costs changed, thereby causing net revenue to change.

Water availability is present in the objective function under several cost conditions. The water cost data were presented in Chapter II.

Activities

The number of activities varies with the model and farm size.

The activities listed in Table 11 account for 79 per cent of total acreage harvested in Maricopa County in 1970; five per cent was in low-value crops other than pasture. These crops included sudan grass, alfalfa, greenchop, silage production, and small grains. Due to similar low-value crops being included in the model, the omission of this five per cent is not considered critical. Since resources used to produce the crops that were omitted are included in the model, it is expected that those low-value crops that are considered will reflect conditions paralleling the low-value crops that were omitted.

Table 11. Alternative Crop Enterprise Activities in Each Farm Model

Crop Enterprise	Farms			
	100	400	900	1800
Solid Plant Cotton	X	X	X	X
Skip-Row Cotton	X	X	X	X
Alfalfa Hay	X	X	X	X
Alfalfa Hay and Pasture	X	X	X	X
Barley	X	X	X	X
Grain Sorghum	X	X	X	X
Barley-Grain Sorghum (double-cropped)	X	X	X	X
Wheat	X	X	X	X
Potatoes	-	X	X	-

The other excluded 16 per cent of total acreage harvested was in vegetables, safflower, sugar beets, and fruit. The reason for not including these crops was the absence of crop response data specific to Maricopa County.

As mentioned previously, four different rates of nitrate nitrogen fertilizer were used per crop. This was done so that the basic model could be made to reflect not only the impact of a total-farm or regional restriction but also the impact of rate-per-acre restrictions. The different farm sizes represent differences in capacities and

efficiencies. The variety of models used based on farm size groups and fertilizer restrictions is outlined below:

1. A separate model is developed for each of the four farm sizes in the SRP with the five possible ways of restricting nitrate fertilizer (four rate restrictions: 60, 120, 150, 180 pounds/acre and a total farm limit based on 120 pounds/acre).
2. A separate model is developed for each of the two farm sizes in the RWCD with the five possible ways of restricting nitrate fertilizer.
3. The representative farm models are run without a restriction on fertilizer, but with limits placed upon crop acreage based upon historical cropping patterns (Mack, 1969). Also, the models had the capability to utilize government program-diverted acreage.
4. Then the representative farm models are run with two nitrogen fertilizer restrictions: first with a total farm restriction and then with a sixty-pound-per-acre restriction, without use of diverted acres and with new crop limits reflecting an expected trend in cultivation patterns.

Forty-two models were needed to show the effect of farm sizes, different fertilizer restrictions, differences in net revenue between SRP and RWCD crop enterprises, and

land diversion with historical crop limits and no land diversion and new crop limits. The objective function is different for each model since the net revenue changes for each model.

Restrictions

Crop acreage limits were set up as constraints to make sure that the solutions would reflect crop rotations and historical and projected patterns in the area. Crop limits were constructed with and without land diversion where diversion is the amount of acreage each size group had to set aside in order to receive a support payment for the cotton enterprise. Crop limits with diversion use were constructed from historical cropping patterns of the various farm size groups. Since acreage has been diverted in the past, this was easily done; however, no data on cropping patterns without diverted acreage were available. Projected patterns were constructed to allow for increased production acreage arising because more land would be available due to removal of crop diversions, and to reflect some form of probable crop rotation and planting pattern. The exact amount crop acreage might increase is unknown. Figures were chosen that would control the model as well as indicate the possibility of increased production acreage. The restrictions, therefore, include land, water, crop allotments, crop acreage limits, and fertilizer. Capital and labor

restrictions are discussed at the end of this chapter. A listing of specific restrictions appears in Table 12.

It is assumed that when a grower is not required to divert acreage he will produce crops on the previously diverted land subject to the new assumed crop limits. Therefore, new limits were applied to the model when diversion use was zero. These limits are illustrated in Table 12.

The construction of forecasted acreage limits was based on the assumption that when diverted acreage was opened to cultivation the amount of land allocated to the various crops would increase. Under these conditions, alfalfa would be 58 per cent of the available cropland in the SRP and 54 per cent in the RWCD. The individual restrictions are discussed in detail in the following material.

Land. Available cropland in the SRP and RWCD currently totals 171,000 acres. Since some crops use land throughout the entire production period while others use land only during part of the production period, land was set up in two parts, land A and land B. Land A refers to uses from January 1 to May 31 and land B from June 1 to December 31.

Water. Water is a major restriction to farming enterprises in Arizona. It is felt that water, in all its sources and characteristics, is critical to any model that

Table 12. Acreage and Water Limits for Different Farm Size Groups, SRP and RWCD

Constraint	SRP Size Groups				RWCD Size Groups	
	I	II	III	IV	I	II
Land A[a]	20,505	39,290	34,660	37,835	9,000	18,000
Land B[b]	20,505	39,290	34,660	37,835	9,000	18,000
Cotton Allotment	5,078	8,895	7,112	5,086	2,457	4,905
Diversion Use	1,016	1,779	1,422	1,017	491	981
Wheat Allotment		1,500	2,000		200	
Alfalfa Hay	6,835	14,007	11,554	12,612	2,500	5,000
Alfalfa Hay-Pasture	6,835	14,007	11,554	12,612	2,500	5,000
Barley	5,126	9,823	8,665	9,459	1,100	2,200
Sorghum	5,126	9,823	8,665	9,459	1,100	2,200
Barley Sorghum	5,126	9,823	8,665	9,459	1,100	2,200
Potatoes		229	367			200
Assessment Flow Water[c]	41,010	78,580	69,320	75,670		
Normal Flow Water[c]	10,253	19,645	17,330	18,918		
Stored and Developed Water[c]	20,505	39,290	34,660	37,835		
Private Pump Water[c]						
Project Pump Water[c]	41,010	78,580	69,320	75,670		
Summer Prorate Water[c]					27,000	54,000

[a]Total land available for production from January 1,to May 31.

[b]Total land available for production from June 1 to December 31.

[c]Total water available from each source.

depicts farming conditions in the SRP and RWCD. The water restrictions were constructed from irrigation district data from the SRP and RWCD. These data described water sources and amount of water per source for both districts. It is assumed that a grower has an unlimited water source in private pump water. That is, he can pump as much water as desired at the cost per acre-foot noted in Table 3. The water cost is considered constant due to the short run nature of this analysis.

Allotments. The farm survey data of Mack (1969) indicated that cotton allotment acreage varies according to model size. More specifically, smaller farms had a larger cotton allotment in relation to farm size than larger farms. Based on the 1970 cotton program (Field Crop Varieties for Arizona, 1970), acreage allotment restrictions and diversion use balances are placed on the models as shown in Tables 13 and 14.

The survey made of the different farm sizes includes the conditions under which the wheat allotments are determined. Tables 13 and 14 illustrate the number of acres devoted to the wheat enterprise for the different farm sizes.

Acreage restrictions are expressed in terms of limits on alfalfa, barley, and sorghum with respect to the SRP and RWCD regions. Salt River Project limits on alfalfa are set at no more than one-third of the available cropland.

Table 13. Assumed Acreage Limits Based on No Diversion Use for Aggregate Farm Models, SRP and RWCD

Constraint	SRP Size Groups				RWCD Size Groups	
	I	II	III	IV	I	II
Land A[a]	20,505	39,290	34,660	37,835	9,000	18,000
Land B[b]	20,505	39,290	34,660	37,835	9,000	18,000
Cotton Allotment	5,078	8,895	7,112	5,086	2,457	4,905
Wheat Allotment		1,500	2,000		200	
Alfalfa Hay	11,888	22,788	20,103	21,945	4,860	9,720
Alfalfa Hay-Pasture	11,888	22,788	20,103	21,945	4,860	9,720
Barley	8,612	16,503	14,558	15,891	2,160	4,320
Sorghum	8,612	16,503	14,558	15,891	2,160	4,320
Barley-Sorghum	8,612	16,503	14,558	15,891	2,160	4,320
Potatoes		229	367			200

[a]Land available for production from January 1 to May 31.

[b]Land available for production from June 1 to December 31.

Table 14. Representative Farm Sizes, Total Nitrogen Available, and Alternative Application Rates Tested

Representative Farm Sizes	Total Nitrogen (lb.)	Nitrogen Rate Alternatives for Each Crop (lbs. of N/ac.)			
		60	120	150	180
Group I Farms, SRP:					
120 lbs./A basis	2,460,600	X	X	X	X
60 lbs./A rates	1,230,300	X			
120 lbs./A rates	2,460,600	X	X		
150 lbs./A rates	3,075,750	X	X	X	
180 lbs./A basis	3,690,900	X	X	X	X
Group II Farms, SRP:					
120 lbs./A basis	4,714,800	X	X	X	X
60 lbs./A rates	2,357,400	X			
120 lbs./A rates	4,714,800	X	X		
150 lbs./A rates	5,893,500	X	X	X	
180 lbs./A basis	7,072,200	X	X	X	X
Group III Farms, SRP:					
120 lbs./A basis	4,159,200	X	X	X	X
60 lbs,/A rates	2,079,600	X			
120 lbs./A rates	4,159,200	X	X		
150 lbs./A rates	5,199,000	X	X	X	
180 lbs./A basis	6,238,800	X	X	X	X
Group IV Farms, SRP:					
120 lbs./A basis	4,540,200	X	X	X	X
60 lbs./A rates	2,270,100	X			
120 lbs./A rates	4,540,200	X	X		
150 lbs./A rates	5,675,250	X	X	X	
180 lbs./A basis	6,810,300	X	X	X	X
Group I Farms, RWCD:					
120 lbs./A basis	1,080,000	X	X	X	X
60 lbs./A rates	540,000	X			
120 lbs./A rates	1,080,000	X	X		
150 lbs./A rates	1,350,000	X	X	X	
180 lbs./A basis	1,620,000	X	X	X	X
Group II Farms, RWCD:					
120 lbs./A basis	2,160,000	X	X	X	X
60 lbs./A rates	1,080,000	X			
120 lbs./A rates	2,160,000	X	X		
150 lbs./A rates	2,700,000	X	X	X	
180 lbs./A basis	3,240,000	X	X	X	X

Barley and sorghum limits are set at no more than one-fourth of the available cropland. Limits in the RWCD for alfalfa are set at 27 per cent and barley and sorghum limits at 12 per cent of available cropland. As was mentioned previously, these crop limits reflect the typical acreages of these crops presently grown in the projects.

Fertilizer. The major objective of this research is to predict the impact of alternative nitrate nitrogen fertilizer restrictions on farms in the SRP and RWCD. Therefore, in order to observe the impact, fertilizer was restricted two ways. These two ways were judged to be the most probable policy action controlling fertilizer use in the agricultural sector.

First, fertilizer will be restricted to four specified per-acre application rates ranging from 60 to 180 pounds per acre for all crops. The models are constructed so that only one rate at a time is used in obtaining an optimum solution. Next, a total farm, or regional restriction is examined as an alternate way of limiting the use of nitrate nitrogen. This latter approach restricts only the total amount of nitrate nitrogen fertilizer consumed by farms in each size group. This form of restriction allows each farmer to allocate the total amount available among the different crops. With this fertilizer policy, the model will choose the optimum application rate for each crop and

allocate fertilizer to that crop until other resource restrictions are reached or until the total amount of fertilizer allowed is consumed.

The four application rates examined are 60, 120, 150, and 180 pounds per acre. A rate of 150 pounds per acre is considered the average rate of use for the crops studied in the SRP and RWCD by soil scientists interviewed by the author. In order to measure the impact of a rate restriction less than, equal to, or greater than the average rate, the rates of 120, 150, 180 pounds per acre were used. The impact of a highly restrictive rate was observed with the restriction of 60 pounds per acre. The total farm restriction was derived by using a 120 pounds per acre basis, i.e., 120 pounds of N multiplied by the number of acres in each farm size group. The choice of a 120 pounds basis is completely arbitrary, since we have no information as to the tolerance level of the region; however, such a basis is a reasonable first approximation of the level of restrictions which policy makers may impose. Time did not permit analysis of several possible bases for computing regional limits. In actual practice, such limits would probably be expressed as an aggregate regional consumptive limit determined by soil-water quality and health standards, hence, a per acre use limit figure, such as our 120 pounds, would not be required to calculate the total amount of fertilizer allowed.

In order to observe the most optimum fertilizer use situation, a 180 pound rate was used to compute the total farm limits. One hundred and eighty pounds was chosen because that level would not restrict the model in its choice of enterprises. The results using the 120 pound farm limit base were then compared with those derived from the total farm restriction using the 180-pound basis.

With more land available without diversion, the 120-pound base total farm restriction and the 60 pound per acre rate restriction were used not only because they were the most restrictive in their respective categories, but also because land use and enterprise combinations would be more affected by these restrictive situations than any of the other limitation situations.

The results of the rate restrictions and total farm limits are discussed in Chapter IV. Tables 15-18 (pp. 68-77) list the different types of fertilizer restrictions used in this analysis.

Capital and Labor Restrictions. Capital and labor restrictions are not included in the model. While particular farmers may face capital shortages, it appears that there is a plentiful supply of capital in the aggregate to farmers. Many farmers have a broad capital base upon which they can obtain credit. Furthermore, increased

mechanization coupled with a declining agricultural sector will reduce the demand for labor in the future.

CHAPTER IV

RESULTS FROM THE LINEAR PROGRAMMING MODEL

Results from the linear programming model were taken directly from the Alphac program printout. These results, listed in Tables 15 through 38, cover the six farm models (SRP-I, SRP-II, SRP-III, SRP-IV, RWCD-I, RWCD-II) for each production year. For each of the six farm models, there are four nitrate restriction situations to discuss: (1) a comparison between historical and projected cropping patterns with farm restrictions based upon 60 pounds, (2) a comparison between restricting per acre applications to 120 or 180 pounds using historical cropping as restraints upon production, (3) a comparison between historical and projected cropping patterns with a total farm restriction based upon 120 pounds per acre, and (4) a study of per acre restrictions set at 60, 120, 150, and 180 pounds using the historical cropping pattern.

For each farm size model the discussion will center on five questions, viz., for each type of fertilizer policy, what is the impact upon: (1) revenue, (2) enterprise combinations, (3) land utilization per crop, (4) the total amount of land used, and (5) the total amount of water used. The answers to these questions will help evaluate one possible

set of impacts, at the farm level in the SRP and RWCD of fertilizer regulations for one year of operation.

Discussion of the various programming solutions follows with those of the Salt River Project discussed first.

Salt River Project--I: 100 Acre Farms

Total Farm Restriction, 120 vs. 180 pounds N/ac. Base, Historical Cropping Patterns

By increasing the basis for computing nitrate fertilizer available to a farm unit from 120 to 180 pounds of N/ac., the revenue above variable costs increases by approximately $21,000 (see Table 15). This revenue figure and others like it mentioned later in this analysis is an aggregate figure for many farms within respective farm sizes. Furthermore, the highest revenue crop activity or enterprise enters the solution until the crop limits are reached and the land A and B resources is exhausted. This is expected because some agronomists feel that 180 pounds of nitrogen per acre is above the average recommended amount. It is interesting to note that the alfalfa hay-pasture (ALPH) enterprise, which requires little or no nitrate fertilizer, uses the residual amount of land A and land B after the cultivation limit of the crops requiring nitrate fertilizer are reached. In this formulation, the early-plant sorghum and wheat enterprise do not enter the solution

Table 15. SRP-I: 100 Acre Farms, Total Farm Restriction, 120 lbs. vs. 180 lbs. N/ac. Base, Historical Cropping Pattern

	120 lbs. N/ac. Basis[a]	180 lbs. N/ac. Basis[a]
Crop Enterprise:		
Cotton Skip-Row	5078 acres at 180 lbs. N/ac.	5078 acres at 180 lbs. N/ac.
Barley-Sorghum	5126 acres at 150 lbs. N/ac.	5126 acres at 180 lbs. N/ac.
Barley	2880 acres at 150 lbs. N/ac.	5126 acres at 150 lbs. N/ac.
Late Plant Sorghum	2880 acres at 120 lbs. N/ac.	5126 acres at 180 lbs. N/ac.
Alfalfa Hay-Pasture	6405 acres at 0 N/ac.	4159 acres at 0 N/ac.
Revenue and Resources:		
Total land used[b] (acres)	22,369	24,615
Total water used (acre-feet)	117,161	116,354
Total N used (lbs.)	2,460,600	3,988,200
Net Revenue[c] (dollars)	2,715,110	2,736,400

[a]Under total farm basis any fertilizer application rate may be used.

[b]Includes land A and land B, see page 59. The model may use all of a land type thereby exhausting the land resource.

[c]Returns over variable costs.

since ALPH has a higher net revenue, thereby allowing ALPH to consume the remaining acres of land A and land B.

Even more interesting, perhaps, is the enterprise combination resulting from the 120 pounds per acre basis. The model allocates resources to the highest net revenue enterprise, then as marginal returns to additional fertilizer fall the model shifts from the highest net revenue enterprise, which also is the heaviest user of fertilizer, to the next highest, thereby allowing more crop enterprises to enter into the solution and increasing the total net revenue of the solution. An example of this can be seen by observing the late-plant sorghum (LPS) crop enterprise under the total farm restriction of 120 pounds of N/A. As in the 180 pounds per acre total farm restriction case, the ALPH enterprise once again fully uses the residual amount of land A and land B. But in observing and evaluating the tables of results, one must be careful to note that the fertilizer resources were completely consumed in the 120 pounds per acre case but not so in 180 pounds per acre formulation.

The amount of land per crop also changes because the model runs out of fertilizer in the case of the total farm restriction of 120 pounds of nitrogen per acre. A little more than half as many acres of barley and late-plant sorghum come into the solution with this restriction compared to 180 pounds.

The land available in this model was totally consumed in both restriction situations, while water use was higher with the total farm restriction base of 120 pounds. The reason for this is that alfalfa hay-pasture (ALPH), which requires more than the average amount of water used by crops in this model, came into the solution with more acreage under the 120 pounds per acre conditions than under the 180 pounds per acre conditions.

Shadow prices are indicators of how the objective function would change with additional units of a constraining resource. Shadow prices are marginal value products, and are calculated by the Alphac program for each resource or crop limit that is completely consumed. As each crop enterprise enters the solution, resources are allocated so as to satisfy resource requirements of that enterprise. When a resource is exhausted, a shadow price is calculated to show what the addition to net revenue would be if an additional unit of that resource was available. For example, a shadow price for land A of $149.50 means that if an additional unit acre of land A were to be made available then the value of the objective function could be increased by that amount.

By observing the results one can see that the shadow prices on land with the 180-pound base are higher than with the 120-pound base. This is caused by the possibility of

higher net revenue if more land A and land B were available to the conditions under the higher total farm restriction.

It is important to note that under conditions of historical crop limits many of the higher net revenue enterprises come into the solution while a relatively smaller number of these enterprises enter the solution with expected crop limits. In the former case, the amount of land per enterprise is restricted to a relatively small amount so that certain production limits are reached quickly allowing for more land to be left over for use by the other enterprises, which, in turn, allows for many enterprises to enter the solution. However, the proposed crop limits are so large that only a few enterprises enter the solution because the land resource is exhausted at an early stage in the optimum solution.

Total Farm Restriction, 120 pounds N/ac.
Base, Historical vs. Projected Cropping Patterns

When the projected crop limits were used with the total farm restriction base of 120 pounds N/ac., the resulting increased acreage available for higher valued crops increased net revenue over variable cost by approximately $50,000 as compared with the model using historical cropping patterns (see Table 16). Since the majority of the acreage is used by the high revenue crops, only a small amount of land was allocated to the lower revenue crops.

Table 16. SRP-I: 100 Acre Farms, Total Farm Restriction, 120 lbs. N/ac., Historical vs. Projected Cropping Pattern

	Using Historical Cropping Pattern	Using Projected Cropping Pattern
Crop Enterprise:		
Cotton Skip-Row	5078 acres at 180 lbs. N/ac.	5078 acres at 180 lbs. N/ac.
Barley-Sorghum	5126 acres at 150 lbs. N/ac.	8612 acres at 150 lbs. N/ac.
Barley	2880 acres at 150 lbs. N/ac.	943 acres at 150 lbs. N/ac.
Late-Plant Sorghum	2880 acres at 120 lbs. N/ac.	943 acres at 120 lbs. N/ac.
Alfalfa Hay-Pasture	6405 acres at 0 N/ac.	5872 acres at 0 N/ac.
Revenue and Resources:		
Total land used[a] (acres)	22,369	21,448
Total water used (acre-feet)	117,161	115,363
Total N used (lbs.)	2,460,600	2,460,600
Net Revenue[b] (dollars)	2,715,110	2,769,569

[a]Includes land A and land B.

[b]Returns over variable costs.

This is typified by the decrease in acres planted to barley, late-plant sorghum, and alfalfa hay-pasture (ALPH) when the proposed limits were imposed. Both types of land (land A, which is available only during the early part of the year, and land B, available only during the latter part of the year) were completely exhausted.

Total water was approximately the same. The slight difference can be primarily attributed to alfalfa hay-pasture. Alfalfa hay-pasture requires more water than most other enterprises and has the ability to consume land even though the fertilizer resource is exhausted since alfalfa requires little or no nitrate fertilizer.

60, 120, 150, 180 pounds N/ac. Rate Restriction, Historical Crop Limits

Revenue increased as higher fertilizer rates were permitted (see Table 17), but at a decreasing rate, reflecting diminishing marginal returns to fertilizer. The phenomenon of diminishing marginal returns is shown in the response functions developed in Chapter II. Resource combinations followed the rate restrictions, i.e., as long as resources were available the model allocated fertilizer to the highest net revenue crop enterprise allowed by the restriction. For example, at a rate restriction of 120 pounds per acre, the crop enterprises that entered the solution came in at a level of 120 pounds per acre since

Table 17. SRP-I: 100 Acre Farms, Rate Restrictions 60, 120, 150, 180 lbs. N/ac., Historical Cropping Pattern

	60 lbs. N/ac.	120 lbs. N/ac.	150 lbs. N/ac.	180 lbs. N/ac.
Crop Enterprise:				
Cotton Skip-Row	5078 ac.	5078 ac.	5078 ac.	5078 ac.
Barley-Sorghum	5126 ac.	5126 ac.	5126 ac.	5126 ac.
Barley	2450 ac.	5126 ac.	5126 ac.	5126 ac.
Late-Plant Sorghum	2450 ac.	5126 ac.	5126 ac.	5126 ac.
Alfalfa Hay-Pasture	6835 ac.	4159 ac.	4159 ac.	4159 ac.
Revenue and Resources:				
Total land used[a] (acres)	21,939	24,615	24,615	24,615
Total water used (acre-feet)	117,659	108,694	117,659	117,659
Total N used (lbs.)	906,240	2,454,720	3,068,400	3,682,080
Net Revenue[b] (dollars)	2,106,799	2,554,273	2,751,227	2,790,859

[a]Includes land A and land B.

[b]Returns over variable costs.

this was the highest net revenue level allowed by the restrictions.

At the rate restriction of 60 pounds per acre, the net revenue was so low for barley and late-plant sorghum (LPS) that only a relatively small number of acres of these enterprises entered the solution. Furthermore, since alfalfa hay-pasture (ALPH) yielded higher net revenue than barley (BAR) and late-plant sorghum (LPS) and requires no nitrate fertilizer, the alfalfa hay-pasture (ALPH) enterprise entered the solution and used the remaining acreage of land A and land B. The other rate restrictions (120, 150, 180 pounds per acre) permitted high enough net revenues so that the crop limits were reached at the highest nitrate level. In these cases, alfalfa hay-pasture (ALPH) did not use as much acreage since higher revenue crops were available.

Total land use does not change but the way in which it was used caused total water use with the 60 pounds per acre rate restriction to be different from water use in the rate restriction. More of the high water using alfalfa hay-pasture (ALPH) enterprise entered the solution under the 60 pounds per acre rate than under the other rates.

The shadow prices increased but at a decreasing rate as the rate restrictions moved from 60 to 180 pounds per acre.

Historical vs. Projected Crop Patterns, Rate Restriction of 60 pounds N/ac.

The revenue over variable costs increased by $44,000 when the projected cropping patterns are used, with the rate restriction of 60 pounds N/ac., in place of historical crop limits (Table 18).

Enterprise combinations change in that more high revenue crops (i.e., alfalfa) enter the solution under the projected limits than under the historical limits. As before, the reason this occurs is that newer enterprises enter the solution but the magnitude of their entrance is greater due to the increased crop limits. Again total land use does not change significantly, but water use does, due to greatly increased acreages of alfalfa hay-pasture (ALPH) under the projected crop limit conditions.

Few shadow prices are provided by the model due to the number of resources and enterprises that were not exhausted in either the existing or proposed limit situations.

Salt River Project--II: 400 Acre Farms

Total Farm Restriction, 120 vs. 180 pounds N/ac. Base, Historical Cropping Patterns

Salt River Project Group II results differed very little from those of SRP Group I except in the magnitude of the resources and crops used. Net revenue increased

Table 18. SRP-I: 100 Acre Farms, Rate Restriction 60 lbs. N/ac., Historical vs. Projected Cropping Pattern

	Historical Cropping Pattern	Projected Cropping Pattern
Crop Enterprise:		
Cotton Skip-Row	5078 ac.	5078 ac.
Barley-Sorghum	5126 ac.	3539 ac.
Barley	2450 ac.	--
Late-Plant Sorghum	2450 ac.	--
Alfalfa Hay-Pasture	6835 ac.	11888 ac.
Revenue and Resources:		
Total land used[a] (acres)	21,939	20,505
Total water used (acre-feet)	117,659	123,521
Total N used (lbs.)	906,240	517,020
Net Revenue[b] (dollars)	2,106,799	2,150,941

[a]Includes land A and land B.

[b]Returns over variable costs.

approximately $300,000 when the total farm restriction was relaxed from the 120 pound base to the 180 pound base. The acreage of the enterprise combinations differed, as can be seen in Table 19. The amount of land per crop changes due to increased availability of fertilizer, but total land use does not change at the higher rate base because more acreage went to the other crop enterprises leaving less land available for alfalfa hay-pasture in the 180 pounds per acre situation. In total, due to more fertilizer, more land was used by the 180- than the 120-pound total farm restriction case. Since less alfalfa hay-pasture was produced with the 180 pound base, there was also less water used. Shadow prices reflected that an increase was possible if some of the existing crop limits were relaxed.

Total Farm Restriction, 120 pounds N/ac. Base, Historical vs. Projected Cropping Patterns

When the existing crop limits were relaxed to the projected limits, in the case of the 120 pound base total farm restriction net revenue increased $101,000 (Table 20). Since more acreage was available to the higher net revenue crops they came into the solution until a resource was exhausted. This forced the lower net revenue crops, which require nitrate fertilizer, into a smaller role on the farm. Alfalfa hay-pasture (ALPH) came into the solution to consume the remaining acreage but not with the magnitude it had in the past. Therefore, total land use was the same but

Table 19. SRP-II: 400 Acre Farms, Total Farm Restriction, 120 lbs. vs. 180 lbs. N/ac. Base, Historical Cropping Pattern

	120 lbs. N/ac. Basis[a]	180 lbs. N/ac. Basis[a]
Crop Enterprise:		
Cotton Skip-Row	8895 acres at 180 lbs. N/ac.	8895 acres at 180 lbs. N/ac.
Barley-Sorghum	9823 acres at 150 lbs. N/ac.	9823 acres at 180 lbs. N/ac.
Barley	5216 acres at 150 lbs. N/ac.	9594 acres at 150 lbs. N/ac.
Late-Plant Sorghum	5445 acres at 150 lbs. N/ac.	9823 acres at 180 lbs. N/ac.
Potatoes	229 acres at 150 lbs. N/ac.	229 acres at 180 lbs. N/ac.
Alfalfa Hay-Pasture	13348 acres at 0 N/ac.	8970 acres at 0 N/ac.
Revenue and Resources:		
Total land used[b] (acres)	42,956	47,334
Total water used (acre-feet)	228,114	226,910
Total N used (lbs.)	4,714,800	6,617,700
Net Revenue[c] (dollars)	6,369,374	6,669,152

[a]Under total farm basis any fertilizer application rate may be used.

[b]Includes land A and land B.

[c]Returns over variable costs.

Table 20. SRP-II: 400 Acre Farms, Total Farm Restriction, 120 lbs. N/ac., Historical vs. Projected Cropping Pattern

	Using Historical Cropping Pattern	Using Projected Cropping Pattern
Crop Enterprise:		
Cotton Skip-Row	8895 acres at 180 lbs. N/ac.	8895 acres at 180 lbs. N/ac.
Barley-Sorghum	9823 acres at 150 lbs. N/ac.	16503 acres at 150 lbs. N/ac.
Barley	5216 acres at 150 lbs. N/ac.	3437 acres at 150 lbs. N/ac.
Late-Plant Sorghum	5445 acres at 150 lbs. N/ac.	2105 acres at 150 lbs. N/ac.
Potatoes	229 acres at 180 lbs. N/ac.	229 acres at 180 lbs. N/ac.
Alfalfa Hay-Pasture	13348 acres at 0 N/ac.	11787 acres at 0 N/ac.
Revenue and Resources:		
Total land used[a] (acres)	42,956	42,956
Total water used (acre-feet)	228,114	224,239
Total N used (lbs.)	4,714,800	4,714,800
Net Revenue[b] (dollars)	6,369,374	6,470,723

[a]Includes land A and land B.

[b]Returns over variable costs.

total water use was less when expected crop limits were used instead of the past crop acreage, water use was low due to decreased acreage of alfalfa hay-pasture.

60, 120, 150, 180 pounds N/ac. Rate Restrictions, Historical Crop Pattern

The rate restriction situations once again showed nothing out of the ordinary. Net revenue increased at a decreasing rate as rate restrictions were relaxed (Table 21). Net revenue for the crop enterprises at the rate of 60 pounds N/ac. was so low that the alfalfa hay-pasture (ALPH) enterprise entered the solution and exhausted its land limit before any of the lower net revenue enterprises entered the solution. In the other rate restriction cases, the enterprises entered the solution at the highest fertilizer-net revenue rates possible; even though the highest net revenue enterprise for barley occurs at the 150 pound per acre level. The amount of land per crop did not change since resources were available so that the crop limits could be reached. Due to the entrance of alfalfa hay-pasture (ALPH) in the 60 pound N/ac. case, few acres were left over for the remaining enterprises; this accounts for the low total acreage in that solution. Total land use did not change among the rates, but the heavy entrance of high water using alfalfa hay-pasture (ALPH) into the 60 pound N/ac. case caused high water use while water

Table 21. SRP-II: 400 Acre Farms, Rate Restrictions 60, 120, 150, 180 lbs. N/ac., Historical Cropping Pattern

	60 lbs. N/ac.	120 lbs. N/ac.	150 lbs. N/ac.	180 lbs. N/ac.
Crop Enterprise:				
Cotton Skip-Row	8895 ac.	8895 ac.	8895 ac.	8895 ac.
Barley-Sorghum	9823 ac.	9823 ac.	9823 ac.	9823 ac.
Barley	4557 ac.	9594 ac.	9594 ac.	9594 ac.
Late-Plant Sorghum	4786 ac.	9823 ac.	9832 ac.	9823 ac.
Potatoes	229 ac.	229 ac.	229 ac.	229 ac.
Alfalfa Hay-Pasture	14007 ac.	8970 ac.	8970 ac.	8970 ac.
Revenue and Resources:				
Total land used[a] (acres)	42,297	47,334	47,334	47,334
Total water used (acre-feet)	227,350	211,322	227,350	227,350
Total N used (lbs.)	1,697,400	4,603,680	5,754,600	6,905,520
Net Revenue[b] (dollars)	4,546,491	5,719,505	6,080,989	6,146,082

[a]Includes land A and land B.

[b]Returns over variable costs.

utilization with each of the other rates was approximately the same.

The values of the shadow prices increase but at a decreasing rate. Since the shadow prices indicate how net revenue would change with an additional unit of an exhausted resource, they follow the same tendencies as net revenue, viz., increasing at a decreasing rate as the rates are relaxed.

Historical vs. Projected Crop Patterns, Rate Restrictions of 60 pounds N/ac.

Net revenue increases as is expected by $100,000 when possible future cropping conditions are used instead of the existing limits with the rate restriction of 60 pounds N/ac. Revenue increases because more acreage is available to high net revenue enterprises under the proposed crop limits than under the existing limits. Enterprise combinations do change as does the amount of land per crop. The fact that projected cropping problems which allow for high revenue crops to enter the solution accounts for the changes. Fewer acres are left for low revenue crops after the high revenue crops have entered the solution at the projected crop limits. Due to the heavy entrance of alfalfa hay-pasture (ALPH) into the projected limit solution, water use was high. Total land use remained the same. The shadow prices decreased in the projected crop limit case due to the heavy entrance of the high net revenue crops and thereby

reduced the possibility of increasing net revenue. It must be remembered that under the 60 pound acre rate restriction, whether under proposed or existing crop limits, the crops that require nitrogen enter the solution at low revenue levels. Therefore, allowing alfalfa hay-pasture (ALPH) to enter the solution to its crop limit until the other crops with lower revenue are allowed to enter the solution. This occurrence had noticeable effects on enterprise combinations, acreage per crop, and water use. These effects can be easily noted by examining Table 22.

Salt River Project--III: 900 Acre Farms

Total Farm Restriction, 120 vs. 180 pounds N/ac. Base, Historical Cropping Patterns

Net revenue increases by $19,000 when the total farm restriction base is increased from 120 pounds to 180 pounds N/ac. (Table 23). Enterprise combinations in this model differ in a unique way from previous models, the basic reason being that the fertilizer resource was exhausted in the 120 pound per acre case. With fertilizer becoming scarce, the model had to allocate fertilizer at lower rates in order to maximize total net revenue. This fact also attributed to acreage per crop differing between the two cases. Total land use does not change significantly. With the farm restriction base of 180 pounds there was enough fertilizer to be applied to the high net revenue rates so

Table 22. SRP-II: 400 Acre Farms, Rate Restriction 60 lbs. N/ac., Historical vs. Projected Cropping Pattern

	Historical Cropping Pattern	Projected Cropping Pattern
Crop Enterprise:		
Cotton Skip-Row	8895 ac.	8895 ac.
Barley-Sorghum	9823 ac.	7378 ac.
Barley	4557 ac.	--
Late-Plant Sorghum	4786 ac.	--
Potatoes	229 ac.	229 ac.
Alfalfa Hay-Pasture	14007 ac.	22788 ac.
Revenue and Resources:		
Total land used[a] (acres)	42,297	39,290
Total water used (acre-feet)	227,350	235,535
Total N used (lbs.)	1,697,400	99,010
Net Revenue[b] (dollars)	4,546,491	4,617,956

[a]Includes land A and land B.

[b]Returns over variable costs.

Table 23. SRP-III: 900 Acre Farms, Total Farm Restrictions, 120 lbs. vs. 180 lbs. N/ac. Base, Historical Cropping Pattern

	120 lbs. N/ac. Basis[a]	180 lbs. N/ac. Basis[a]
Crop Enterprise:		
Cotton Skip-Row	7112 acres at 180 lbs. N/ac.	7112 acres at 180 lbs. N/ac.
Barley-Sorghum	8665 acres at 150 lbs. N/ac.	8665 acres at 180 lbs. N/ac.
Barley	5540 acres at 150 lbs. N/ac.	8298 acres at 180 lbs. N/ac.
Late-Plant Sorghum	443/5464 acres at 60/120 lbs. N/ac.	8665 acres at 180 lbs. N/ac.
Potatoes	367 acres at 180 lbs. N/ac.	367 acres at 180 lbs. N/ac.
Alfalfa Hay-Pasture	11554 acres at 0 N/ac.	8796 acres at 0 N/ac.
Revenue and Resources:		
Total land used[b] (acres)	39,145	41,903
Total water used (acre-feet)	200,316	197,385
Total N used (lbs.)	4,159,200	5,710,320
Net Revenue[c] (dollars)	5,200,440	5,219,343

[a]Under total farm restrictions any fertilizer application rate may be used.

[b]Includes land A and land B.

[c]Returns over variable costs.

that there was not very much land remaining for the alfalfa hay-pasture (ALPH) enterprise. With this reduced acreage of alfalfa hay-pasture (ALPH), total water use decreased from its level under the conditions of the 120-pound farm restriction base.

Total Farm Restrictions, 120 pounds N/ac. Base, Historical vs. Projected Cropping Patterns

When expected cropping acreage is used with the 120 pound farm restriction base, instead of the past limits, net revenue increases $28,000 (Table 24). The new crop limits do not change the enterprise combinations or total land use, but they do change acreage per crop. The expected limits allow most of the available land to be allocated to the high net revenue crops while alfalfa hay-pasture (ALPH) and the other lower revenue crops are allocated much less land than under the existing crop limits. The reduced level of alfalfa also reduces total water use. Exhaustion of the fertilizer resource restricted the magnitude of the entry of some of the crop enterprises which had revenue values higher than alfalfa hay-pasture (ALPH) but which required nitrate fertilizer. This caused shadow prices to be lower in the total farm restriction example of 120 pounds per acre.

60, 120, 150, 180 pounds N/ac. Rate Restrictions, Historical Crop Patterns

As the rate restrictions are relaxed from 60 to 180 pounds N/ac., the net revenue over variable cost figure

Table 24. SRP-III: 900 Acre Farms, Total Farm Restriction, 120 lbs. N/ac., Historical vs. Projected Cropping Pattern

	Using Historical Cropping Pattern	Using Projected Cropping Pattern
Crop Enterprise:		
Cotton Skip-Row	7112 acres at 180 lbs. N/ac.	7112 acres at 180 lbs. N/ac.
Barley-Sorghum	8665 acres at 150 lbs. N/ac.	14558 acres at 150 lbs. N/ac.
Barley	5540 acres at 150 lbs. N/ac.	1914 acres at 150 lbs. N/ac.
Late-Plant Sorghum	443/5464 acres at 60/120 lbs. N/ac.	2281 acres at 150 lbs. N/ac.
Potatoes	367 acres at 180 lbs. N/ac.	367 acres at 180 lbs. N/ac.
Alfalfa Hay-Pasture	11554 acres at 0 N/ac.	10709 acres at 0 N/ac.
Revenue and Resources:		
Total land used[a] (acres)	39,145	36,941
Total water used (acre-feet)	200,316	200,047
Total N used (lbs.)	4,159,200	4,159,200
Net Revenue[b] (dollars)	5,200,440	5,228,113

[a]Includes land A and land B.

[b]Returns over variable costs.

increases but at a decreasing rate (Table 25). The only rate that leads to results greatly different from the others is the 60 pound per acre case. The difference is that at this rate crops that require nitrate fertilizer do not enter the solution until after the alfalfa hay-pasture (ALPH) enterprise. Because net revenue for alfalfa hay-pasture is higher than all crop enterprises except for skip-row plant cotton (COT SK) and barley sorghum (BARSOR). After the entrance of alfalfa hay-pasture, there were not many acres of the land resource left which accounts for the low relative magnitude of the barley (BAR) and late-plant sorghum (LPS) crop enterprises. With all of the rates the model allocated resources to the highest net revenut-highest fertilizer rate crop activity allocated by the rate restriction. The amount of land per crop did not change between the rates except in the previously mentioned 60 pound per acre case. The land resource was used completely, except in the 60 pound per acre case, by all the rates. Water use was greater under the 60 pound per acre rate restriction than under the other rates due to the heavy entrance of the alfalfa hay-pasture (ALPH) enterprise in the 60 pound per acre situation.

Historical vs. Projected Crop Patterns,
Rate Restrictions of 60 pounds N/ac.

When projected limits instead of the historical patterns are used in conjunction with the rate restriction

Table 25. SRP-III: 900 Acre Farms, Rate Restrictions 60, 120, 150, 180 lbs. N/ac., Historical Cropping Pattern

	60 lbs. N/ac.	120 lbs. N/ac.	150 lbs. N/ac.	180 lbs. N/ac.
Crop Enterprise:				
Cotton Skip-Row	7112 ac.	7112 ac.	7112 ac.	7112 ac.
Barley-Sorghum	8665 ac.	8665 ac.	8665 ac.	8665 ac.
Barley	5540 ac.	8298 ac.	8298 ac.	8298 ac.
Late-Plant Sorghum	5907 ac.	8665 ac.	8665 ac.	8665 ac.
Potatoes	367 ac.	367 ac.	367 ac.	367 ac.
Alfalfa Hay-Pasture	11554 ac.	8796 ac.	8796 ac.	8796 ac.
Revenue and Resources:				
Total land used[a] (acres)	39,145	41,903	41,903	41,903
Total water used (acre-feet)	200,316	186,488	186,488	186,488
Total N used (lbs.)	1,655,460	3,972,840	4,966,050	5,959,260
Net Revenue[b] (dollars)	4,175,266	5,411,730	5,730,406	5,822,703

[a]Includes land A and land B.

[b]Returns over variable costs.

of 60 pounds, the net revenue increases by $290,000 (Table 26). Again, due to the heavy entrance of alfalfa hay-pasture, low revenue crops are forced to enter at a low magnitude. Under the anticipated crop cultivation acreages, alfalfa hay-pasture has a lot of acres to draw from and when the limit is reached there are not many acres left for the other crops. Alfalfa hay-pasture used more acres in the projected limit situation than in the existing limit situation. Enterprise combinations and land use remain about the same. But water use increased when the projected crop limits are used due to the heavy entrance of the alfalfa hay-pasture crop enterprise.

Salt River Project--IV: 1,800 Acre Farms

Total Farm Restrictions, 120 vs. 180 pounds N/ac. Base, Historical Cropping Pattern

The programming results for the size group SRP-IV differed from the previous SRP size groups only in activity levels and objective function values.

When the farm restriction base of 120 pounds N/ac. was relaxed to 180 pounds per acre, the net revenue increased by $32,000 (Table 27). The enterprise combinations were similar, except that as before the fertilizer resource was exhausted with the lower base which caused the model to choose the crop enterprises that did not require high levels of nitrate fertilizer. Fertilizer was allocated to crop

Table 26. SRP-III: 900 Acre Farms, Rate Restriction 60 lbs. N/ac., Historical vs. Projected Cropping Pattern

	Historical Cropping Pattern	Projected Cropping Pattern
Crop Enterprise:		
Cotton Skip-Row	7112 ac.	7112 ac.
Barley-Sorghum	8665 ac.	--
Barley	5540 ac.	7078 ac.
Late-Plant Sorghum	5907 ac.	7445 ac.
Potatoes	367 ac.	367 ac.
Alfalfa Hay-Pasture	11554 ac.	20103 ac.
Revenue and Resources:		
Total land used[a] (acres)	39,145	42,105
Total water used (acre-feet)	200,316	219,944
Total N used (lbs.)	1,655,460	1,320,120
Net Revenue[b] (dollars)	4,175,266	4,460,799

[a]Includes land A and land B.

[b]Returns over variable costs.

Table 27. SRP-IV: 1800 Acre Farms, Total Farm Restriction, 120 lbs. vs. 180 lbs. N/ac. Base, Historical Cropping Pattern

	120 lbs. N/ac. Basis[a]	180 lbs. N/ac. Basis[a]
Crop Enterprise:		
Cotton Skip-Row	5086 acres at 180 lbs. N/ac.	5086 acres at 180 lbs. N/ac.
Barley-Sorghum	9459 acres at 150 lbs. N/ac.	9459 acres at 180 lbs. N/ac.
Barley	9459 acres at 150 lbs. N/ac.	9459 acres at 180 lbs. N/ac.
Early-Plant Sorghum	201 acres at 120 lbs. N/ac.	201 acres at 180 lbs. N/ac.
Late-Plant Sorghum	9459 acres at 120 lbs. N/ac.	9459 acres at 180 lbs. N/ac.
Alfalfa Hay-Pasture	12612 acres at 0 N/ac.	12612 acres at 0 N/ac.
Revenue and Resources:		
Total land used[b] (acres)	42,676	42,676
Total water used (acre-feet)	219,166	219,166
Total N used (lbs.)	4,540,200	5,775,900
Net Revenue[c] (dollars)	5,959,292	5,991,344

[a]Under total farm restrictions any fertilizer application rate may be used.

[b]Includes land A and land B.

[c]Returns over variable costs.

enterprises in amounts lower than the highest revenue but in so doing allowed additional enterprises to enter. This resulted in the highest total net revenue possible with the given restriction circumstances. The total land use did not change and the amount of land per crop did not change either. For the first time the Grain Sorghum enterprise was divided into two growing seasons, late and early plant. This occurred since there were enough resources available after the initial allocation to allow for the double cropping of Grain Sorghum. This phenomenon happened throughout the SRP-IV analysis except in the two cases where proposed crop limits were present instead of the existing crop limits. The proposed crop limits are large enough to allow full utilization of all land resources. Total water use remained the same.

Total Farm Restriction, 120 pounds N/ac. Base, Historical vs. Projected Cropping Pattern

Net revenue over variable costs increased about $230,000 when the assumed crop limits were used (Table 28). Enterprise combinations, however, were different. With the projected limits, the model had more acreage per crop available. The large acreages that entered the solution demanded a large amount of fertilizer. The resulting fertilizer requirements forced the model to choose a lower fertilizer rate per crop in order to meet the overall fertilizer restriction. The fertilizer resource was

Table 28. SRP-IV: 1800 Acre Farms, Total Farm Restriction, 120 lbs. N/ac., Historical vs. Projected Cropping Pattern

	Using Historical Cropping Pattern	Using Projected Cropping Pattern
Crop Enterprise:		
Cotton Skip-Row	5086 acres at 180 lbs. N/ac.	5086 acres at 180 lbs. N/ac.
Barley-Sorghum	9459 acres at 150 lbs. N/ac.	--
Barley	9459 acres at 150 lbs. N/ac.	12082 acres at 150 lbs. N/ac.
Early-Plant Sorghum	201 acres at 120 lbs. N/ac.	--
Late-Plant Sorghum	9459 acres at 120 lbs. N/ac.	12082 acres at 150 lbs. N/ac.
Alfalfa Hay-Pasture	12612 acres at 0 N/ac.	20667 acres at 0 N/ac.
Revenue and Resources:		
Total land used[a] (acres)	42,676	49,917
Total water used (acre-feet)	219,166	229,523
Total N used (lbs.)	4,540,200	4,540,200
Net Revenue[b] (dollars)	5,959,292	6,184,071

[a]Includes land A and land B.

[b]Returns over variable costs.

exhausted under the projected crop limit conditions. Few crops entered the solution under the proposed limits because the increased magnitude of their entry consumed the land resource thereby bringing lower net revenue crops into solution. The total amount of land used did not change, but water use increased with the projected limits. The alfalfa hay-pasture crop enterprise used more acres under the projected crop limits than under the existing crop limits and alfalfa hay-pasture is a heavy user of water resources.

60, 120, 150, 180 pounds N/ac. Rate
Restrictions, Historical Crop Patterns

Net revenue over variable cost increases but at a decreasing rate as the rate restrictions move from 60 to 180 pounds N/ac. (Table 29). Enterprise combinations do not change as the rate restrictions were relaxed. Adequate amounts of land, water, and fertilizer are part of the reason the enterprise combinations remained constant as restrictions were relaxed. The relationship between the net revenue of the crop enterprises also account for the enterprise combinations remaining constant. These same reasons explain why the amount of land per crop remained the same as rate restrictions were relaxed. The total amount of land and water used did not change,

Table 29. SRP-IV: 1800 Acre Farms, Rate Restrictions 60, 120, 150, 180 lbs. N/ac., Historical Cropping Pattern

	60 lbs. N/ac.	120 lbs. N/ac.	150 lbs. N/ac.	180 lbs. N/ac.
Crop Enterprise:				
Cotton Skip-Row	5086 ac.	5086 ac.	5086 ac.	5086 ac.
Barley-Sorghum	9459 ac.	9459 ac.	9459 ac.	9459 ac.
Barley	9459 ac.	9459 ac.	9459 ac.	9459 ac.
Early-Plant Sorghum	201 ac.	201 ac.	201 ac.	201 ac.
Late-Plant Sorghum	9459 ac.	9459 ac.	9459 ac.	9459 ac.
Alfalfa Hay-Pasture	12612 ac.	12612 ac.	12612 ac.	12612 ac.
Revenue and Resources:				
Total land used[a] (acres)	46,276	46,276	46,276	46,276
Total water used (acre-feet)	219,166	219,166	219,166	219,166
Total N used (lbs.)	2,019,840	4,039,680	5,049,600	6,059,520
Net Revenue[b] (dollars)	4,951,090	5,650,041	5,949,741	5,988,979

[a]Includes land A and land B.

[b]Returns over variable costs.

Historical vs. Projected Crop Patterns,
Rate Restriction of 60 pounds N/ac.

The results of the comparison between past and possible future cropping "preferences" with the rate of 60 pounds N/ac. are similar to those of the same comparison using the 120 pound base (Table 30).

When the future patterns were used net revenue increased by $360,000. Enterprise combinations change because under the proposed limits more land is available for cultivation. Therefore, high net revenue crop enterprises enter the solution at high levels forcing lower net revenue crops to lower acreage. Fewer crop enterprises are optimal under future patterns of cultivation with the historical patterns. Due to the higher acreages available, the amount of land per crop is greater. Total land use does not change, but due to the increased magnitude at which alfalfa hay-pasture entered the solution, total water use once again changes.

Before moving to the discussion of the Roosevelt Water Conservation District size groups, it should be noted that a shortage of response function data caused the elimination of some crops, such as sugar beets, lettuce, green silage, etc. These other crops could have made the discussion of the SRP size groups more inclusive of the characteristics of the SRP. Chapter V contains a summary of the conclusions derived from this analysis, including data

Table 30. SRP-IV: 1800 Acre Farms, Rate Restriction 60 lbs. N/ac., Historical vs. Projected Cropping Pattern

	Historical Cropping Pattern	Projected Cropping Pattern
Crop Enterprise:		
Cotton Skip-Row	5086 ac.	5086 ac.
Barley-Sorghum	9459 ac.	--
Barley	9459 ac.	10804 ac.
Early-Plant Sorghum	201 ac.	--
Late-Plant Sorghum	9459 ac.	10804 ac.
Alfalfa Hay-Pasture	12612 ac.	21945 ac.
	0 N/ac.	0 N/ac.
Revenue and Resources:		
Total land used[a] (acres)	46,276	48,639
Total water used (acre-feet)	219,166	231,006
Total N used (lbs.)	2,019,890	1,601,640
Net Revenue[b] (dollars)	4,951,090	4,652,419

[a]Includes land A and land B.

[b]Returns over variable costs.

shortage, and the quality of this information used in this report.

Roosevelt Water Conservation District--I: 400 Acre Farms

Total Farm Restriction, 120 vs. 180 pounds N/ac. Base, Historical Cropping Pattern

The results from the optimum solution show that the conditions under the 120 pound rate base are the same as those under the 180 pound base, except in residual amounts of nitrogen left over in the 180 pound case. Enterprise combinations, the amount of land per crop, the total amount of land used, total amount of water used, and shadow prices are the same in the two restriction situations (Table 31).

Total Farm Restriction, 120 pounds N/ac. Base, Historical vs. Projected Cropping Patterns

When comparing the 120 pound farm restriction base under existing crop limits with the case of assumed crop limits, some notable differences arise. Revenue increases approximately $47,000 with the projected limits (Table 32). The enterprise combinations shift to positions which optimize the usage of water and fertilizer. With the projected limits more land is available which, in turn, puts a strain on the water and fertilizer resources. The increased demand for the resources forces the model to adopt

Table 31. RWCD-I: 100 Acre Farms, Total Farm Restriction, 120 lbs. vs. 180 lbs. N/ac. Base, Historical Cropping Pattern

	120 lbs. N/ac. Basis[a]	180 lbs. N/ac. Basis[a]
Crop Enterprise:		
Cotton Skip-Row	2750 acres at 180 lbs. N/ac.	2750 acres at 180 lbs. N/ac.
Barley-Sorghum	779 acres at 180 lbs. N/ac.	779 acres at 180 lbs. N/ac.
Barley	779 acres at 150 lbs. N/ac.	779 acres at 150 lbs. N/ac.
Early-Plant Sorghum	779 acres at 180 lbs. N/ac.	779 acres at 180 lbs. N/ac.
Late-Plant Sorghum	779 acres at 180 lbs. N/ac.	779 acres at 180 lbs. N/ac.
Wheat	106 acres at 180 lbs. N/ac.	106 acres at 180 lbs. N/ac.
Alfalfa Hay-Pasture	1469 acres at 0 N/ac.	1469 acres at 0 N/ac.
Revenue and Resources:		
Total land used[b] (acres)	7,441	7,441
Total water used (acre-feet)	36,037	36,037
Total N used (lbs.)	1,051,590	1,051,590
Net Revenue[c] (dollars)	1,107,243	1,107,243

[a]Under total farm restrictions any fertilizer application rate may be used.

[b]Includes land A and land B.

[c]Returns over variable costs.

Table 32. RWCD-I: 100 Acre Farms, Total Farm Restriction, 120 lbs. N/ac., Historical vs. Projected Cropping Pattern

	Using Historical Cropping Pattern	Using Projected Cropping Pattern
Crop Enterprise:		
Cotton Skip-Row	2750 acres at 180 lbs. N/ac.	2750 acres at 180 lbs. N/ac.
Barley-Sorghum	779 acres at 180 lbs. N/ac.	2100 acres at 150 lbs. N/ac.
Barley	779 acres at 150 lvs. N/ac.	1800 acres at 150 lbs. N/ac.
Early-Plant Sorghum	779 acres at 180 lbs. N/ac.	--
Late-Plant Sorghum	779 acres at 180 lbs. N/ac.	--
Wheat	106 acres at 180 lbs. N/ac.	--
Alfalfa Hay-Pasture	1469 acres at 0 N/ac.	--
Revenue and Resources:		
Total land use[a] (acres)	7,441	6,650
Total water use (acre-feet)	36,037	32,550
Total N use (lbs.)	1,051,590	1,080,000
Net Revenue[b] (dollars)	1,107,243	1,154,042

[a]Includes land A and land B.

[b]Returns over variable costs.

enterprises that are one step lower than the highest net revenue enterprise.

The amount of land per crop changes due to the assumed crop limits being greater than the past limits. Under assumed crop limits fertilizer and water were totally consumed by the model, thereby forcing out of the solution enterprises previously accepted under existing limits.

Due to the new crop limits, approximately 800 fewer acres entered the solution. The new crop limits allowed high revenue crops to enter the solution in higher amounts. This increased acreage of high revenue crops required more water than before, which, in turn, exhausted water resources and precluded cultivation of other crops.

The shadow prices or marginal value products of the exhausted resources are higher in the case of existing limits, than with the projected limits, even though revenue is higher under the projected limits. If another pound of fertilizer were available to the model, it would raise the value of the objective function (net revenue) by 22 cents. One more acre-foot of water would raise the value of the objective function by $5.60.

60, 120, 150, 180 pounds N/ac. Rate Restrictions, Historical Crop Patterns

As can be seen in Table 33, revenue steadily increases as the rate restriction is allowed to increase from 120 to 150 and then to 180 pounds of nitrogen per acre.

Table 33. RWCD-I: 100 Acre Farms, Rate Restrictions 60, 120, 150, 180 lbs. N/ac., Historical Cropping Pattern

	60 lbs. N/ac.	120 lbs. N/ac.	150 lbs. N/ac.	180 lbs. N/ac.
Crop Enterprise:				
Cotton Skip-Row	2750 ac.	2750 ac.	2750 ac.	2750 ac.
Barley-Sorghum	779 ac.	779 ac.	779 ac.	779 ac.
Barley	779 ac.	779 ac.	779 ac.	779 ac.
Early-Plant Sorghum	779 ac.	779 ac.	779 ac.	779 ac.
Late-Plant Sorghum	779 ac.	779 ac.	779 ac.	779 ac.
Wheat	--	106 ac.	106 ac.	106 ac.
Alfalfa Hay-Pasture	1537 ac.	1469 ac.	1469 ac.	1469 ac.
Revenue and Resources:				
Total land used[a] (acres)	7,403	7,441	7,441	7,441
Total water used (acre-feet)	38,152	36,105	36,105	36,105
Total N used (lbs.)	351,960	716,640	895,800	1,074,960
Net Revenue[b] (dollars)	863,551	1,007,613	1,086,348	1,107,118

[a]Includes land A and land B.

[b]Returns over variable costs.

From 120 to 150 pounds, the revenue increase is about $80,000 and from 150 to 180 pounds, the increase is about $20,000 (Table 33).

Enterprise combinations change but only to the highest fertilizer level (highest net revenue) allowed by the respective restriction. That is, when fertilizer is restricted to a rate of 60 pounds per acre that rate is the only one used by the model because it is the highest rate and revenue level available. The same is true for the rates of 120 and 150 pounds per acre. These rates are the only ones used by the model when so restricted. One exception is that wheat did not enter the model under the 60 pounds per acre restriction because alfalfa hay-pasture had a higher net revenue. Therefore, alfalfa hay-pasture entered and increased the usage of the water resources.

The amount of land per crop remained the same except for wheat and alfalfa hay-pasture when comparing 60 pounds of N/acre with the other rate levels. Total land and water use did not change appreciably. The one value that did change significantly is the amount of nitrogen used, which increased as the rate restriction was relaxed.

The shadow prices increased along with revenue as the allowable rate increased. As an example, one additional unit of the cotton allotment under 60 pounds per acre would increase the value of the objective function by $137; under 120 pounds per acre, $178; and under 150 pounds per acre,

$192. If one wants to check the results of a rate restriction of 180 pounds per acre, observe the total farm restriction of 180 pounds per acre. The 180 pounds per acre rate is in line with the previous discussion of the rate restrictions; resources combinations changed with the rate, land per crop did not change, total land and total water usage did not significantly change. Residual nitrogen did increase. What is interesting to note is that the shadow prices and objective function value increased but at a decreasing rate, indicating diminishing marginal returns. This occurs first in the move from the rate of 120 to 150 pounds of N/ac., but is most obvious in the move from 150 to 180 pounds. In simpler terms, diminishing marginal returns means that the shadow prices and net revenue above variable costs are increasing but at a decreasing rate.

Historical vs. Projected Crop Patterns,
Rate of Restriction of 60 pounds N/ac.

When comparing net revenues, the 60 pounds per acre restriction with the projected limits yields $10,000 more than the case with existing limits (Table 34). Again, the new crop limits force the solution to take on different combinations. The model allocated resources to the highest net revenue enterprises until the respective crop limits were met and until the water resource was consumed. The barley-sorghum enterprise was not allowed to reach its limit due to a shortage of water. Approximately 600 more acres

Table 34. RWCD-I: 100 Acre Farms, Rate Restriction 60 lbs. N/ac., Historical vs. Projected Cropping Pattern

	Historical Cropping Pattern	Projected Cropping Pattern
Crop Enterprise:		
Cotton Skip-Row	2750 ac.	2750 ac.
Barley-Sorghum	779 ac.	1020 ac.
Barley	779 ac.	2160 ac.
Early-Plant Sorghum	779 ac.	2160 ac.
Late-Plant Sorghum	779 ac.	--
Wheat	--	--
Alfalfa Hay-Pasture	1537 ac.	--
Revenue and Resources:		
Total land used[a] (acres)	7,463	8,090
Total water used (acre-feet)	36,105	33,990
Total N used (lbs.)	351,960	485,400
Net Revenue[b] (dollars)	863,551	874,135

[a]Includes land A and land B.

[b]Returns over variable costs.

were used by the rate restriction of 60 pounds per acre with the existing limits. The reasons for this are the same as in the previous case of existing versus projected crop limits. Total water use was about the same as before.

Although the majority of the shadow prices were down from the previous values, the water shadow prices increased from $5.63 to $8.80 under the projected crop limit conditions. This condition was caused by a number of high return enterprises not completely entering the solution due to a shortage of water.

Roosevelt Water Conservation District--II: 400 Acre Farms

Total Farm Restriction, 120 vs. 180 pounds N/ac. Base, Historical Cropping Patterns

The results for farm size Group II are very similar to those for Group I. More acreage and water are available to RWCD-II which allows for more acreage to be allocated to various enterprises than in TWCD-I. However, enterprise combinations are the same for both groups.

When comparing these base restrictions, it is found that the revenues, enterprise combination, the amount of land per crop, the total amount of land used, the total amount of water used, and the shadow prices are the same under both restriction levels. This occurs because there is more than sufficient fertilizer available and that water was

restricted to the model at the same level in both cases (Table 35).

Total Farm Restriction, 120 pounds N/ac. Base, Historical vs. Projected Cropping Patterns

When anticipated crop limits are used in conjunction with the base restriction of 120 pounds, the results are quite different from those obtained with the past crop limits (Table 36). For instance, net revenue increases by approximately $130,000 and only a few enterprises enter the solution due to a shortage of fertilizer. The amount of land per crop of the crops that did enter the solution increased; but only up to the amount of the crop limit. Land available in the early part of the growing season was completely exhausted. More acreage of the alfalfa hay-pasture enterprise entered under the historical cropping patterns than projected crop patterns; this resulted in more water being used by the historical cropping patterns.

60, 120, 150, 180 pounds N/ac. Rate Restrictions, Historical Crop Patterns

Under these rate restrictions (Table 37), the model allocated resources to the highest revenue enterprise available. Since more than sufficient amounts of fertilizer were available at all rates, residual fertilizer decreased as rates increased. The phenomenon of diminishing marginal returns can be observed in the shadow prices and revenue values for the respective rates. It can be especially

Table 35. RWCD-II: 400 Acre Farms, Total Farm Restriction, 120 lbs. vs. 180 lbs. N/ac. Base, Historical Cropping Pattern

	120 lbs. N/ac. Basis[a]	180 lbs. N/ac. Basis[a]
Crop Enterprise:		
Cotton Skip-Row	5500 acres at 180 lbs. N/ac.	5500 acres at 180 lbs. N/ac.
Barley-Sorghum	1558 acres at 180 lbs. N/ac.	1558 acres at 180 lbs. N/ac.
Barley	1558 acres at 150 lbs. N/ac.	1558 acres at 150 lbs. N/ac.
Early-Plant Sorghum	1558 acres at 180 lbs. N/ac.	1558 acres at 180 lbs. N/ac.
Late-Plant Sorghum	1558 acres at 180 lbs. N/ac.	1558 acres at 180 lbs. N/ac.
Wheat	250 acres at 180 lbs. N/ac.	250 acres at 180 lbs. N/ac.
Potatoes	200 acres at 180 lbs. N/ac.	200 acres at 180 lbs. N/ac.
Alfalfa Hay-Pasture	6276 acres at 0 N/ac.	6276 acres at 0 N/ac.
Revenue and Resources:		
Total land used[b] (acres)	18,458	18,458
Total water used (acre-feet)	62,811	62,811
Total N used (lbs.)	2,146,020	2,146,020
Net Revenue[c] (dollars)	2,794,465	2,794,465

[a]Under total farm restrictions any fertilizer application rate may be used.

[b]Includes land A and land B.

[c]Returns over variable costs.

Table 36. RWCD-II: 400 Acre Farms, Total Farm Restriction, 120 lbs. N/ac., Historical vs. Projected Cropping Pattern

	Using Historical Cropping Pattern	Using Projected Cropping Pattern
Crop Enterprise:		
Cotton Skip-Row	5500 acres at 180 lbs. N/ac.	5500 acres at 180 lbs. N/ac.
Barley-Sorghum	1558 acres at 180 lbs. N/ac.	4320 acres at 150 lbs. N/ac.
Barley	1558 acres at 150 lbs. N/ac.	3240 acres at 150 lbs. N/ac.
Early-Plant Sorghum	1558 acres at 180 lbs. N/ac.	--
Late-Plant Sorghum	1558 acres at 180 lbs. N/ac.	--
Wheat	250 acres at 180 lbs. N/ac.	--
Potatoes	200 acres at 180 lbs. N/ac.	200 acres at 180 lbs. N/ac.
Alfalfa Hay-Pasture	6276 acres at 180 lbs. N/a.c	3640 acres at 0 N/ac.
Revenue and Resources:		
Total land used[a] (acres)	18,458	16,900
Total water used (acre-feet)	62,811	62,166
Total N used (lbs.)	2,146,020	2,160,000
Net Revenue[b] (dollars)	2,794,465	2,927,329

[a]Includes land A and land B.

[b]Returns over variable costs.

Table 37. RWCD-II: 400 Acre Farms, Rate Restrictions 60, 120, 150, 180 lbs. N/ac., Historical Cropping Pattern

	60 lbs. N/ac.	120 lbs. N/ac.	150 lbs. N/ac.	180 lbs. N/ac.
Crop Enterprise:				
Cotton Skip-Row	5500 ac.	5500 ac.	5500 ac.	5500 ac.
Barley-Sorghum	1558 ac.	1558 ac.	1558 ac.	1558 ac.
Barley	1558 ac.	1558 ac.	1558 ac.	1558 ac.
Early-Plant Sorghum	1558 ac.	1558 ac.	1558 ac.	1558 ac.
Late-Plant Sorghum	1558 ac.	1558 ac.	1558 ac.	1558 ac.
Wheat	--	250 ac.	250 ac.	250 ac.
Potatoes	200 ac.	200 ac.	200 ac.	200 ac.
Alfalfa Hay-Pasture	6526 ac.	2008 ac.	2008 ac.	2008 ac.
Revenue and Resources:				
Total land used[a] (acres)	18,458	14,190	14,190	14,190
Total water used (acre-feet)	62,514	62,374	62,374	62,374
Total N used (lbs.)	715,920	1,461,840	1,827,300	2,192,760
Net Revenue[b] (dollars)	2,276,249	2,351,485	2,482,040	2,518,761

[a]Includes land A and land B.

[b]Returns over variable costs.

observed when moving from the 150 pounds per acre to the 180 pounds per acre rate.

Historical vs. Projected Crop Patterns, Rate Restriction of 60 pounds N/ac.

Revenue increases by $150,000 when projected crop limits are used with a rate restriction of 60 pounds (Table 38). Since the new crop limits allow for more acreage to come into the model fewer enterprises entered than with the existing limit case. Once again, the fertilizer resource was exhausted thereby forcing some enterprises out of the optimum solution. The land per crop does change as the crops approach the amounts of the proposed crop limits. Water usage increases since the number of acres used increases.

The shadow prices decrease as the projected crop limits are applied to the rate restriction of 60 pounds per acre. As before, this is caused by a decrease in the total number of enterprises brought into the solution.

It is interesting to note that in both the RWCD-I and RWCD-II, if more enterprises were available under existing crop limits there are resources available to accommodate them. However, the shortage of response data limited the crops considered.

This concludes the discussion of the results from the Alphac linear programming model. Tabular summaries of the results are shown in Tables 39 and 40. Conclusions

Table 38. RWCD-II: 400 Acre Farms, Rate Restriction 60 lbs. N/ac., Historical vs. Projected Cropping Pattern

	Historical Cropping Pattern	Projected Cropping Pattern
Crop Enterprise:		
Cotton Skip-Row	5500 ac.	5500 ac.
Barley-Sorghum	1558 ac.	4320 ac.
Barley	1558 ac.	4320 ac.
Early-Plant Sorghum	1558 ac.	--
Late-Plant Sorghum	1558 ac.	3660 ac.
Wheat	--	--
Potatoes	200 ac.	200 ac.
Alfalfa Hay-Pasture	6526 ac.	2560 ac.
Revenue and Resources:		
Total land used[a] (acres)	18,458	20,560
Total water used (acre-feet)	62,514	76,527
Total N used (lbs.)	715,920	1,080,000
Net Revenue[b] (dollars)	2,276,249	2,429,345

[a]Includes land A and land B.

[b]Returns over variable costs.

Table 39. Summary of Potential Fertilizer Restriction Upon Salt River Project and Roosevelt Water Conservation District (One Crop Year by Farm Size, 1971 Prices)

Region	Application Rate Restrictions					Total Farm Restrictions		
	60 lbs. N/ac.	60 lbs. N/ac. Projected Cropping Patterns	120 lbs. N/ac.	150 lbs. N/ac.	180 lbs. N/ac.	120 lbs. N/ac. Basis	120 lbs. N/ac. Basis, Projected Cropping Patterns	180 lbs. N/ac. Basis
Salt River Project I--100 ac.:								
Net revenue over variable costs (dollars)	2,106,799	2,150,941	2,554,274	2,751,227	2,790,859	2,715,110	2,769,569	2,736,400
Total land use (acres)	21,939	20,505	24,615	24,615	24,615	22,369	21,448	24,615
Total water use (acre-feet)	117,659	123,521	108,694	117,659	117,659	117,161	115,363	110,354
Fertilizer use (lbs.)	906,240	517,020	2,454,720	3,068,400	3,682,080	2,460,600	2,460,600	3,988,200
Salt River Project II--400 ac.:								
Net revenue over variable costs (dollars)	4,546,491	4,617,956	5,719,505	6,080,989	6,146,082	6,369,374	6,470,723	6,669,152
Total land use (acres)	42,297	39,290	47,334	47,334	47,334	42,956	42,956	47,334
Total water use (acre-feet)	227,350	235,535	211,322	227,350	227,350	228,114	224,239	226,910
Fertilizer use (lbs.)	1,697,400	990,120	4,603,680	5,754,600	6,905,520	4,714,800	4,714,800	6,617,700
Salt River Project III--900 ac.:								
Net revenue over variable costs (dollars)	4,175,266	4,460,799	5,411,730	5,730,406	5,822,703	5,200,400	5,288,113	5,219,343
Total land use (acres)	39,145	42,105	41,903	41,903	41,903	39,145	36,941	41,903
Total water use (acre-feet)	200,316	219,944	186,488	186,488	186,488	200,316	200,047	197,365
Fertilizer use (lbs.)	1,655,460	1,320,120	3,972,840	4,966,050	5,959,260	4,159,200	4,159,200	5,710,320
Salt River Project IV--1800 ac.:								
Net revenue over variable costs (dollars)	4,951,090	4,652,419	5,650,041	5,949,741	5,988,979	5,959,292	6,184,071	5,991,344
Total land use (acres)	46,276	48,639	46,276	46,276	46,276	42,676	49,917	42,676
Total water use (acre-feet)	219,166	231,006	219,166	219,166	219,166	219,166	229,523	219,166
Fertilizer use (lbs.)	2,019,890	1,601,640	4,039,680	5,049,600	6,059,520	4,540,200	4,540,200	5,774,900
Roosevelt Water Conservation District I--100 ac.:								
Net revenue over variable costs (dollars)	863,551	874,135	1,007,613	1,086,348	1,107,118	1,107,243	1,154,042	1,107,243
Total land use (acres)	7,402	8,090	7,441	7,441	7,441	7,441	6,650	7,441
Total water use (acre-feet)	38,152	33,990	36,105	36,105	36,105	36,037	32,550	36,037
Fertilizer use (lbs.)	351,960	485,400	716,640	895,800	1,074,960	1,051,590	1,080,000	1,051,590
Roosevelt Water Conservation District IV--400 ac.:								
Net revenue over variable costs (dollars)	2,276,249	2,429,345	2,351,485	2,482,040	2,518,761	2,794,465	2,927,329	2,794,465
Total land use (acres)	18,458	20,560	14,190	14,190	14,190	18,458	16,900	18,458
Total water use (acre-feet)	62,514	76,527	62,374	62,374	62,374	62,811	62,166	62,811
Fertilizer use (lbs.)	715,920	1,080,000	1,461,840	1,827,300	2,192,760	2,146,020	2,160,000	2,146,020

Table 40. Summary of the Impact of Fertilizer Restrictions Upon the Salt River Project and the Roosevelt Water Conservation District (One Crop Year, 1971 Prices)

Region	Application Rate Restrictions					Total Farm Restriction		
	60 lbs. N/ac.	60 lbs. N/ac. Projected Cropping Patterns	120 lbs. N/ac.	150 lbs. N/ac.	180 lbs. N/ac.	120 lbs. N/ac. Basis	120 lbs. N/ac. Basis, Projected Cropping Patterns	180 lbs. N/ac. Basis
Salt River Project:								
Net revenue over variable costs (dollars)	15,779,646	15,882,115	19,335,550	20,512,363	20,748,623	20,244,216	20,652,476	20,616,239
Total land use (acres)	149,657	150,539	160,128	160,128	160,128	147,146	151,267	156,528
Total water use (acre-feet)	764,491	803,006	713,830	750,663	750,663	764,757	769,181	759,815
Fertilizer use (lbs.)	6,278,990	4,428,900	15,070,920	18,838,650	22,606,380	15,877,800	15,877,800	22,092,120
Roosevelt Water Conservation District:								
Net revenue over variable costs (dollars)	3,139,800	3,303,480	3,359,098	3,568,388	3,625,879	3,901,708	4,081,371	3,901,708
Total land use (acres)	25,861	28,650	21,631	21,631	21,631	25,899	23,550	25,899
Total water use (acre-feet)	100,666	110,517	98,479	98,479	98,479	98,848	94,716	98,848
Fertilizer use (lbs.)	1,067,800	1,565,400	2,178,480	2,723,100	3,267,720	3,197,610	3,240,000	3,197,610
Total for Two Regions:								
Net revenue over variable costs (dollars)	18,919,446	19,185,595	22,694,648	24,080,751	24,374,502	24,145,924	24,733,841	24,517,947
Total land use (acres)	175,518	179,189	181,759	181,759	181,759	173,045	174,812	182,427
Total water use (acre-feet)	865,157	913,523	812,309	849,142	849,142	863,605	863,897	858,663
Fertilizer use (lbs.)	7,346,870	5,994,300	17,249,300	21,561,750	25,874,100	19,075,410	19,117,800	25,289,730

drawn from these results are discussed in the following chapter.

CHAPTER V

SUMMARY, CONCLUSIONS, AND IMPLICATIONS FOR FUTURE RESEARCH

The main objective of this analysis, as stated in Chapter I, is to measure probable short run economic consequences of alternative nitrate fertilizer restrictions on Salt River Project and Roosevelt Water Conservation District growers. This analysis is an attempt at improving the accuracy of impact data associated with nitrate fertilizer restrictions by using Linear Programming models.

In this study, the Salt River Project is divided into four farm group sizes and the Roosevelt Water Conservation District into two farm group sizes for separate analysis. This makes it possible to project agricultural adjustment for various farm sizes within the two irrigation districts. A comparison of the changes occurring in the different farm sizes of the irrigation districts is made in the first section of this chapter. A later section deals with an aggregate analysis of adjustments of the irrigation districts. The last section puts forth the general conclusions reached and makes recommendations as to data requirements for future studies.

Although this study has certain limitations, which will be discussed, it is important to realize the usefulness

of this research before reading its closing sections. This study, it is hoped, will illustrate the need to the general public, the agricultural sector, and the state legislature for further research into nitrate pollution and the impacts of nitrate fertilizer restrictions. By illustrating present weaknesses, future research could provide better results using this study as a basis.

Comparison of Farm Size Groups

Dividing the irrigation districts into farm size groups allows separate analysis of each group differing substantially as to its mode of operation. It is theorized that agricultural adjustments will occur at different nitrate fertilizer restrictions within the farm size groups. A summary of the results obtained from the linear programming model for each farm size group is given in Tables 39 and 40.

Impacts on the Individual Farms

A characteristic of the production function is the concept of diminishing returns. Hence, as the amount of fertilizer input increases, the output, represented in this case by net returns over variable costs, increases but at a decreasing rate. In most cases, at some point, net revenue over variable costs began to decrease.

As more fertilizer was allowed for use in the model there was initially a corresponding increase in net revenue.

However, it was found that diminishing returns were present when fertilizer rates were relaxed from 150 to 180 pounds per net acre. A rate restriction approaching 120 pounds per acre would be less onerous, in terms of net revenue over variable cost, than a rate restriction of 60 or in some cases 150 pounds per acre. In most cases, a total farm restriction of 150 pounds per acre farm size group exhausted the fertilizer resource forcing crops out of the solution thereby reducing net revenue over variable cost.

Enterprise combinations will follow the highest level of fertilizer allowed by the rate restriction. If the rate is high enough to yield a return that warrants entry into the farm operation the crop will be grown at that rate. But, if the rate is restricted at a low level, forcing yield and thereby revenue to a low level, then the highest revenue returning crop will be grown at that low rate. A total farm restriction will allow the highest fertilizer rate-highest revenue crop level to enter the farm operation until fertilizer becomes scarce, thereby forcing the use of lower fertilizer rates.

The rational grower will always plant as much acreage as possible of a potentially high net revenue returning crop enterprise. Some governing factors as to the amount of acreage he plants to these high returning enterprises are crop rotations and government program requirements. No matter what the restriction amount or characteristic is, the

profit maximizing grower will always plant as much acreage as possible of a high returning crop enterprise.

Total land use and thereby total water use will increase as more fertilizer is allowed for use. A strict restriction of nitrate fertilizer could cause total land used to decline since there would be no fertilizer available for the raising of more crops. Total water use could possibly increase as total land use declines, the farmer may attempt a trade-off of water for fertilizer.

As touched upon previously, the highest fertilizer rate allowable would be used to produce the crops. Under a total farm restriction, the highest revenue-highest fertilizer rate crop enterprise will enter the operation until fertilizer becomes scarce, then lower application rates follow. As high value crops exhaust allotments, etc., low value crops are produced.

The projected crop limits allowed the entry of high revenue crops at high acreage levels. This points out the fact that when allowed the grower will raise as much of a high returning crop as possible. As witnessed in this study, if growers were to use the new or projected crop limits they could keep net revenue up, even though they were restricted with their fertilizer usage. Therefore, it is concluded that a trade-off of land for fertilizer could occur. This would happen if fertilizer were restricted at such a level that farmers were forced to abandon crop

rotation techniques in order to salvage net returns. Growers would be forced to replace low revenue rotation crops with high revenue returning crops.

Aggregate Impact on the Irrigation Districts

Fertilizer restrictions could have certain impacts on the irrigation districts. Rate restriction up to 120 pounds per acre and, due to diminishing returns, rates above could reduce net revenue over variable costs to the growers. High value crops would be grown at the highest rate possible and a possible increase in acreage of these crops would occur if land-fertilizer trade-offs were available. It is conceivable that land and water use would increase in an attempt by the grower to keep total production up with the decreased aid of nitrate fertilizers, depending on the degree of restriction. Total farm restrictions, as expected, offered more flexibility to growers. A total farm restriction would allow high revenue crops to be grown at the highest revenue-highest fertilizer level. The acreage of low revenue crops would decrease because the fertilizer was being absorbed by the high revenue crops. Land and water use could increase in order to allow production of low revenue crops and to conserve crop rotation practices.

The overall impact of nitrate fertilizer on the irrigation districts depends on the degree of the

restrictions. Strict fertilizer restrictions could force net revenue down. That is being so strict that farmers could not raise high revenue crops at profitable production levels. However, fertilizer restrictions set at recommended agronomic levels could have the effect of making some growers more efficient. They would be forced to use fertilizers at recommended rates instead of, in some cases, excessive amounts. High revenue crops would have priority over low revenue crops for available acreage. This could force the abandonment of crop rotations and, consequently, be harmful to the soil. Due to the increased demand for water, in an attempt to maintain total crop production without nitrate fertilizer, and the declining water table of the area, water could become very expensive in the irrigation districts. The combination of restricted fertilizer use and expensive water could force agriculture out of these irrigation districts.

What is the least "costly" way of reaching some prescribed level of nitrogen use? It may be best to use a total farm restriction if one is trying to regulate a region. However, if the problem is found in a specified sector of a region then rate restrictions could help in regulation. Physical restrictions of nitrate fertilizer is one method of regulation. Another method could be that of taxing fertilizer usage, thereby making undesirable fertilizer usage too expensive for growers. The absence of

data makes it very difficult to evaluate alternative regulation procedures. The limitations of this study and recommendations for future studies are discussed in the next section.

Limitations of this Research and Recommendations for Future Studies

Limitations arise out of the assumption in which certain variables were held constant, such as technology, imports, exports, and prices. New technology could possibly offset the effects on production of reduced nitrogen use. Imports and exports could have important effects on prices and crop enterprises. Price would fluctuate as demand for and quantities of crops shifted due to fertilizer restrictions. Furthermore, this model illustrates conditions after an instantaneous adjustment while adjustments are made by farmers over a period of time. This period of time may be sufficient for one of the above variables to shift, bringing new consequences to bear on the farmer.

Many limitations of this analysis are derived from the data. One crucial question of the data is:

Is land the only trade-off possible? What about water? Regretfully, due to a shortage of data, this possibility could not be observed or tested. This model was constructed with water use as a function of the amount of water required by a crop per acre. What is needed are more

response function analyses of irrigation water and nitrogen fertilizer. That is, stating yield as a function of water and fertilizer instead of only fertilizer as in this study. Then one can look at the possibility of trade-offs between fertilizer and water, in order to keep revenue at constant levels.

Another shortcoming of the existing data is the absence of crop response data. The crops in this study do account for much acreage in the SRP and RWCD. But, the vegetable crops that are not included in this study account for more net revenue per acre than those listed in this study. Obviously, the presence of these crops in a study would cause quite different results than those obtained here. Furthermore, in some cases there were enough resources available for more crops but more crops were not available. Crop limits were reached for the existing crops before all of the production resources were used. The need for more crop response data as a function of fertilizer and water is evident.

The need for more conclusive data on nitrate nitrogen as a pollutant is evident. Earlier in this study it was stated that little conclusive evidence exists regarding contamination of water supplies from the application of fertilizer. But even so there is always the possibility that public reaction to further deterioration could encourage substantial restrictions on fertilizer use before adequate

evidence is collected. More data are needed as to the extent of nitrate pollution and the characteristics of nitrate pollution for Arizona in particular. Because restricting fertilizer use in an individual state has quite different consequences for the affected farm public as well as the food consuming public than a nationwide restriction.

A reduction in Arizona fertilizer use would lower income to farmers, while no change would necessarily occur in consumer food costs. With production potential available in other states, the farm portion of consumer food prices need not change. Thus the major effect of a single state limiting the use of nitrate fertilizer is felt by that state's farmers.

In closing, the public must decide which set of consequences are acceptable. For intelligent public decisions, a flow of conclusive information is essential. This study has presented one set of estimates. More sets will be needed in order to make the critical decisions as to nitrate pollution and the handling of possible nitrate fertilizer restrictions.

SELECTED BIBLIOGRAPHY

Annual Arizona Fertilization Conference Report. Tucson: The University of Arizona, College of Agriculture, Agriculture Experiment Station and Agriculture Extension Service, January 21, 1959.

Arizona Agricultural Statistics 1971. Arizona Crop and Livestock Reporting Service Bulletin 5-6, Phoenix, 1971.

Arizona Thirty-Third Annual Report. Commercial Fertilizer and Agriculture Minerals Year ending December 31, 1970, Office of State Chemist, University of Arizona Agriculture Experiment Station Mesa, Arizona Special Bulletin, May, 1971.

Biology and Ecology of Nitrogen. Proceedings of a Conference, University of California, Davis, November 28 to December 1, 1967. National Academy of Sciences, Washington, D. C., 1969.

Burdak, Thomas George. "Projections of Farmer Response to a Falling Groundwater Table: A Marriage of Economic and Hydrological Models." Master's Thesis, The University of Arizona, 1970.

Clark, Stephen D., Joan E. Thilly, and Steven R. Tannenbaum. "Environmental Nitroso Compounds: Reaction of Nitrate with Creatine and Creatinine," Science, Vol. 174, No. 4016 (December 24, 1971), pp. 1341-1342.

Collected Papers Regarding Nitrates in Agricultural Waste Water. Department of Interior, Water Pollution Control Research Series. Washington: Government Printing Office, December, 1969.

Connor, Larry, and Allen Schmidt. Potential Effects of Pollution Controls on Farming. Department of Agricultural Economics, Michigan State University, No. 326, March, 1970.

Consumption of Commercial Fertilizers in the United States. Department of Agriculture, Agricultural Stabilization and Conservation Service. Washington: Government Printing Office, April, 1971.

Economic Implications of a Dynamic Land and Water Base for Agriculture in Central Arizona. Department of Agricultural Economics, The University of Arizona, File Report 68-2, October, 1968.

Economic Issues in Controlling Agricultural Pollution. Department of Agriculture, Economic Research Service, Natural Resource Economics Division. Washington: Government Printing Office, 1969.

Economics of Fertilization for Selected California Crops. University of California, Division of Agricultural Sciences, Giannini Foundation of Agricultural Economics Report Number 230, March, 1960.

Eighth Annual Report on Soil Fertility and Fertilizer Research. The University of Arizona, Agricultural Experiment Station and Agricultural Extension Service Report Number 7, February, 1965.

Fertilizer Recommendations for Arizona. The University of Arizona, Cooperative Extension Service Folder 107, July, 1964.

Fertilizer Summary Data. National Fertilizer Development Center, Tennessee Valley Authority, Muscle Shoals, Alabama, 1968.

Fertilizer Trends. National Fertilizer Development Center, Tennessee Valley Authority, Muscle Shoals, Alabama, 1969.

Fertilizer Used in Arizona. The University of Arizona, Economic Research Service, Farm Products Economics Division, 1967.

Field Crop Varieties for Arizona. The University of Arizona, Cooperative Extension Service and Agricultural Experiment Station Bulletin A-4, Revised December, 1970.

Fifth Annual Report on Soil Fertility and Fertilizer Research. The University of Arizona, Agricultural Experiment Station and Agricultural Extension Service Report Number 4, January, 1962.

Fourth Annual Report on Soil Fertility and Fertilizer Research. The University of Arizona, Agricultural Experiment Station and Agricultural Extension Service Report Number 3, February, 1961.

Ibach, D. B., and J. R. Adams. Crop Yield Response to Fertilizer in the United States. Department of Agriculture, Economic Research and Statistical Service Bulletin Number 431, Washington: Government Printing Office, August, 1968.

Johnson, Gordon. Soil Chemist, Department of Soils, Water and Engineering, The University of Arizona, Tucson, personal interview, September, 1971.

Kohl, D. H., G. B. Shearer, and B. Commoner. "Fertilizer Nitrogen: Contribution to Nitrate in Surface Water in a Corn Belt Watershed," Science, Vol. 174, No. 4016 (December 24, 1971), pp. 1331-1334.

Lathwell, D. J., D. R. Bouldin, and W. S. Reid. Effects of Nitrogen Fertilizer Application in Agriculture. Cornell University, Agronomy Department Paper Number 884, n.d.

Mack, Lawrence E. "Economic Implications of a Dynamic Land and Water Base for Agriculture in Central Arizona." Ph. D. dissertation, The University of Arizona, 1969.

Mayer, Leo V., and Stanley H. Hargrove. Food Costs, Farm Incomes, and Crop Yields, with Restrictions on Fertilizer Use. Iowa State University, Department of Economics Center for Agricultural and Economic Development, Report Number 38, March, 1971.

Nitrogen, Phosphate, Potash, the Fertilizer Supply 1970-71. Department of Agriculture, Agricultural Stabilization and Conservation Service. Washington: Government Printing Office, April, 1971.

Progressive Agriculture in Arizona. The University of Arizona, College of Agriculture, Volume XXII, Number 5, September-October, 1970.

Rainbow 4-Seasons News. International Minerals and Chemical Corporation, Rainbow Division, Volume I, Number 4. Skokie, Illinois, Summer, 1971.

The Salt River Project. Annual Report, Phoenix, Arizona, 1970.

Seventh Annual Report on Soil Fertility and Fertilizer Research. The University of Arizona, Agricultural Experiment Station and Agricultural Extension Service Report Number 6, February, 1964.

Sixth Annual Report on Soil Fertility and Fertilizer Research. The University of Arizona, Agricultural Experiment Station and Agricultural Extension Service Report Number 5, February, 1963.

Spivey, W. Allen. Linear Programming an Introduction. 2nd Printing. New York: The Macmillan Company, 1964.

Stults, Harold M. "Predicting Farmer Response to a Falling Water Table: An Arizona Case Study." Ph. D. dissertation, The University of Arizona, 1967.

Tenth Annual Report on Soil Fertility and Fertilizer Research. The University of Arizona, Agricultural Experiment Station and Agricultural Extension Service Report Series P-6, February, 1967.

Third Annual Report on Soil Fertility and Fertilizer Research. The University of Arizona, Agricultural Experiment Station and Agricultural Extension Service Report Number 2, January, 1960.

Thompson, W. W. Operations Research Techniques. University of Houston, Charles E. Merrill Books, 1967.

Tucker, T. C. Nitrate Pollution from Fertilizer is Deemed Slight. Arizona Farm News, Agricultural Extension Service, The University of Arizona, Tucson, 1971.

Twelfth Annual Report on Agricultural Chemicals. The University of Arizona, Agricultural Experiment Station and Agricultural Extension Service Report Series P-8, February, 1969.

Wadleigh, Cecil H. The Significance of Fertilizers and Soil Management. Paper presented at the National Canners Association 63rd Annual Convention, Washington, D. C., 1970, pp. 11-15.

Who's to Blame for Water Pollution? (A Realistic Appraisal of Agriculture's Role). International Minerals and Chemical Corporation, Rainbow Division, Skokie, Illinois, n.d.