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Determining Maximum Net Returns For Cropping Systems on Marshall Soil Using Linear Programming

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INTRODUCTION

The supply of agriculturally productive land is limited in the United States. The actual area a farmer controls can be expanded by purchasing additional land or renting land owned by someone else. Most farmers have limited capital resources, thus the quantity of land controlled by an individual operator is actually quite restricted.

While deriving adequate income from the available land, erosion control is necessary. The problems of erosion control and land use have a number of alternative solutions. On some farms, a system of terraces or contouring may be needed. Sometimes a crop rotation, without other positive erosion control practices, is adequate.

Developing the land use program involves a number of considerations. The type and quantity of livestock to be produced on the farm, and the climate, are important factors in this decision. A fertility program that will achieve a high level of crop production is also very important. Fertilizer use, water management practices, seeding rates, and cultural practices, add further to the complexity of land use decisions.

A farmer must choose from the many land use alternatives the one system which will contribute the most to fulfilling his goals. Maximum net return is the goal, or it is the means of obtaining the goals of most farmers. Attainment of this goal requires efficient organization.

The problem of determining the most profitable crop rotation or rotations for a specific farm involves all the factors which influence the land use program. It must also be recognized that the profitability of a rotation should be measured by the contribution it makes to the business rather than the cash market value of the crops produced.

The Problem

To objectively choose between alternative land use systems, the farmer and the farm management specialist must have an abundance of information concerning the situation on the particular farm and the resource requirements of the various alternatives. Some information is readily available from research results and past experience, whereas other information is hard to obtain.

Also needed in choosing between alternative land use systems is a method of analyzing the data. Frequently, a budgeting technique is used to systematically state and analyze pertinent coefficients of the solutions to the problem. Alternatives can then be objectively evaluated by the farmer and specialist in terms of the conditions outlined in the problem.

A problem with a large number of answers requires much time to use a manual budgeting technique for each possibility. Thus, time may reduce the number of solutions considered. It also reduces the number of individual problems which may be considered.

Linear programming has been proposed and demonstrated by several agricultural research specialists as a technique for analyzing various types of land use problems. The use of electronic computers has facilitated linear programming.

A linear programming problem has three quantitative components: an objective, various methods for attaining the objective, and resource or other restrictions.[1] Land use problems have these qualifications; therefore, the use of linear programming in solving land use problems presents a challenge and an opportunity.

Objectives of the Study

With the land use problem posed in the preceding paragraphs as the basis, this study had two broad purposes. The first purpose was to demonstrate the application of linear programming to land use problems. The second purpose is to apply linear programming to a specific set of land use problems. The three major objectives of this study in applying linear programming to a specific set of land use problems are:

1. To determine for a model farm with a given level of resources the crop rotation or rotations which will yield maximum net returns on Marshall silt loam soil if the land is not terraced.
2. To determine for a model farm with a given level of resources the crop rotation or rotations which will yield maximum net returns on Marshall soil if the land is terraced.
3. To determine the effects of terracing on net returns by comparing the optimum plans on terraced land, land farmed on the contour, and land on which there is no erosion control.

Method of Analysis

To obtain data for (1) developing a model resource situation, and (2) determining coefficients to use in thé linear programming, a survey was made of farmers living on Marshall soil. Secondary data were used to supplement survey data where necessary.

Twenty-four problems were analyzed using the simplex linear programming technique. Various slopes (percent), the presence or absence of erosion control

[1]Earl O. Heady and Wilfred Candler, *Linear Programming Methods* (Ames: The Iowa State College Press, 1958), p. 2.

Figure 1. Location of Area of Study

measures, and two different price assumptions formed the problem situations. Each situation represented a farm with a specified percent of slope averaging 300 feet in length and a designated supply of land and labor.

AREA OF STUDY

Location

The Marshall soil area of Lafayette County was chosen as the location of this study, because a considerable amount of terracing has been done there and the land is relatively homogeneous. Another reason for using this area was that much information was available on the large number of farms that have been in the Extension Service Balanced Farming Program there.

Climate

The average annual rainfall for west central Missouri is around 38 inches. The monthly rainfall for May, June, July, September, and October, is of major importance in terms of the time available for completion of farming operations. The rush spring field work months of May and June have the highest average monthly rainfall. The rain during the fall harvesting months of September and October is generally less than in the spring months and, consequently, causes fewer field work problems, although in certain years it can cause costly interference with field operations. Average monthly rainfall in west central Missouri is 4.86 inches in June, 4.80 inches in May, and 2.86 inches in October.

Annual and monthly average temperatures, are as variable as the rainfall. Temperature ranges from an average of 16 degrees in January to an average exceeding 90 degrees in the summer months. Daily temperatures range from below zero to above 100 degrees. The growing season in the area ranges from 180 to 200 days, which permits the growing of corn, soybeans, oats, wheat, barley, red clover, and alfalfa.

Soil and Topography

Marshall silt loam is inherently very productive and is one of the more important agricultural soils in Missouri. The parent material from which Marshall soil has developed is the loessial deposits which blanket much of the western and central parts of the State.

Developed under prairie conditions, it has a top soil of 8 to 12 inches, a silt loam texture, a very dark brown color and high organic matter content. The subsoil is somewhat lighter in color, normally dark brown to yellowish brown, and ranges from a silt loam to a silty clay loam. Depth of the subsoil may extend from six or eight feet to as deep as twenty-five feet.[2] The profile exhibits a moderate degree of development high in concretions and calcium carbonate deposits.

[2]Missouri Agricultural Experiment Station, *The Soils of Missouri:* Bulletin 264, Columbia, Missouri, University of Missouri, College of Agriculture, 1929, p. 31.

TABLE 1

INFORMATION ON ACREAGE OF LAND, TOPOGRAPHY, AND AMOUNT OF TERRACING ON FARMS OF 65 FARM OPERATORS SURVEYED IN LAFAYETTE COUNTY, 1959

	Total Tillable Acres	Total Tillable Acres Terraced	Percent of Land Terraced	Total Acres Per Farm	Tillable Acres Per Farm
All Farms	13,618	9,352	68.6	253	209.5
Topography of Land:					
Below 3 percent slope	2,650	1,041	39.2	-	-
3-6 percent slope	7,212	5,599	77.6	-	-
7-10 percent slope	3,441	2,435	70.7	-	-
Above 10 percent slope	315	277	87.9	-	-

The topography of Marshall silt loam is gently rolling to rolling, although some flat and depressional areas may exist. Good surface drainage exists, except in the depressional areas. The surface and subsoil have free permeability of air and water.

Erosion is a major problem on Marshall soil, but because of the deep top soil it is not as noticeable as on shallow soils until considerable gullying has occurred. The large number of water management plans on farms in the area attests to the erosive nature of Marshall soil.[3]

Type of Farms in Area

The primary type of farming in the area is mixed livestock-grain. In the 1959 Preliminary Census of Agriculture, 47.9 percent of all farms in Lafayette County are classified as livestock farms (excluding dairy and poultry). Dairy and poultry farms comprised 11.3 percent of all farms; cash grain farms, 18 percent; general farms, 6.6 percent; and miscellaneous and unclassified farms, 21.6 percent.

Livestock sales in Lafayette County amounted to 80.6 percent of the value of all products sold in the county in 1954. Crops sold contributed only 19.4 percent.[4] The large acreage of feed grain produced, together with the high percentage of livestock sales, indicates that livestock and feed grain production are complementary in the area.

SURVEY OF FARMERS

The first phase of this study involved a survey of farmers in the Marshall soil area who were members of Balanced Farming Associations. The purposes of the survey were: (1) to obtain primary data concerning farm size, available labor, land use, crop yields; and (2) to obtain farmers' estimates of the effects of terraces on land use, yields, operating costs, and labor requirements. The data were used in the development of the model farm, and crop inputs and outputs (coefficients) for linear programming.

Balanced Farming Cooperators were chosen for the survey because active Balanced Farming Programs, stressing water management, have been in effect in Lafayette County since 1940. Many of the farms in the sample had both terraced and nonterraced land thus providing an experience base from which comparisons of the effects of terraces could be drawn.

An attempt was made to obtain data from as many farmers as possible who participated in the Balanced farming Program before 1957. A total of 65 completed survey schedules were obtained. The results of the survey are presented in the following paragraphs.

Size of Farms and Slope of Land

Total acreage on the farms surveyed ranged from 50 to 611 acres, with the

[3]Reference is made in Missouri Agricultural Experiment Station Bulletin 264 to the deep soils of the loess hills along the Missouri and Mississippi Rivers as the most severely eroded areas of the state.

[4]United States Department of Commerce, Bureau of the Census, *Census of Agriculture: 1954. Missouri*, Vol. 1, pt. 10, (Washington: Government Printing Office, 1956) pp. 75-77.

average size farm being 253 acres. Thirty-four of the 65 farmers had between 150 and 249 acres. The average number of tillable acres per farm was 209.5. This amounted to 86.5 of total farm acreage. A majority of the farms had between 100 and 199 tillable acres.

Of the 65 farmers surveyed, 40 owned all the land they operated, 14 owned part of the land they operated and 11 rented all the land they operated. The usual tenure-acreage relationship existed in that the part-owners operated the larger farms on the average, and the full-owners the smallest.

The average slope of all tillable land on the 65 farms was 4.8 percent. Of the total tillable acreage, 9,352 acres, or 68.6 percent were terraced. In general, the percent of land terraced increased as the slope increased.

Labor Supply

The labor supply on each individual farm in 1959 was obtained in terms of the yearly total, and labor available in May, June, and October. The average yearly labor supply on the 65 farms in the sample was 430 days. Of the total labor supply 286 days were contributed by the operator, 88 days provided by the family and 56 days were hired labor.

The average yearly labor supply in terms of number of men based on 300 days per man per year was 1.4 men. Available labor in May, June, and October, averaged 40, 41, and 37 days, respectively.

TABLE 2

LAND USE ON 65 FARMS IN LAFAYETTE COUNTY IN 1959

Land Use	Terraced		Nonterraced	
	Total tillable acres	Percent of total	Total tillable acres	Percent of total
Row Crop	4932.5	52.7	1502	35.2
Small Grain	1941.5	20.7	815	19.1
Hay and Pasture	2478.0	26.6	1949	45.7
Totals	9352.0	100.0	4266	100.0

Land Use

Crops produced on farms studied were classified into 3 classes: row crops, small grain, and hay and pasture. The percentage of total acres in each land use class indicates the degree of land use intensity. Farmers in this study were using terraced land more intensively than nonterraced, as 52.7 percent of the terraced land was in row crops compared to only 35.2 percent of the nonterraced land. The nonterraced land in the sample had 45.7 percent hay and pasture compared to 26.6 percent of the terraced land. The data reveal that farmers in this study realized the value of increasing land use intensity on terraced land and the need for protective cover in erosion control if mechanical methods are not used.

Yield and Fertilizer Use

In a later section the results of the farmers' estimates of expected average yields for the next 10 years on terraced and nonterraced land are presented. The farmers estimated that they expect considerably higher crop yields on terraced land than on nonterraced upland. The average yields obtained on all farms surveyed, however, showed little beneficial effect of terraces on 1959 crop yields.

Several reasons underly the variation between actual yields and the 10 year estimates. Weather conditions and differences in total fertilizer programs (fertilizer applied in previous year on other crops, etc.) are among the more important factors.

A comparison of yields on those farms on which corn was produced on both terraced and nonterraced land during 1959 provided somewhat different results. Corn yields on the 27 farms producing corn on both terraced and unterraced land averaged 4.7 bushels higher on the terraced land. Eleven of these farmers reported higher corn yields on terraced land, 15 reported equal corn yields on terraced and nonterraced land and one reported a 4 bushel lower corn yield on the terraced land. Of the eleven farmers reporting higher corn yields on terraced land, nine reported increases of 10 bushels or more.

Because of the variation between 1959 yields obtained and the farmers' estimates of expected yields, a mail survey was conducted to acquire 1960 crop yields on the same farms. The results are shown in Table 3 along with the 1959 yields.

In 1960, the crop yields on terraced land averaged higher than on unterraced land for all crops except red clover. A comparison of corn yields on farms producing corn on both terraced and unterraced upland was again made. On the 20 farms producing corn under both conditions the average corn yield was 11.4 bushels higher on terraced land. Sixteen of these twenty farmers reported their 1960 corn yields were higher on terraced land. Thirteen of them reported increases of 10 bushels or more. One farmer reported a 5 bushel lower corn yield on terraced land. Not enough farmers produced other crops on both terraced and unterraced land to make similar comparisons.

Percent of Grain Fed

Feeding grain to livestock is a well established practice among the farmers in the study area. Of the four major feed grain crops produced in the area, oats and barley were the crops of which the highest percentages were fed on the farm produced (95.2 and 95.8 percent respectively). Over 91 percent of the milo and 85.4 percent of the corn produced was fed on the farm produced. All of the forage produced on these farms was fed to livestock.

TABLE 3

AVERAGE PER ACRE CROP YIELDS ON TERRACED AND UNTERRACED LAND ON FARMS SURVEYED IN LAFAYETTE COUNTY 1959 AND 1960*

Crop	Average Yields on Unterraced Land**		Average Yields on Terraced Land	
	1959	1960	1959	1960
Corn (bu.)	75.0	68.4	75.6	76.6
Corn yields on farms producing corn on both terraced and unterraced land***	73.4	68.4	78.1	79.8
Milo (bu.)	****	66.2	****	81.0
Wheat (bu.)	28.4	23.5	27.2	26.2
Oats (bu.)	33.9	38.8	40.4	45.7
Alfalfa (tons)	3.7	3.5	3.4	3.8
Red Clover (tons)	1.7	2.1	2.1	2.1

*1960 yields obtained by mail questionnaire. Fifty of 65 farmers answered mail questionnaire.

**Excludes crops produced on bottomland.

***Corn was produced both on terraced and unterraced land on 27 farms in 1959 and 20 farms in 1960.

****Not enough of these farmers produced milo on upland soils in 1959 to make a meaningful comparison. The same thing was true of soybean production in both years.

Farmer Estimates of Yields

Although state and county average yield data are published annually, very little information is available on the effects of terraces on crop yields over a period of time. Farmer estimates were, therefore, collected to gain the benefit of the experiences of farmers who actually have had terraces on their farms. Farmers were asked to estimate the "average" yields they believed they could expect on their farms with existing levels of fertilizer use and technology during the next ten years on terraced and nonterraced land.

The farmers estimated yields of all grain and forage crops grown on terraced land to be higher than on nonterraced land. They estimated that corn yields would be 15 bushels higher on terraced land than on nonterraced land. Small grain crops were estimated to be less affected by terraces than corn. This is not surprising, for small grains growing during the spring months would be less benefited by the water retention of terraces than corn growing during the normally dry summer months. Soybean yields were estimated to be 3.2 bushels per acre higher on terraced land. Alfalfa hay was estimated to be affected more by terraces than clover hay.

Farmer Estimates on Operating Costs and Labor Requirements

The farmers estimated that the use of terraces increased the operating costs of producing all crops. Annual operating costs in corn production were estimated to be $1.08 per acre higher on terraced land. Farmers estimated that terraces increased the annual operating costs of producing alfalfa and red clover only $0.34 per acre.

Except for soybeans the farmers estimated that using terraces also increased the labor requirements of producing crops. As with operating costs, the effects of terraces on labor requirements were estimated greatest on corn.

Farmer estimates of the effects of terraces on operating costs and labor requirements appear to be low. This is possible, because farmers do not usually keep records on these items.

TABLE 4

EXPECTED 10 YEAR AVERAGE YIELDS ON TERRACED AND UNTERRACED LABOR, ESTIMATED BY 65 FARM OPERATORS IN LAFAYETTE COUNTY

	Average Ten Year Extimated Yield		Average
	Nonterraced	Terraced	Difference
Corn	53.76 bu.	69.05 bu.	15.29 bu.
Soybeans	22.00	25.20	3.2
Wheat	24.28	31.08	6.8
Oats	40.19	48.49	8.3
Alfalfa Hay	2.9 tons	3.5 tons	.6 tons
Red Clover	1.7	2.0	.3

Estimated 10 Year Intensity

Farmers were asked to estimate how intensively they could use their land without encouraging excessive erosion and reducing yields. The intensity estimates show the number of years in a 10 year period each of the three general classes of crops (row crops, small grains, and grass and legumes) would be grown on a field if the land was used at its maximum feasible intensity (Table 6).

The average estimated maximum feasible intensity of land use on terraced land in a 10 year period was 7 years row crops, 2 years small grain and 1 year grasses and legumes. Average maximum feasible intensity of use for nonterraced land was 4 years row crops, 4 years small grains and 2 years of grasses and legumes.

The use of continuous row crops was estimated to be feasible on terraced land by 18 farmers while only 1 farmer estimated continuous row crops was possible on nonterraced land.

Care must be exercised in studying the figures in Table 6. Small grains, and grasses, and legumes, represent lower levels of land use intensity than row crops and, consequently, can be produced more frequently than is shown in the table. The figures represent the number of years they would be produced out of 10 if the land were used at maximum feasible intensity.

TABLE 5

ESTIMATED EFFECT OF TERRACES ON YIELD, OPERATING COSTS AND LABOR PER ACRE FOR 65 LAFAYETTE COUNTY FARMS

	Average Increase on Terraced Land	
	Operating cost	Labor hours
Corn	$1.08	0.59
Soybeans	0.41	0.00
Wheat	0.62	0.24
Oats	0.48	0.29
Alfalfa Hay	0.34	0.16
Red Clover Hay	0.34	0.16

BASIC DATA FOR LINEAR PROGRAMMING APPLICATION

The starting point in linear programming is the accumulation of basic quantitative data. The data required includes: (a) resource supplies, (b) input-output coefficients defining per unit resource requirements of the activities used, and (c) prices of the resources used and products produced. Secondary data and the data obtained by surveying 65 Lafayette County farmers have been used in the linear programming problems of this study.

TABLE 6

DISTRIBUTION OF ESTIMATED MAXIMUM INTENSITY OF USE OF TERRACED AND NONTERRACED LAND BY GENERAL CROP CLASSES FOR 65 LAFAYETTE COUNTY FARMS

Estimated intensity in number of years	Terraced			Nonterraced		
	Row crops	Small grain	Grass legume	Row crops	Small grain	Grass legume
0	2	20	31	1	2	9
1	0	3	16	0	0	5
2	0	10	11	8	9	9
3	2	22	3	24	36	12
4	5	4	2	12	11	24
5	14	6	2	16	6	2
6	16	0	0	3	1	4
7	6	0	0	0	0	0
8	2	0	0	0	0	0
9	0	0	0	0	0	0
10	18	0	0	1	0	0
Totals	65	65	65	65	65	65
Average intensity in years	7	2	1	4	4	2

Land Input

The land area on an individual farm is relatively fixed quantitatively in terms of present acres and the amount which can be acquired during a planning period.

The average number of tillable acres on the 65 Lafayette County farms was 209.5 acres. For the sake of simplicity, 200 tillable acres was used as the land restriction in the programming models.

Labor Input

Total hours of labor available for crop production per month were calculated from the average labor supply on the 65 farms studied (Table 7).

TABLE 7

AVAILABLE LABOR IN HOURS PER MONTH FOR CROP PRODUCTION FOR PROGRAMMING MODEL

	May	June	July	Sept.	Oct.
Total hours available per month	480*	504*	504*	432	444
Livestock labor	63	63	63	63	63
Hours available labor excluding livestock labor	417	441	441	369	381
Hours unfavorable weather**	47	47	19	28	28
Hours available for crop production	370	394	422	341	353

*The larger supply of labor during May, June, and July is due to the employing of part-time labor, particularly high school and college students.

**The hours of unfavorable weather were computed from the average number of unfavorable working days per month for the 30 year period (1930-1959). Weather data were supplied by State Climatologist, U. S. Weather Bureau, Columbia, Missouri.

Hours lost due to unfavorable weather and labor used for livestock were subtracted from the total available labor to obtain hours available for crop production. The average daily livestock labor requirement based on the amount of grain and roughage fed was computed at 2.5 hours per day for the farm operator.

Hours of unfavorable weather during normal working days were computed from the average days per month with .5 inch or more of rain as recorded at the

TABLE 8

HOURS OF LABOR REQUIRED PER ACRE DURING THE STATED MONTHS FOR CROPS ADAPTED TO LAFAYETTE COUNTY*

	Corn (hours)	Soybeans (hours)	Wheat (hours)	Oats (hours)	Alfalfa hay (hours)	Red Clover hay (hours)
Nonterraced						
May	1.95	1.46	-	-	3.48	-
June	.92	.87	1.91	-	.93	1.52
July	.75	.67	1.91	2.44	3.85	1.20
September	.14	.60	.72	-	3.25	.53
October	1.04	1.81	.72	-	-	-
Terraced						
May	2.12	1.46	-	-	3.54	-
June	.99	.87	1.93	-	.94	2.84
July	.84	.67	1.93	2.59	3.89	2.24
September	.15	.60	.75	-	3.42	1.06
October	1.18	1.81	.75	-	-	-

*Bowlen and Heady, op. cit., p. 380.
Labor requirements were adjusted to Missouri conditions.

Weather Bureau, Columbia, Missouri. Rainfall of .5 inches or more was assumed to cause a loss of 2 days of field work for usual cropping operations.

Because of a small amount of unfavorable weather and the extra part-time labor employed on the farms studied during the summer months, the largest number of hours of labor available for crop production was in July. The hours available for crop production in the months shown were used as the labor supply restrictions in the labor equations of the programming model. As peak labor needs on farms generally occur in these months, labor availability in these months becomes a definite restriction on crops grown.

The monthly labor requirements of various crops are presented in Table 8 The larger labor requirements for terraced land reflect the estimates of Lafayette farmers surveyed.

Prices

Two price situations were used in this study. The first price situation assumed all products were sold at an expected market price. The second price situation assumes a 10 percent increase above the market price for that percentage of the grain and roughage normally fed to livestock on the farms surveyed. It was thus assumed that the average livestock producer could increase the value of his grain crops 10 percent by feeding them to livestock.

TABLE 9
PRICE PER BUSHEL OR TON FOR CROPS GROWN ON 200 ACRE MODEL FARM BASED ON EXPECTED MARKET PRICES

Crop	Assumed market price	Price if grain was fed	Percent grain fed on farm surveyed	Weighted* price per unit
Corn	$ 1.00	$1.10	85.4	$ 1.08
Soybeans	2.00	-	-	2.00
Barley	.85	.94	95.8	.93
Oats	.60	.66	95.2	.65
Wheat	1.73	-	-	1.73
Alfalfa Hay	18.00	-	-	18.00
Clover Hay	16.00	-	-	16.00

*These prices were used on those problems having the average amount of grain fed on farms surveyed.

The prices used to develop the returns per crop and per rotation acre are presented in Table 9. A price per unit weighted according to the percentages sold and fed of various grains was used as the price for the grain fed situation.

Production Costs Per Acre

Production costs used in the programming are presented in Table 10. Operating costs include tractor and machinery use, seed, fertilizer, lime and miscellaneous costs which are the variable costs of planting, growing and harvesting crops.[5] A distinction was made in the cost of producing corn one year in a rotation and the cost where corn is produced more than one year in succession. An additional 3 dollars per acre for fertilizer was charged where corn is produced more than one year in succession.

The cost of producing alfalfa was figured for four different time periods, as the establishment cost was prorated over the number of years alfalfa appeared in the rotation.

[5]Operating costs were derived from the following publications and adjusted to 1960 price level: *More Money From Your Farm*, (Agriculturtl Extension,Service, University of Missouri, 1955), p. 3, (Mimeographed); *Farm Management Manual*, (University of Illinois, Department of Agricultural Economics, 1959) p. 3. (Mimeographed; Bernard Bowlen, and Earl O. Heady, *Optimum Combinations of Competitive Crops*, Research Bulletin 426 (Agricultural Experiment Station, Iowa State College, 1955) p. 380.

TABLE 10

PRODUCTION COSTS PER ACRE FOR CROPS ADAPTED TO LAFAYETTE COUNTY

Crop	Nonterraced Operating cost	Nonterraced Labor cost	Nonterraced Land cost	Nonterraced Total	Terraced Operating cost	Terraced Labor cost	Terraced Land cost	Terraced Total
Corn	$30.00	$ 7.00	$2.70	$ 39.70	$31.08	$ 7.59	$5.10	$43.77
Corn 2*	33.00	7.00	2.70	42.70	34.08	7.59	5.10	46.77
Soybeans	26.68	6.00	2.70	35.38	27.09	6.00	5.10	38.19
Wheat	25.73	6.00	2.70	34.43	26.35	6.24	5.10	37.69
Oats	19.42	5.00	2.70	27.12	19.90	5.29	5.10	30.29
Alfalfa (1 year)	33.21	11.60	2.70	47.51	33.55	11.76	5.10	50.41
Alfalfa (2 years)	28.40	10.90	2.70	42.00	28.74	11.06	5.10	44.63
Alfalfa (3 years)	26.79	10.67	2.70	40.16	27.13	10.83	5.10	43.06
Alfalfa (4 years)	26.00	10.54	2.70	39.24	26.34	10.70	5.10	42.14
Red Clover	21.42	6.40	2.70	30.52	21.76	6.56	5.10	33.42

*These data are the costs of producing corn the second and subsequent years in a rotation and the cost of producing continuous corn. The additional cost is for the larger fertilizer applications necessary when corn is produced more than one year in succession.

Labor cost was calculated at a rate of one dollar per hour of labor required in planting, growing, and harvesting a crop acre.

The land charge was for taxes only. The charge was based on the taxes paid on several Lafayette County farms on which the University has business data. No interest on capital invested in land was charged; therefore, a charge for interest must be made against the net returns per acre derived in the linear programming solutions before the returns may be called profit.

The estimated effect of terraces on operating costs and labor cost has been added to the production costs on terraced land. Interest at 6 percent was charged against the terraced land for the investment in terraces and outlets.

Returns Per Acre

Gross returns for the various crops were calculated by multiplying the average estimated ten year yields provided by farmers surveyed times the assumed price per bushel or per ton. The difference between gross returns and total production costs represents the net return per acre of crops. Net returns per acre of the various crops on terraced and nonterraced land is presented in Table 11.

TABLE 11

ANNUAL NET RETURNS PER ACRE FOR CROPS ADAPTED TO LAFAYETTE COUNTY

Crop	Nonterraced		Terraced	
	All grain sold	Part of grain fed	All grain sold	Part of grain fed
Corn	$14.30	$18.62	$ 25.23	$30.75
Corn 2*	11.30	15.62	22.23	27.75
Soybeans	8.62	8.62	11.81	11.81
Wheat	8.77	8.77	18.11	18.11
Oats	-3.12	-1.52	- .89	1.07
Alfalfa 1	4.69	4.69	12.59	1.07
Alfalfa 2	10.20	10.20	18.37	12.59
Alfalfa 3	12.04	12.04	19.94	19.94
Alfalfa 4	12.96	12.96	20.86	20.86
Red Clover	-1.62	-1.62	.58	.58

*These figures are for the second and succeeding years corn is produced in the same field such as where corn is produced continuous or more than one year in succession in a rotation.

Oats showed a net loss on nonterraced land and under the all-grain-sold price situation on terraced land. If all oats were sold a yield of 45.2 bushels on nonterraced land and 50.5 bushels on terraced land would have been necessary to cover production costs. The estimated yield of oats for nonterraced and terraced land were 40.2 and 48.5 bushels respectively. A yield of 41.7 bushels would have been necessary to cover production costs on nonterraced land if part of the grain was fed.

Red clover showed a loss on nonterraced land. As in the case of oats, a higher yield would be necessary to cover production costs. Red clover yield to achieve this position would have to be 1.9 tons, whereas the estimated yield was 1.7 tons.

On both terraced and nonterraced land, corn produced the greatest net returns per acre. Net return per acre from alfalfa was also quite high when alfalfa was left in the rotation more than one year.

Soil Erosion

The independent variables affecting soil erosion have been outlined and discussed by many leaders in the field of Soil and Water Management. Several methods have been developed for determining a quantitative measure of soil erosion associated with each crop (commonly referred to as the erosion factor) to use as guides in long term planning of farm soil and water management system.

Erosion factors were computed using the following erosion equation quoted from a paper by Van Doren and Bartelli.[6]

$A = {}^{f}(T, S, L, P, K, I, E, R, M)$ where:

A = Annual estimated soil loss in tons per acre.

T = Tons per acre of measured soil loss from a soil type (considered unity) of given slope, with known conservation practices and cropping patterns.

S = Steepness of slope.

L = Length of slope.

P = Practice effectiveness. Appropriate factor expressing effectiveness of the particular supporting practices, or practices under consideration.

K = Soil erodibility.

I = Intensity and frequency of 30 minute rainfalls.

E = Previous erosion.

R = Rotation effectiveness.

M = Management.

A set of two soil loss tables have been developed for various crop rotations and soil groups based on the computed annual soil loss. The first table included the independent variables (TSLP) while the second table consisted of the variables (KIERM). The erosion factor for a specific rotation is the product of the

[6]C. A. Van Doren and L. J. Bartelli, *Guides for Farm Planning Based on Soil Conserving Rotations and Practices*. A mimeograph paper prepared by Illinois Agricultural Experiment Station, the USDA, ARS, and SCS and presented to Annual Meeting of the American Society of Agricultural Engineers, June, 1955, p. 20.05.

values found in Tables 12 and 13 for the appropriate soil group, degree of erosion, conservation practice, length and degree of slope. An erosion factor for a specific soil has to be equal to or less than the tolerated soil loss in tons per acre per year for the rotation to be acceptable from the standpoint of erosion control.

TABLE 12

COMBINED SOIL LOSS FACTORS FOR DIFFERENT ROTATIONS AND SOILS*

	Soil Factor			
Rotation	1.0**	1.25	1.50	1.75
R-O (x)	2.42	2.85	3.6	4.24
R-R-O-M-M	1.25	1.55	1.87	2.19
R-O-M	1.00	1.25	1.50	1.75
R-W-M	.86	1.07	1.30	1.50
R-O-M-M	.65	.81	.77	1.19
R-O-M-M-M	.52	.66	.80	.93
W-O-M-M	.27	.33	.40	.47
Continuous Corn	4.22	***		

*Data derived by Van Doren and Bartelli in reference stated.

**Soil factor 1.0 includes Marshall soil.

***No figures given for other soils.

Use of an erosion factor results in a restriction which distinguishes between feasible and nonfeasible rotations from the viewpoint of erosion control. A rotation which is entirely feasible on a terraced slope may not be feasible for a slope on which no erosion control measures have been applied. Therefore, a method of determining the feasibility of a rotation from the aspect of soil erosion control seems necessary to prevent unwise soil exploitation.

The described erosion factor computation method was used in this study. Table 14 presents the soil losses in tons per acre per year for various rotation sequences considered in the profit maximization phase of this project. Soil losses are the product of the values for the appropriate situations in Tables 12 and 13.

Annual soil loss data have been computed for three assumed farming situations. The first assumption employs no erosion control practices and all plowing,

TABLE 13

AVERAGE ANNUAL SOIL LOSSES IN TONS PER ACRE PER YEAR: USING A ROTATION OF R-O-M HAVING A SOIL FACTOR * OF 1.0**

Slope	Length of Slope												
	No Practices				Contouring				Strip Cropping				
(%)	100'	200'	300'	400'	100'	200'	300'	400'	100'	200'	300'	400'	Terraced
2	1.7	2.4	3.0	3.4	1.0	1.4	1.7	2.0	0.5	0.7	0.9	1.0	0.6
4	3.3	4.6	5.7	6.6	1.7	2.3	2.9	3.3	0.8	1.2	1.4	1.7	0.8
6	5.3	7.6	9.3	10.7	2.7	3.8	4.7	5.4	1.3	1.9	2.3	2.7	1.2
8	8.0	11.2	13.7	15.8	4.7	6.7	8.2	9.5	2.4	3.4	4.1	4.7	2.0
10	11.0	15.5	19.0	22.0	6.5	9.3	11.3	13.1	3.3	4.7	5.7	6.6	2.7
12	14.5	20.5	25.5	29.0	8.7	12.3	15.0	17.3	4.4	6.2	7.5	8.7	3.5
14	18.5	26.0	32.0	37.0	14.8	21.0	25.5	30.0	5.5	7.5	9.1	10.5	***
16	23.0	32.0	40.0	46.0	18.0	26.0	32.0	37.0	6.7	9.5	11.0	13.0	

*Data derived by Van Doren and Bartelli in reference stated.
**Soil factor of 1.0 includes Marshall soil.
***No figure given for slope greater than 12%.

TABLE 14

ANNUAL SOIL LOSS ASSOCIATED WITH DIFFERENT ROTATIONS IN TONS PER ACRE FOR MARSHALL SILT LOAM SOIL WITH A SLOPE OF 300 FEET*

	2%	4%	6%	8%	10%	2%	4%	6%	8%	10%	2%	4%	6%	8%	10%
Continuous Corn R-O	12.6	24.0	37.2	57.8	80.2	8.8	16.8	27.4	40.5	56.1	2.5	3.4	5.0	8.4	11.4
R-R-O (X) R-R-R-O-M	9.3	17.8	29.0	42.7	59.3	6.5	12.5	20.3	29.9	41.5	1.9	2.5	3.7	6.2	8.4
R-O (X) R-R-O-M	7.2	13.8	22.5	33.2	45.9	5.0	9.7	15.8	23.2	32.1	1.5	1.9	2.9	4.8	6.5
R-R-O-M-M	3.8	7.1	11.6	17.1	23.8	2.7	4.9	8.1	11.9	16.7	.8	1.0	1.5	2.5	3.4
R-O-M R-O-W-M	3.0	5.7	9.3	13.7	19.0	2.1	4.0	6.5	9.6	13.3	.6	.8	1.2	2.0	2.7
R-O-M-M	1.9	3.7	6.5	8.9	12.4	1.3	2.6	4.6	6.2	8.7	.4	.5	.8	1.3	1.8
R-O-M-M-M	1.6	2.9	4.8	7.1	9.9	1.1	2.0	3.4	4.9	6.9	.3	.4	.6	1.0	1.4
R-O-M-M-M-M O-W-M-M	.8	1.5	2.5	3.7	5.1	.6	1.1	1.8	2.6	3.6	.2	.2	.3	.5	.8

*Figures to right of black line are greater than the tolerated soil loss of 5 tons per acre per year. These rotations are therefore not feasible in land use planning.

planting, cultivation and harvesting is performed up and down hill. The second situation assumes contour performance in all cultural operations. This reduces the effective slope to 150′ and the erosion factor to .7 of the up and down hill, no conservation practice method. The third and final assumption employs normal spaced terraces with cultural operations performed parallel to the terraces. In Table 14, all soil losses to the right of the black line are not feasible with a maximum permissible annual soil loss of 5 tons per acre.

Annual soil loss increases with each increase in percent of slope. Under the assumption of no control practices, and up and down hill cultural operations, any rotation with more than one year of row crops would be nonfeasible with a tolerated 5 tons per acre per year soil loss. For slopes greater than 4 percent, feasible rotations require two or more years of meadow with one year of row crop. Each 2 percent increase in slope above 4 percent slope requires an additional year of meadow to obtain a feasible rotation. As slope and soil loss increases, the number of years of high profit row crops in the rotation decreases.

Continuous corn, two years row crop with no meadow and three years corn and one year meadow are not feasible under the assumption of no practices other than contouring. Slopes of 4 percent or greater require one or more years of meadow with one year of corn with the exception of the five year rotation of 2 years row crop, 1 year small grain and 2 years meadow which is entirely feasible under 6 percent slope. In general for each 2 percent increase in slope an additional year of meadow is added to the rotation.

At 6 percent slope or less any of the alternative rotations presented are within the tolerated soil loss if land is terraced. Above 6 percent, continuous corn and a few very intensive rotations become nonfeasible. The remaining alternatives are well within the allowable soil loss up to and including 12 percent. In comparing feasible rotations for the three situations, the effect of terraces in reducing soil loss and in increasing intensity of land use is very apparent.

Input-Output Coefficients for Rotation Acre

Rotation acre input-output coefficients differ from individual crop inputs and outputs. A rotation acre contains a combination of crops with a different set of input-output coefficients for each crop. The method of combining crop coefficients for calculating rotation coefficients can be represented by the general equation:

$$Y = S\,\frac{(X_1 \ldots X_m)}{N}$$

where Y = The rotation coefficient to be determined.

S = The sum.

$X_1 \ldots X_m$ = The individual crop coefficients for crops in the rotation.

N = The length of the rotation in years.

Net Returns Per Rotation Acre

Fifty-four rotations varying in length from two years to eight years were considered feasible on terraced land (Table 15). Continuous corn is classified as a rotation under the liberal definition of a crop rotation as a regular and recurring crop succession.

The 28 rotations considered feasible on nonterraced land (Table 16) show lower annual net returns per rotation acre than those on terraced land. Variation in yields between terraced and nonterraced land, and differences of rotation intensities account for the higher annual net return per rotation acre on terraced land.

LINEAR PROGRAMMING APPLICATION

Many farm business plans are developed with the supposition that only land is limited and any plan can be adopted regardless of the supply of other resources. Using linear programming, the limitational effect of any one or all resources can be considered. Once the problem has been defined in terms of relevant quantitative data, the simplex method of programming can be employed to select the optimum program from all feasible alternatives.

A linear programming problem requires several assumptions concerning the relationship of the various activities, the nature of the data, and the products which can be produced.

Basic Assumptions

Assumptions used in linear programming and concerned with the problems to be solved by the simplex method are:

1. The total product of all activities must be the sum of the individual products of the activities.
2. Total amount of available resources must be equal to or greater than the sum of the resources used by the individual activities.
3. Increasing or decreasing returns to scale are not allowed because returns per unit of an activity are considered constant.
4. Fractional units of resources can be used and commodities can be produced in fractional units.
5. The resource supplies, input-output coefficients and prices are known.

In addition to these basic assumptions, certain factors concerning crops produced and the organization of the model farm have been assumed for use in this study. These additional assumptions are:

1. Operating capital for the production of crops is not limited. The authors assumed that if a farmer can control the amount of resources represented by the model farm, he can obtain the operating capital for crop production. Capital limitations would be more pressing in developing the livestock producing phase of the farm business.
2. The model farm used in this study contains 200 tillable acres, representing the average acreage on the farms surveyed.

TABLE 15

CROP ROTATIONS AND NET RETURNS PER ROTATION ACRE
FOR THE MARSHALL SOIL AREA WITH TERRACES
LAFAYETTE COUNTY, MISSOURI

Rotation number	Rotations*	Length of rotations in years	Annual Net Return Per Acre	
			All grain sold	Part of grain fed
1	Continuous corn	**	$23.73	$29.25
2	C-C-W(x)	3	21.86	25.53
3	C-C-O-W(x)	4	18.33	19.42
4	C-C-C-C-W-R C1	6	18.44	22.12
5	C-C-C-C-O-W-R C1	7	18.02	19.10
6	C-SB	2	18.52	21.28
7	C-C-W-R C1	4	17.57	20.30
8	C-SB-W(x)	3	18.39	20.23
9	C-C-O(x)	3	15.52	19.85
10	C-C-C-SB-W-R C1	6	16.70	19.46
11	C-C-C-O-R C1	6	15.27	19.28
12	C-C-SB-W-R C1	5	15.99	18.20
13	C-C-W-A-A	5	19.31	21.52
14	C-W-A-A-A-A	6	19.18	20.10
15	C-C-O-W-A-A-A-A	8	17.05	18.68
16	C-W-R C1	3	19.11	20.95
17	C-W-A-A	4	18.57	19.95
18	C-C-O-W-A-A	6	15.94	18.11
19	C-SB-W-A-A	5	17.22	18.32
20	C-C-O-A-A	5	15.51	18.11
21	C-C-O-W-A-A-A	7	16.51	18.37
22	C-C-C-O-R C1	5	14.28	17.98
23	C-O-A-A-A-A	6	16.02	17.27
24	C-C-C-SB-O-R C1	6	13.53	16.62
25	C-C-O-R C1	4	12.79	16.04
26	C-SB-W-R C1	4	14.94	16.32
27	C-C-SB-SB-W-R C1	6	14.97	16.81
28	C-O-W(x)	3	9.32	16.64
29	SB-W-A-A-A-A	6	16.94	16.94

*Symbols used in defining the rotations represent the crops used in the rotation:

C = Corn
SB = Soybeans
W = Wheat
O = Oats
R C1 = Red Clover
A = Alfalfa
(x) = Catch crop grown with the small grain, normally sweet clover

**Length of rotation unspecified. Number of years equal to the length of planning period.

TABLE 15 (Continued)

Rotation number	Rotations*	Length of rotations in years	Annual Net Return Per Acre	
			All grain sold	Part of grain fed
30	SB-W-A-A-A	5	16.17	16.17
31	C-O-A-A-A	5	15.05	16.55
32	C-SB-O-W-A-A-A	7	15.02	16.09
33	C-O(x)	2	12.17	15.91
34	C-SB-SB-W-R C1	5	13.91	15.01
35	C-O-A-A	4	11.97	15.69
36	C-SB-O-A-A	5	13.42	14.92
37	SB-W-A-A	4	15.22	15.22
38	C-SB-O-R C1	4	10.18	12.05
39	C-O-R C1	3	10.31	12.80
40	C-O-W-R C1	4	10.76	12.63
41	SB-W-A-A	4	15.22	15.22
42	SB-SB-W-A-A	5	14.54	14.54
43	SB-O-A-A-A-A	6	13.78	14.11
44	C-W-A-A-A	5	13.05	14.55
45	C-O-W-A-A-A	6	15.56	16.80
46	SB-O-A-A-A	5	12.36	12.75
47	SB-W-R C1	3	12.17	12.17
48	SB-SB-O-A-A	5	10.74	11.13
49	SB-O-A-A	4	10.47	10.96
50	C-O-R C1	3	10.31	12.80
51	SB-O-R C1	3	5.84	6.71
52	C-O-W-A-A	5	14.68	16.18
53	SB-SB-W-R C1	4	11.78	11.78
54	C-SB-O-R C1	4	10.18	12.05

*Symbols used in defining the rotations represent the crops used in the rotation:

TABLE 16-CROP ROTATIONS AND NET RETURNS PER ROTATION ACRE FOR MARSHALL SOIL AREA WITH NO TERRACES LAFAYETTE COUNTY, MISSOURI

Rotation number	Rotation*	Length of rotations in years	Net Returns Per Acre	
			All grain sold	Part of grain fed
1	C-C-O-A-A	5	$ 7.48	$ 9.53
2	C-SB-O-A-A	5	6.94	8.12
3	SB-SB-O-A-A	5	5.80	6.12
4	C-C-W-A-A	5	9.85	11.58
5	C-SB-W-A-A	5	9.32	10.18
6	SB-SB-W-A-A	5	8.18	8.18
7	C-O-R Cl	3	4.24	6.21
8	SB-O-R Cl	3	2.34	2.88
9	C-W-R Cl	3	8.36	9.64
10	SB-W-R Cl	3	6.31	6.31
11	C-O-A-A	4	6.52	7.99
12	SB-O-A-A	4	5.10	5.40
13	C-W-A-A	4	9.94	10.57
14	SB-W-A-A	4	8.07	8.07
15	C-O-A-A-A	5	66.58	7.76
16	C-W-A-A-A	5	7.63	8.81
17	SB-O-A-A-A	5	6.49	6.81
18	SB-W-A-A-A	5	8.87	8.87
19	C-O-A-A-A-A	6	8.50	9.47
20	SB-O-A-A-A-A	6	7.56	7.83
21	C-W-A-A-A-A	6	10.49	11.21
22	SB-W-A-A-A-A	6	9.54	9.54
23	C-C-O-W-A-A	6	7.69	9.40
24	C-O-W-E Cl	4	4.58	6.06
25	C-O-W-A-A	5	6.96	8.15
26	C-O-W-A-A-A	6	7.80	8.80
27	C-O-W-A-A-A-A	7	8.54	9.39
28	C-SB-O-W-A-A-A	7	6.69	7.54

*Symbols used for crops in the rotations:

C = Corn
SB = Soybeans
W = Wheat
O = Oats
R Cl = Red Clover
A = Alfalfa
(x) = Catch crop grown with the small grain

3. Milo has been eliminated from rotations because of difficulty in drying. It was assumed that there was no artificial drying equipment on the model farm.
4. All land is assumed to be owned by the operator for the purpose of accounting for real estate taxes and interest on capital invested in terraces.
5. Rotations containing barley did not appear in the programming solutions; therefore, rotations with barley have been eliminated from the report.
6. Coefficients have been based on a model situation representing the average of the 65 farms in the study.
7. There are no governmental acreage restrictions.

Definition of the Problem

The problems in this study are concerned with determining the rotations which will maximize profits on terraced and nonterraced land in the Marshall soil area. A total of 24 problems based on percent slope, the presence or absence of erosion control measures, and two price situations were considered. Each problem represents a farm which has limited resources, a specified slope of land and an average length of slope of 300 feet. These problems are described in Table 21.

One problem is presented here as an example for discussing the steps and data used in applying linear programming to profit maximization problems.

The Example Problem

Problem 17, chosen as an example, represents a farm having nonterraced land with an average slope of 4 percent and farming operations performed on the contour. It is assumed that all grain produced on the farm has been sold at the expected market price. Land and monthly labor supplies, represent the resource restrictions. In this problem 370 hours of May labor, 394 hours of June labor, 422 hours of July labor, 341 hours of September and 353 hours of October labor are available.

Only rotations with at least 1 year of hay or meadow and two years or less of row crop are feasible considering the maximum permissible soil loss that will maintain long time land productivity (See Table 14). The rotations considered in the example problem are presented in the first column of Table 17.

Land and Labor Requirement Coefficients

An equal amount of land was required for each unit of the 25 rotations considered. Each rotation required one rotation acre of land which indicates that a particular rotation has no advantage over another rotation in respect to land requirement.

Labor requirements for the rotations had a relatively narrow range of variation within any given month, whereas variation of requirements between months had a wider range. The effect that monthly labor supply and needs can have on the rotations selected and the returns can be illustrated in the following simple example.

TABLE 17-LAND AND MONTHLY LABOR REQUIREMENTS PER ROTATION ACRE FOR ROTATIONS ON NONTERRACED LAND WITH 4 PERCENT SLOPE OPERATED ON THE CONTOUR

Rotation	Activity code	Land requirement	Labor Requirement in Hours				
			May	June	July	September	October
C-C-O-A-A	P7	1	2.17	0.74	2.32	1.36	0.47
C-SB-O-A-A	P8	1	2.07	0.73	2.31	1.45	0.60
SB-SB-O-A-A	P9	1	1.98	0.72	2.29	1.54	0.72
C-SB-W-A-A	P10	1	2.04	1.11	2.20	1.59	0.87
SB-SB-W-A-A	P11	1	1.98	1.10	2.19	1.68	0.87
C-O-R Cl	P12	1	0.65	1.16	1.66	1.13	0.39
SB-W-R Cl	P13	1	0.49	1.78	2.14	0.62	0.84
C-W-R Cl	P14	1	1.50	1.79	1.52	0.47	0.46
C-O-W-R Cl	P15	1	0.49	1.35	1.75	0.35	0.47
C-O-A-A-	P16	1	2.28	0.69	2.72	1.66	0.29
SB-O-A-A	P17	1	2.10	0.68	2.70	1.78	0.45
C-W-A-A	P18	1	2.22	2.44	2.59	1.84	0.40
SB-W-A-A	P19	1	2.10	2.43	2.57	1.95	0.63
C-O-A-A-A	P20	1	2.48	0.74	2.95	1.98	0.24
SB-O-A-A-A	P21	1	1.38	0.73	2.93	2.07	0.36
C-W.A-A-A	P22	1	2.48	1.12	2.84	2.12	0.38
SB-W-A-A-A	P23	1	2.38	1.11	2.82	2.21	0.51
C-O-W-A-A-A	P24	1	2.23	0.80	2.26	1.25	0.51
C-O-A-A-A-A	P25	1	2.65	0.78	3.10	2.19	0.77
SB-O-A-A-A-A	P26	1	2.57	0.77	3.08	2.27	0.30
C-W-A-A-A-A	P27	1	2.65	1.09	3.01	2.31	0.32
C-O-W-A-A-A-A	P28	1	2.36	0.93	2.66	1.75	0.38
SB-W-A-A-A-A	P29	1	2.57	1.08	2.99	2.39	0.42
C-C-O-W-A-A	P30	1	1.81	0.93	2.25	1.25	0.51
C-C-W-A-A	P31	1	2.17	1.12	2.22	1.50	0.61

Suppose a rotation with a $20 net return per acre and a rotation with a $15 net return per acre are competing with each other for the labor resource. The first rotation has a 2.8 hours per acre June labor coefficient and the second has a 2.0 hours per acre June labor coefficient. Suppose further that the June labor supply is 370 hours. With 200 acres of land, the first rotation without regard to labor would produce a $4000 net return and the second would produce a $3000 net return, but when the labor coefficients are considered the first rotation is limited to 132 acres and a net return of $2640, while the second rotation is limited to the 185 acres and $2775 net return. The rotation with the highest net return (the second rotation) is selected as the optimum solution based on the coefficient for the restricting month of labor.

Net Return Per Rotation Acre

Net returns per rotation acre together with the labor restrictions determine the optimum solution to the profit maximizing problem. If labor were not a restriction, it is obvious that the rotation corn-wheat and four years of alfalfa would produce the highest net return per acre for the all-grain-sold price situation whereas the corn-oats and red clover rotation would yield the lowest return per acre (Table 18).

TABLE 18-NET RETURN PER ACRE FOR ROTATIONS ON NONTERRACED LAND WITH 4 PERCENT SLOPE OPERATED ON THE CONTOUR

Rotation	Net Return Per Rotation Acre If: All grain sold	Part of grain sold
C-C-O-A-A	$ 7.48	$ 9.53
C-SB-O-A-A	6.94	8.12
SB-SB-O-A-A	5.80	6.12
C-SB-W-A-A	9.32	10.18
SB-SB-W-A-A	8.18	8.18
C-O-R Cl	4.24	6.21
SB-W-R Cl	6.31	6.31
C-W-R Cl	8.36	9.64
C-O-W-R Cl	4.58	6.06
C-O-A-A	6.52	7.99
SB-O-A-A	5.10	5.40
C-W-A-A	9.49	10.57
SB-W-A-A	8.07	8.07
C-O-A-A-A	7.63	8.81
SB-O-A-A-A	6.49	6.81
C-W-A-A-A	6.58	7.76
SB-W-A-A-A	8.87	8.87
C-O-W-A-A-A	7.80	8.80
C-O-A-A-A-A	8.50	9.47
SB-O-A-A-A-A	7.56	7.83
C-W-A-A-A-A	10.49	11.21
C-O-W-A-A-A-A	8.54	9.39
SB-W-A-A-A-A	9.54	9.54
C-C-O-W-A-A	7.69	9.40
C-C-W-A-A	9.85	11.58

Cost for Nonuse of Land

A charge for nonuse of land has been introduced into the linear programming problems presented herein. In all problems involving nonterraced land, a $2.70 cost for nonuse of land was charged as a negative return against the land disposal activity. This has the effect of forcing land into use. Nonuse of an acre reduces returns by $2.70. The cost was based upon average land tax rates in the study area.

Setting Up the Programming Problem

The land and labor resources will limit the amount of a rotation that can be produced. Linear equations are set up which will contain the amount of available resource, the amount of real activities produced, the resource requirement for the real activities and the disposal activities. Real activities are the crop rotations which can be produced by the farm organization. Disposal activities are activities set up to allow for nonuse of a resource, such as allowing land to remain idle. In addition to the land and labor equations, a profit equation expressing the relation of the total profit to each activity is developed.

The disposal activities allow for nonuse of resources and require an input coefficient as do real activities. Disposal activity coefficients are expressed in terms of 1 acre or 1 hour per unit not used.

The land, labor and profit equations when combined into a computational table form the initial tableau of the simplex method. The initial tableau (Table 19) presents all the necessary coefficients to compute a solution to the example profit maximization problem using the simplex method.

The "C" row shows the net return for each activity considered. The –$2.70 above the land disposal represents the average tax rate on one acre of land.

Column 1, labeled "C_s," contains the net returns per unit of activity appearing in the supply or activity level column.

Column 2, labeled as resource or activity at the non-zero level, shows the disposal and real activities which have greater than zero supply leve. The supplies of these are indicated in the "P_0" column.

Column "P_0" has the actual supply of resources available for use in solving the problem. Columns P_1 thru P_6 give the input coefficients for each of the disposal activities. Columns P_7 thru P_{31} present the land and labor requirements for each rotation. These requirements are in terms of the amount of these resources necessary to produce one acre of the rotation (not one acre of each crop in the rotation).

The "R" column values denote the maximum level to which an incoming activity can be increased. In the example problem the C-W-A-A-A-A activity has been selected as the incoming activity in the next tableau. The R values are computed by dividing the "P_0" column values by their respective coefficients under the P_{27} activity column. A zero profit exists in the initial tableau.

The intermediate tableaus between the initial and final tableaus have been computed on a Burroughs electronic computer and were not printed. Table 20 presents the final tableau with the exception of the disposal and real activity coefficients which were not printed.

Entries in the resource or activity column at non-zero level are the land and labor resources which were not used and the rotations which comprise the optimum solution. The P_0 column indicates 133.31 hours of unused June labor, 93.78 hours of unused September labor, 229.09 hours of unused October labor. Full use was made of land, May, and July, labor. The P_0 column also indicates the acreages of the rotations which will give maximum profit under the assumptions of the example problem. The optimum land use (profit maximization) for this problem is 144.85 acres of C-C-W-A-A and 28.36 acres of C-W-R Cl, and 26.79 acres of SB-W-R Cl. In terms of acreage in the various crops the optimum land use for these conditions is 67.5 acres of corn, 8.9 acres of soybeans, 47.4 acres of wheat, 57.8 acres of alfalfa, and 18.4 acres of red clover.

The figure in the "Z" row for any given activity represents the opportunity cost of other activities, that is, the net return which would be sacrificed if an additional unit of the selected activity or activities were brought into the program.

The "Z - C" row indicates in the P_0 column the maximum profit of $1828.38 for the example problem. The "Z - C" figures under the disposal activity columns (P_1 - P_6) and the real activity columns (P_7 - P_{31}) represent the marginal returns of using or producing a unit of these activities.

TABLE 19-BASIC INITIAL SIMPLEX TABLEAU FOR LINEAR PROGRAMMING CALCULATIONS OF EXAMPLE PROBLEM

		C	-2.70	0	0	0	0	0
	Resource or activity at non-zero level	Supply or activity level		Disposal Activities				
			Land	May labor	June labor	July labor	Sept. labor	Oct. labor
		PO	P1	P2	P3	P4	P5	P6
-2.70	Land P1	200	1	0	0	0	0	0
0	May Labor P2	370	0	1	0	0	0	0
0	June Labor P3	394	0	0	1	0	0	0
0	July Labor P4	422	0	0	0	1	0	0
0	Sept. Labor P5	341	0	0	0	0	1	0
0	Oct. Labor P6	353	0	0	0	0	0	1
	Z	0	-2.70	0	0	0	0	0
	Z - C	0	0	0	0	0	0	0

7.48	6.94	5.80	9.32	8.18	4.24	6.31	8.36	4.58
Real Activities								
C-C-O-A-A	C-SB-O-A-A-	SB-SB-O-A-A-	C-SB-W-A-A	SB-SB-W-A-A	C-O-R Cl	SB-W-R Cl	C-W-R Cl	C-O-R Cl
P7	P8	P9	P10	P11	P12	P13	P14	P15
1	1	1	1	1	1	1	1	1
2.17	2.07	1.98	2.04	1.98	.65	.49	1.50	.49
.74	.73	.72	1.11	1.10	1.16	1.78	1.79	1.35
2.32	2.31	.29	2.20	2.19	1.66	2.14	1.52	1.75
1.36	1.45	1.54	1.59	1.68	1.13	.62	.47	.35
.47	.60	.72	.87	.87	.39	184	.46	.47
- 2.70	-2.70	-2.70	- 2.70	- 2.70	-2.70	-2.70	- 2.70	-2.70
-10.18	-9.64	-8.50	-12.02	-10.88	-6.94	-9.01	-11.06	-7.28

6.52	5.10	9.49	8.07	7.63	6.49	6.58	8.87	7.80
Real Activities								
C-O-A-A	SB-O-A-A	C-W-A-A	SB-W-A-A	C-O-A-A-A	SB-O-A-A-A-	C-W-A-A-A	SB-W-A-A-A	C-O-W-A-A-A
P16	P17	P18	P19	P20	P21	P22	P23	P24
1	1	1	1	1	1	1	1	1
2.28	2.10	2.22	2.10	2.48	1.38	2.48	2.38	2.23
.69	.68	2.44	2.43	.74	.73	1.12	1.11	.80
2.72	2.70	2.59	2.57	2.95	2.93	2.84	2.82	2.26
1.66	1.78	1.84	1.95	1.98	2.07	2.12	2.21	1.25
.29	.45	.40	.63	.24	.36	.38	.51	.51
-2.70	-2.70	- 2.70	- 2.70	- 2.70	-2.70	-2.70	- 2.70	- 2.70
-9.22	-7.80	-12.19	-10.77	-10.33	-9.19	-9.28	-11.57	-10.50

8.50	7.56	10.49	8.54	9.54	7.69	9.58	
C-O-A-A-A-A	SB-O-A-A-A-A	C-W-A-A-A-A	C-O-W-A-A-A-A	SB-W-A-A-A-A	C-C-O-W-A-A	C-C-W-A-A	R
P25	P26	P27	P28	P29	P30	P31	
1	1	1	1	1	1	1	200
2.65	2.57	2.65	2.36	2.57	1.81	2.17	139.62
.78	.77	1.09	.93	1.08	.93	1.12	Unlimited
3.10	3.08	3.01	2.66	2.99	2.25	2.22	140.20
2.19	2.27	2.31	1.75	2.39	1.25	1.50	147.62
.77	.30	.32	.38	.42	.51	.61	Unlimited
- 2.70	- 2.70	- 2.70	- 2.70	- 2.70	- 2.70	- 2.70	
-11.20	-10.26	-13.19	-11.24	-12.24	-10.39	-12.55	

TABLE 20-FINAL SIMPLEX TABLEAU FOR LINEAR PROGRAMMING EXAMPLE PROBLEM

		C	-2.70	0	0	0	0	0
			Disposal Activities					
Cs C	Resource or activity at non-zero level	Supply or activity level (P_O)	Land	May labor	June la bor	July labor	Sept. labor	Oct. la bor
0	June Labor P3	133.31	-*	--	--	--	--	--
0	Sept. Labor P5	93.78	-	--	--	--	--	--
0	Oct. Labor P6	229.09	-	--	--	--	--	--
9.85	C-C-W-A-A P31	144.85	-	--	--	--	--	--
8.36	C-W-R C1 P14	28.36	-	--	--	--	--	--
6.31	SB-W-R C1 P13	26.79	-	--	--	--	--	--
	Z	$1828.38	4.52	2.09	0	.35	0	0
	Z - C	1828.38	7.22	2.09	0	.35	0	0

*Coefficients were not printed by electronic computer.

7.48	6.94	5.80	9.32	8.18	4.24	6.31	8.36	4.58
Real Activities								
C-C-O-A-A	C-SB-O-A-A	SB-SB-W-A-A	C-SB-W-A-A	SB-SB-W-A-A	C-O-R C1	SB-W-R C1	C-W-R C1	C-O-W-R C1
P7	P8	P9	P10	P11	P12	P13	P14	P15
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9.89	9.67	9.48	9.57	9.44	6.47	6.31	8.36	6.17
2.41	2.73	3.68	.25	1.26	2.23	0	0	1.59

6.52	5.10	9.49	8.07	7.63	6.49	6.58	8.87	7.80
Real Activities								
C-O-A-A	SB-O-A-A	C-W. A-A	SB-W-A-A	C-O-A-A-A	SB-O-A-A-A	C-W-A-A-A	SB-W-A-A-A	C-O-W-A-A-A
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10.26	9.87	10.08	9.83	10.76	8.45	10.72	10.50	9.99
3.74	4.77	.59	1.76	3.13	1.96	4.14	1.63	2.19

8.50	7.56	10.49	8.54	9.54	7.69	9.85
Real Activities						
C-O-A-A-A-A	SB-O-A-A-A-A	C-W-A-A-A-A	C-O-W-A-A-A-A	SB-W-A-A-A-A	C-C-O-W-A-A	C-C-W-A-A
P25	P26	P27	P28	P29	P30	P31
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11.17	10.99	11.13	10.40	10.96	9.10	9.85
2.67	3.43	.64	1.86	1.42	1.41	0

The addition of one hour of May labor would increase net returns $2.09. One hour of July labor $0.35 and one acre of land would increase net returns $4.52.

Since the final tableau presents the optimum solution for a profit maximization problem, the marginal return of the real activities indicates the amount by which maximum profit would be reduced through the use of an additional unit of the real activities (note that the marginal returns of the three rotations that comprise the optimum solution are zero). As an example, replacing one acre of the rotations in the optimum solution with one acre of C-SB-A-A (activity 10) would reduce total profit by $.25. In the intermediate tableaus, which are not presented here, the Z - C row values would be negative for all activities which could increase profit through the addition of 1 unit of the particular activities. When the values in the Z - C row are either zero or positive, the optimum solution for a maximization problem has been achieved; therefore, the Z - C row values become the criteria for determining when the optimum solution has been reached.

ANALYSIS OF LINEAR PROGRAMMING RESULTS

The problems included in this study (Table 21) have been concerned with determining the rotations which will maximize profit on terraced and nonterraced land of Marshall Silt Loam Type under two price assumptions. A total of 24 problems (12 for each price assumption) based on the percent of slope, and the presence or absence of erosion control measures were considered. Each situation represents a farm with a specified percent of slope averaging 300 feet in length and a limited supply of land and labor. The problems have been classified into three groups based on erosion control practices; in one group the farming operations are performed up and down hill, in the second group the farming operations are performed on the contour, and in the third group the land is terraced and the operation performed with the terraces. The optimum solution for each problem is referred to as an optimum plan in the remainder of this study.

Optimum Plans for Problems

The optimum plans for the 24 problems are presented in Table 22. Each problem has an optimum plan which includes rotation(s) selected, acreage of each rotation, the restricting resources, the net returns for each of the two price assumptions and the *next best alternative rotation.* The next best alternative is the rotation which would cause the least reduction of maximum net returns if a unit of that rotation were added or substituted into the optimum plan.

Land Use Intensity of Optimum Plans

There was considerable variaion in the crop rotations that comprised the optimum plans for the 24 problem situations. In some situations, only one rotation was included in the optimum plan. In other situations, 3 different rotations were included in the optimum plan. The acreage that will be in the various crops under the optimum plans is presented in Table 23.

TABLE 21-DESCRIPTION OF PROBLEMS INCLUDED IN STUDY

Problem number	Average percent slope	Price situation
	Terraced Land	
1	6 and under	All grain sold
2	6 and under	Part of grain fed
3	8	All grain sold
4	8	Part of grain fed
5	10	All grain sold
6	10	Part of grain fed
	Nonterraced Land, Up and Down Hill	
7	2	All grain sold
8	2	Part of grain fed
9	4	All grain sold
10	4	Part of grain fed
11	6	All grain sold
12	6	Part of grain fed
13	8	All grain sold
14	8	Part of grain fed
	Nonterraced Land, Operated on the Counter	
15	2	All grain sold
16	2	Part of grain fed
17	4	All grain sold
18	4	Part of grain fed
19	6	All grain sold
20	6	Part of grain fed
21	8	All grain sold
22	8	Part of grain fed
23	10	All grain sold
24	10	Part of grain fed

TABLE 22-OPTIMUM PLANS OBTAINED BY LINEAR PROGRAMMING FOR 24 LAND USE PROBLEMS

Problem	Rotation selected	Acres of rotation	Restricting resources	Net Return: All grain sold	Net Return: Part of grain fed	Next best alternative rotation	Intensity factor*
1 Terraced	Continuous corn	123.9	Land				
Average slope	C-C-W (x)	76.1	May Labor	$4604	-----	C-W-R	.87
6% and under							
2 Terraced	C-C-W (x)	76.1	Land				
Average slope	Continuous corn	123.9	May Labor	-----	$5567	C-W-R	.87
6% and under							
3 & 4 Terraced	C-C-W-A-A	144.3	Land				
Average slope 8%	C-W-R	55.7	July Labor	3851	4272	C-W-A-A	.38
4 & 6 Terraced	C-C-W-A-A	144.3	Land				
Average Slope 10%	C-W-R	55.7	July Labor	3851	4272	C-W-A-A-A-A	.38
7 & 8 Up & Down Hill	C-C-W-A-A	111.8	Land				
Average slope 2%	C-W-R	53.4	May Labor				
	C-O-W-A-A-A-A	34.9	July Labor	1836	2136	C-SB-W-A-A	.34
9 & 10 Up & Down Hill			June Labor				
Average slope 4%	C-W-A-A	163.3	July Labor	1450	1627	C-W-A-A-A-A	.25
11 & 12 Up & Down Hill	C-O-W-A-A-A	143.5	May Labor				
Average slope 6%	C-O-W-A-A-A-A	36.7	July Labor	1380	1554	C-W-A-A-A-A	.16
13 & 14 Up & Down Hill			May Labor				
Average slope 8%	C-W-A-A-A-A	139.6	July Labor	1302	1402	SB-W-A-A-A-A	.17
15 Contoured	C-C-W-A-A	101.8	Land				
Average slope 2%	SB-W (x)	57.9	May Labor				
	C-W-A-A-A-A	40.3	July Labor	1929	-----	C-C-W-R C1	.38
16 Contoured	C-C-W-A-A	146.7	Land	$----	$2278	C-W-A-A-A-A	.43
Average slope 2%	C-C-W-R C1	53.3	May Labor				
17 Contoured	C-C-W-A-A	144.8	Land				
Average slope 4%	C-W-R C1	28.4	May Labor				
	SB-W-R C1	26.8	July Labor	1828	-----	C-SB-W-A-A	.33
18 Contoured	C-C-W-A-A	104.5	Land				
Average slope 4%	C-W-R C1	95.5	May Labor	-----	2130	C-O-A-A	.38
19 & 20 Contoured			June Labor				
Average slope 6%	C-W-A-A	163.3	July Labor	1450	1627	C-W-A-A-A	.25
21 & 22 Contoured							
Average slope 8%	C-W-A-A-A-A	139.6	May Labor	1302	1402	C-O-W-A-A-A	.17
23 & 24 Contoured							
Average slope 10%	C-W-A-A-A-A	139.6	May Labor	1302	1402	C-O-W-A-A-A	.17

*Intensity factors were calculated by dividing total acres of row crops by total acres of land used.

TABLE 23-ACREAGE OF CROPS PRODUCED IN THE OPTIMUM PLANS

Situation number	Total acres	Acres Planted To						
		Corn	Soybeans	Wheat	Oats	Alfalfa	Red Clover	Acres of idle land
1 & 2	200	174.6		25.4				0
3 & 4	200	76.4		47.4		57.7	18.5	0
5 & 6	200	76.4		47.4		57.7	18.5	0
7 & 8	200	67.5		45.1	5.0	64.6	17.8	0
9 & 10	163.3	40.8		40.8		81.7		36.7
11 & 12	180.2	29.2		29.2	29.2	92.6		19.8
13 & 14	139.6	23.2		23.2		93.2		60.4
15	200.0	47.5	28.9	56.0		67.6		0
16	200.0	85.5		42.6		58.6	13.3	0
17	200.0	67.5	8.9	47.4		57.8	18.4	0
18	200.0	73.6		52.8		41.8	31.8	0
19 & 20	163.3	40.8		40.8		81.7		36.7
21 & 22	139.6	23.2		23.2		93.2		60.4
23 & 24	139.6	23.2		23.2		93.2		60.4

The optimum plans reveal two important relationships concerning the intensity of land use. A negative relationship existed between percent of slope and intensity of optimum rotations. In other words, the greater the percent of slope the lower the intensity of the optimum rotations. This is evident in comparing the intensity factors, the percent of total land in row crops. The relationship was true whether the land was terraced, farmed on the contour, or farmed up and down the hills.

The second relationship is that the intensity of land use of the optimum plans was much higher for the terraced land than for the contoured land. Further, the intensity of optimum plans for contoured land was higher than the intensity of the plans for land farmed up and down hill.

As only the rotations which hold annual soil losses below 5 tons per acre at the assumed slope and erosion control measures were considered, these relationships, to a certain extent, were determined before the programs were run through the computer. Even though this restriction was not actually in the linear programs (it could have been), the significance of the relationships is not lessened.

Net Returns From Optimum Plans

In Figures 2 and 3, the net returns from the optimum plans are graphically presented. A comparison of these figures shows the effect of contouring and terracing on net returns. Net returns from the optimum plans on terraced land are more than doubled the net returns on nonterraced land of the same slope. This is true whether the unterraced land was farmed on the contour or up and down hill.

Net returns from the optimum plans for contoured land were somewhat higher than net returns on land farmed up and down hill. The increase, however, is small compared with the increase obtained by terracing.

Terracing, and contouring to a smaller extent, has the effect of reducing the effective slope of land. The importance of this is evident when we examine the critical slopes. The critical slope is here defined as the lowest percent slope at which the net returns from the optimum plans are reduced considerably. Slope had no effect on net returns on terraced land with 6 percent or less slope. As the slope increased from 6 to 8 percent, however, net returns were reduced $753 under the all grain sold assumption, and $1295 under the grain fed assumption. Thus, 6 to 8 percent was the critical slope on terraced land.

Although the net returns declined somewhat between 2 and 4 percent land slope the critical slope on contoured land was between 4 and 6 percent. On unterraced land farmed up and down hill, the critical slope was between 2 and 4 percent. This relationship is of major importance in land use planning.

Influence of Price Change on Net Returns

Price variation due to the 10 percent increase in expected price for grain fed affected annual net return more for slopes of 6 percent and under than for slopes of more than 6 percent.

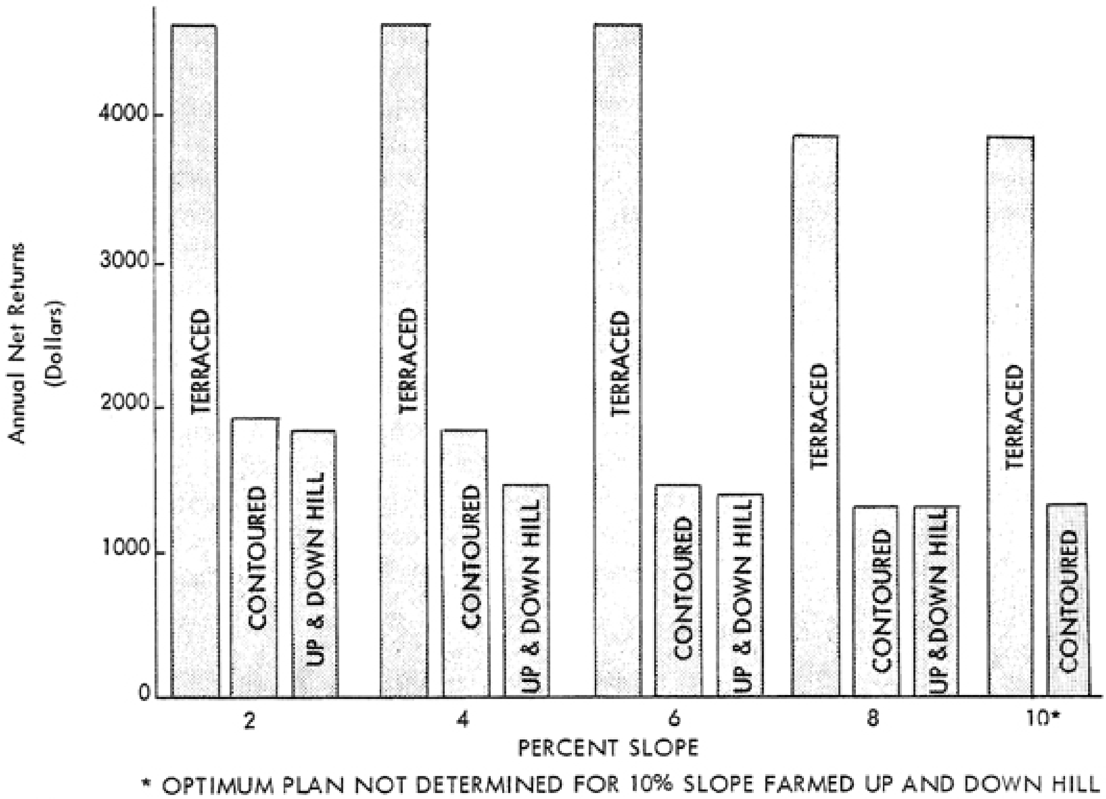

Figure 2. Annual Net Returns from Optimum Plans on Marshall Soils of Designated Slopes. Terraced, Contoured and Farmed Up and Down Hill (All Grain Sold)

This is not surprising as the grain fed has a direct relationship to the rotation intensity, particularly as it influences the acreage of corn produced. The net returns were always higher, however, on the situations having part of the grain fed than on comparable situations having all grain sold.

Resource Utilization of Optimum Plans

In optimum plans where the total land supply (200 acres) was used, at least one of the months of labor also appeared as a restricting resource. In optimum plans where total land supply was not used, monthly labor was the limiting resource.

The linear programming actually selects for each problem the rotation or rotations with the highest net return per acre which can be produced without exceeding the land or labor supply.

The amount of land used and the amount of land idle for each situation has value as it measures productive employment of the available land resources. As there is a relatively high cost in terms of taxes and interest on capital invested in the land, the utilization of land has importance to the farm operator, owner or the manager. This cost has to be paid regardless of use or nonuse of the land.

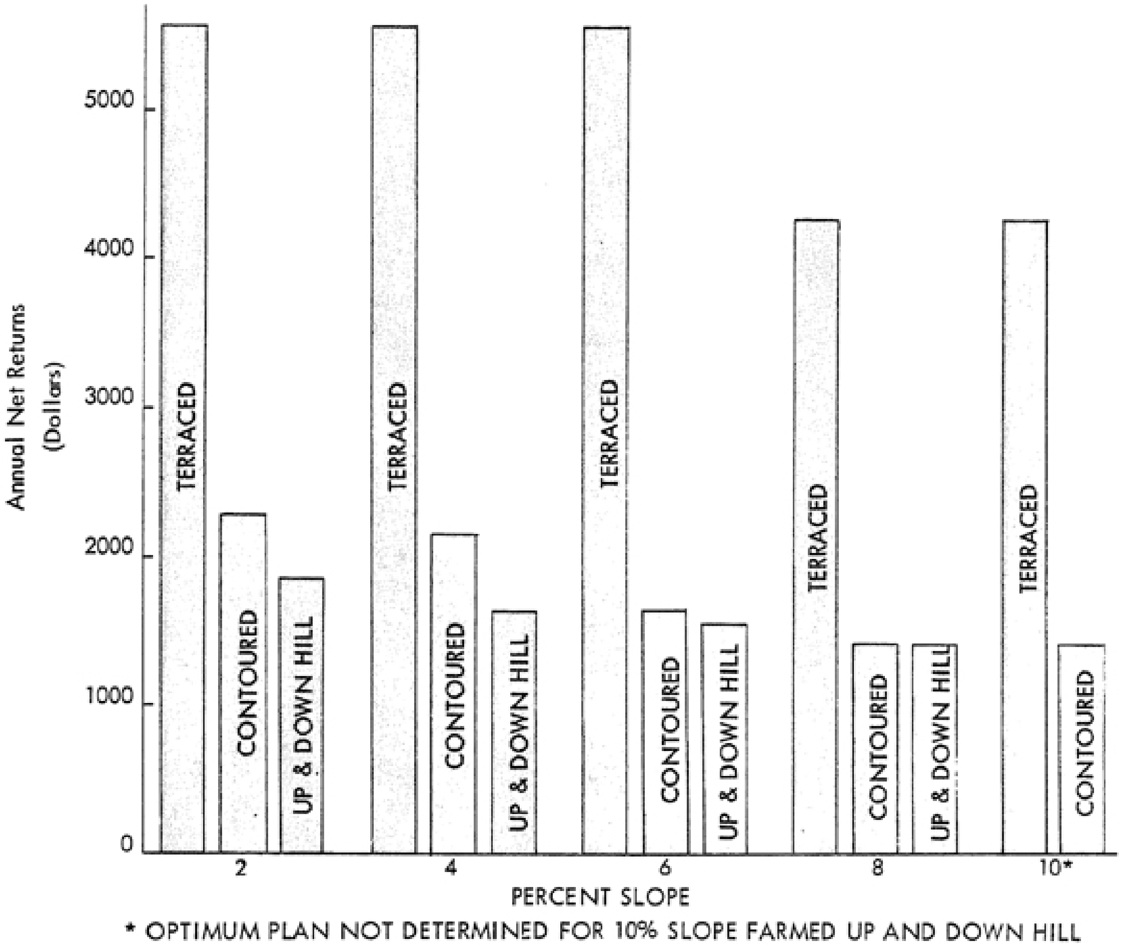

Figure 3. Annual Net Returns From Optimum Plans on Marshall Soils of Designated Slopes. Terraced, Contoured, and Farmed Up and Down Hill. (Part of Grain Fed)

The idle land column (Table 23) indicates that several optimum plans do not use all of the available land resource. When land remains idle the burden of paying the taxes and interest on investment in the land resource falls on the working land.

Labor used in the optimum plans for the problems in this study is presented in Table 24. Monthly labor was found to be restrictive for all problems considered. Most of the optimum plans utilized or nearly utilized the labor available in two different months although not necessarily the same two months in each plan. Two months May and July were found to be limiting for most of the problems. June labor limited the optimum plan for problems, 17, 18, 37 and 38. Idle labor, for the five months considered as critical, is shown in Table 25. Because of the immobility of labor from one month to another, labor which has not been used remains lost to the operator. Some farm work due to its nature may be transferred from rush months to slack months, but, for the most crop work, a critical period exists within which the work must be done.

The months of May and July had a very small amount of idle labor. October shows the greatest amount of idle labor followed by September and June.

Problems 1 and 2 with the most intensive land use had the greatest total amount of idle labor for the five months.

Relationship of Land and Labor Restrictions to Expansion of the Farm Organization

The relationships of land and labor restrictions to net return has been emphasized by this study. The marginal value of product for land and labor resources presented in Table 26 indicates the addition to net return that would

TABLE 24-UTILIZATION OF LABOR RESOURCE BY THE OPTIMUM PLANS

Situation number	Hours of Labor Used					Hours of labor used in five months
	May	June	July	Sept.	Oct.	
1 & 2	370.0	221.6	195.4	45.2	127.6	958.8
3 & 4	365.6	274.4	422.0	264.2	125.1	1451.3
5 & 6	365.6	274.4	422.0	264.2	125.1	1451.3
7 & 8	370.0	253.1	422.0	253.8	106.0	1404.8
9 & 10	362.6	394.0	422.0	298.7	65.7	1543.0
11 & 12	370.0	167.6	422.0	243.6	87.2	1209.4
13 & 14	370.0	152.8	422.0	323.4	45.0	1313.2
15	370.0	238.4	422.0	284.1	147.9	1462.4
16	370.0	248.0	398.7	241.3	130.5	1388.5
17	370.0	260.7	422.0	259.2	123.9	1435.8
18	370.0	288.0	377.1	201.6	107.7	1344.4
19 & 20	362.6	394.0	422.0	298.7	65.7	1543.0
21 & 22	370.0	152.2	420.3	322.5	44.7	1309.7
23 & 24	370.0	152.2	420.3	322.5	44.7	1309.7
Available Monthly Labor	370	394	422	341	353	1880

TABLE 25-IDLE LABOR FOR PROBLEMS WITH NO WHEAT RESTRICTION

Problem number	Hours of Idle Labor					Total idle hours
	May	June	July	Sept.	Oct.	
1 & 2	0	172.4	226.6	295.8	225.4	921.2
3 & 4	4.4	119.6	0	76.8	227.9	428.7
5 & 6	4.4	119.6	0	76.8	227.9	428.7
7 & 8	0	140.9	0	87.2	247.0	475.2
9 & 10	7.4	0	0	42.3	287.3	337.0
11 & 12	0	226.4	0	97.4	265.8	670.6
13 & 14	0	241.2	0	17.6	307.9	566.8
15	0	155.6	0	56.9	205.1	417.6
16	0	146.0	23.3	100.7	222.5	491.5
17	0	133.3	0	93.8	229.1	444.2
18	0	106.0	44.9	139.4	245.3	535.6
19 & 20	7.5	0	0	42.2	287.4	337.0
21 & 22	0	241.6	0	17.4	308.1	570.3
23 & 24	0	241.8	1.7	18.5	308.3	570.3

TABLE 26-MARGINAL VALUE OF PRODUCT PER UNIT OF LABOR AND LAND RESOURCES OBTAINED BY LINEAR PROGRAMMING FOR 24 PROBLEMS

Plan number	Marginal Value of Product Per Unit of Resource					
		Labor				
	Land	May	June	July	Sept.	Oct.
1	$18.15	$2.63	$0	$0	$0	$0
2	18.14	5.24	0	0	0	0
3	18.56	0	0	.33	0	0
4	19.39	0	0	.93	0	0
5	18.56	0	0	.33	0	0
6	19.39	0	0	.93	0	0
7	1.83	1.90	0	.53	0	0
8	5.30	2.77	0	.12	0	0
9	0	0	.11	4.59	0	0
10	0	0	.01	5.06	0	0
11	0	.88	0	3.77	0	0
12	0	1.14	0	3.96	0	0
13	0	.43	0	4.00	0	0
14	0	.20	0	4.44	0	0
15	7.67	.46	0	.53	0	0
16	10.29	.59	0	0	0	0
17	4.52	2.09	0	.35	0	0
18	5.29	2.89	0	0	0	0
19	0	0	.10	4.61	0	0
20	0	0	.35	3.71	0	0
21	0	3.04	0	1.70	0	0
22	0	3.36	0	1.66	0	0
23	0	4.97	0	0	0	0
24	0	5.24	0	0	0	0

be gained from using another unit of each input. For example, adding another acre of land in problem 1 would increase the annual net returns $18.15 and adding another hour of May labor would increase the net return $2.63. These values show the relationship of land and labor to the expansion of the cropping system. The values in this table also indicate the resource which would be most profitable to increase if increasing of both resources were not possible.

All optimum plans derived in this study could be expanded profitably by increasing the supply of the limiting resources. These limiting resources, as stated earlier, varied by plans.

Effect of Expansion Upon Optimum Plans Obtained by Linear Programming

Once the expansion is undertaken whether it is increasing of the supply of the restricting resource with the highest marginal value of product or increasing of all limiting resources the existing optimum plans are no longer completely effective. Changes of any restriction in a linear programming problem requires re-evaluation of the problem which establishes a new optimum plan.

SUMMARY AND CONCLUSIONS

Summary

The selection of an optimum plan for each of the 24 problems considered was achieved by using the simplex technique of linear programming. The problems considered were developed for a model farm with specified sets of conditions. These conditions were: (1) three methods of performing farming operations, up and down hill, contouring, and terracing; (2) two price assumptions, one with all grain sold at an expected market price, and the other assuming part of the grain was fed to livestock at a price 10 percent higher than the expected market price; (3) varying percentages of slope for each of the methods of performing farming operations; (4) a land restriction of 200 tillable acres with an average length of slope of 300 feet; (5) restriction of hours of monthly labor for May, June, July, September and October; (6) the basic assumptions of linear programming.

The model farm of 200 tillable acres was developed from survey data obtained from 65 farmers on Marshall soil in Lafayette County. Secondary data were used to supplement the survey data in determining the linear programming coefficients.

Farmers estimated average crop yields, operating costs, and hours of needed labor to be higher for terraced land than nonterraced land. The average yield for corn on terraced land was estimated to be 15 bushels per acre greater than for nonterraced land. All other crop yields and the operating costs of producing all crops were estimated to be higher for terraced land. The amount of labor used was estimated to be higher for all crops except soybeans.

The feasibility of a rotation to be considered in the linear programming was determined by using soil erosion factors which state soil loss in tons per acre per year. Any rotation with an annual soil erosion loss greater than 5 tons per acre for the specific percent slope and erosion control measures was not considered feasible.

The optimum plans determined were those rotations or combinations of rotations which maximize annual net returns for the specific land and labor resource available.

The results of the analysis of optimum plans showed an inverse relationship between slope, intensity of land use and annual net returns. This was true, but to varying degrees, whether the land was terraced, contoured, or farmed up and down hill.

Terracing, and contouring to a smaller extent, has the effect of reducing the effective slope of the land. The importance of this is evident upon examination of the critical slopes. The critical slope was here defined as the lowest percent slope at which the net returns from the optimum plans are reduced considerably. Slope had no effect on net return on terraced land of 6 percent or less slope, but a definite decline in net returns resulted between 6 and 8 percent slope. This was the critical slope on terraced land. On contoured land, the critical slope was between 4 and 6 percent. On land farmed up and down hill the critical slope was between 2 and 4 percent.

Net returns from the optimum plans on terraced land were more than double the net returns on nonterraced land of comparable slope. The net returns from optimum plans on contoured land were somewhat higher than on land farmed up and down hill. The increase in net returns was small, however, compared to the increase obtained by terracing.

The marginal value of product and the restricting resource varied among the optimum plans. The marginal value of products indicated that additional land and monthly labor would be profitable in the specified plans in which these resources were restricting. In plans where land and labor were both restricting the optimum plan the addition of more units of either or both resources would increase net returns.

Conclusions Regarding Methodology

The entire study was designed in terms of the long run situation under a set of specific assumptions. The results may not be applicable to conditions which are not similar to those specified in the assumptions.

Solutions of farm management problems requiring a choice between a number of feasible alternatives can be determined by linear programming providing sufficient quantitative data are available and a practical set of assumptions for the existing conditions can be developed.

It is necessary to understand that linear programming is a tool that permits the comparison of many alternative courses of action. The results obtained, however, are no better than the data used in developing the restrictions and the coefficients.