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EC60-815 Linear Programing....A New Farm Management Tool

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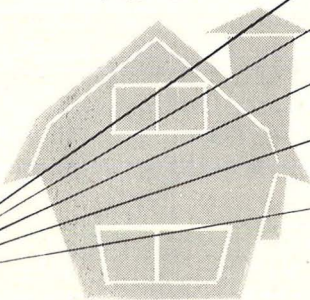
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Linear Programming...

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A NEW
FARM MANAGEMENT
TOOL



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Linear Programing¹

A New Farm Management Tool

By Robert Finley and Dean Brown²

In recent years county agents, vocational agriculture instructors and farmers have asked questions in regard to the need for better planning tools and techniques in farm management. Linear programing—now being widely used in farm management research—is such a planning tool. It can be used as a highly exact method of farm, ranch and home planning.

This circular is designed to show how linear programing can be used by county agents and other agricultural leaders to help solve some of their management problems. The circular provides answers to the following questions:

1. What is linear programing? How does it compare with budgeting techniques?
2. How can linear programing principles be used in solving farm management problems?
3. What kind of information is needed in using programing methods?
4. What limitations need to be considered in using linear programing and in interpreting results obtained from its use?

WHAT IS LINEAR PROGRAMING?

Linear programing involves linear or straight line relationships. This means that constant proportions or amounts of resources are used in the mathematical process. If one acre of land, eight hours of labor and \$30 of capital will produce 60 bushels of corn; then two acres of land, 16 hours of labor and \$60 of capital will produce 120 bushels of corn.

Another example is shown in Figure 1. If one beef cow and her replacement requires 10 acres of pasture, 4 cows will require 40 acres and 10 cows will require 100 acres of pasture. Thus, as more units of livestock or crops are added, the resource requirement per unit and income per unit is not changed.

Economic problems exist on the farm because of scarce resources and competing goals or objectives. If enough resources and goods were available, there would be no economic problems. For example, air is necessary for animal and plant life but because of its abundance, no economic problem exists.

The same situation existed at one time for water and land. As time went by, these resources became scarce and economic problems concerning their use arose. On the farm, all economic resources—land, labor and capital—are usually limited. The operator has only so

¹ Webster's New International Dictionary, preferred spelling, 1959 edition.

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many months of labor, so many dollars of capital and so many acres of land at his disposal. In linear programming the available amounts of these and other resources are considered and allocated for farm production in a manner that will produce maximum returns.

A logical question now arises: "Isn't the goal of farm budgeting also to maximize profits or returns?" Farm budgeting has the same goal as linear programming. This point should be emphasized—**linear programming is only a more exact budgeting method**. The two techniques are not competitive, but rather are alternative methods of studying and solving farm management problems. In fact, the two methods need identical information for solution: (1) resource needs for livestock and crop production, (2) levels of livestock and crop production (such as milk per cow, eggs per hen, and bushels per acre), (3) prices received for products, and (4) production costs.

Budgeting and linear programming differ in at least two respects.

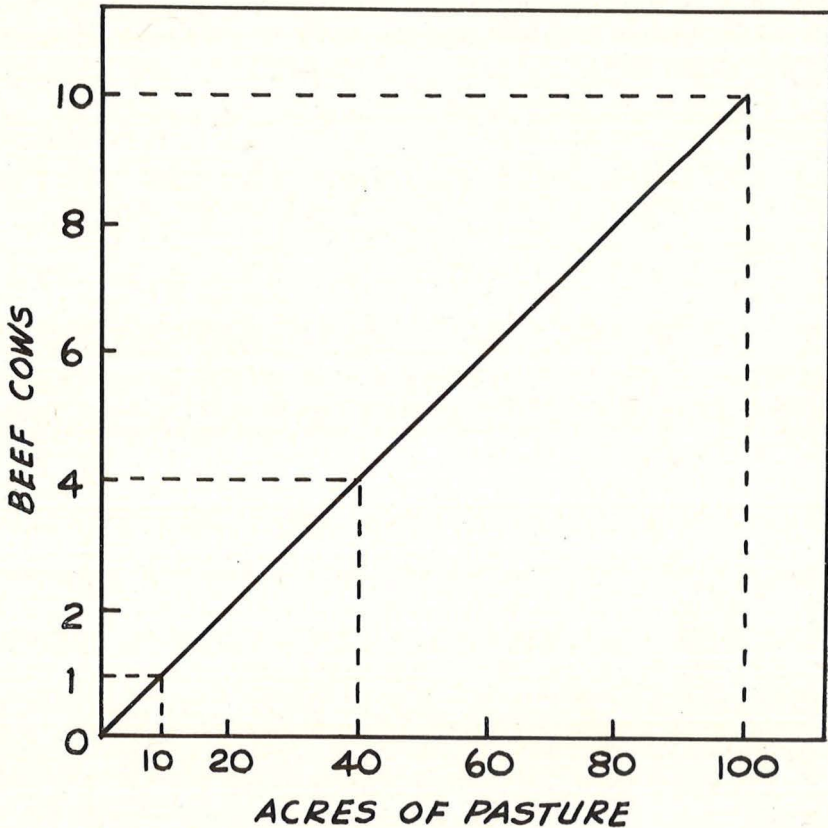


Figure 1. Pasture requirements for beef cows, showing linear or straight line relationship.

First, budgeting uses simple arithmetic processes, such as multiplication and addition, while programing in its simplest form must resort to a graphic or geometric analysis. Second, we usually assume that a farm organization plan obtained by budgeting makes good use of the available resources. However, it is not certain that the most efficient use is made of them. When a solution is obtained by linear programing we can be certain that no better use of resources exists.

LINEAR PROGRAMING—A MANAGEMENT AID

In our present agricultural economy, the farm manager is the most important resource used in the farm business. The amount of profit that can be made from a given amount of land, labor, capital and other scarce resources is largely determined by the quality of management. For many farmers, efficient management may mean the difference between continuing farming and seeking employment elsewhere. Linear programing can be used to determine the maximum income potential of the farm family's resources. In addition, it will show the combinations of crop and livestock enterprises which will give the greatest returns from use of the family's resources.

The linear programing method also can be used to solve problems where keeping costs to a minimum is the objective. It might be used to determine what combination of feed will give the lowest cost dairy ration containing 12 percent digestible protein, 75 percent total digestible nutrients and not more than 10 percent fiber.

Decisions in the home can also be considered in linear programing. However, it is necessary to place values that can be measured on the various farm and home goals being considered. For example, a farm family decides it will use capital for non-farm purposes (vacations, remodeling the house, landscaping, etc.) when the interest return on capital used in farming drops below 10 percent. It would be possible to combine this information into a farm and home problem. The real requirement is that the family have some knowledge of how it rates farm and home investments on a priority basis.

HOW LINEAR PROGRAMING CAN SOLVE FARM PROBLEMS

Assume that a farmer asks: "How can I use my labor and feed grain in the most profitable manner to produce feeder cattle and hogs?" To simplify matters, assume that his supplies of labor and feed grain are the only limited resources. This means that his present labor and feed grain supplies will be completely used up before he runs out of forage, pasture, capital, housing facilities, etc.

To determine the most profitable organization of feeder cattle and hogs, we must know:

1. The amounts of labor and feed available;
2. The amount of labor required per unit of cattle and hogs;
3. The amount of grain needed per unit of cattle and hogs;
4. The net return or income per unit of cattle and hogs.

This information has been compiled in Table I.

Table 1. Data needed in linear programing example.

	Requirement	Per Unit
	Hogs	Feeder Cattle
Labor—600 hours available	2.4	12
Feed grain—2,700 bushels available	15	45
Returns per unit (to operator)*	\$25	\$79

* These figures represent returns to labor, capital and feed grain.

First Step: To determine how the resources should be allocated (for the most profitable combination of cattle and hog production) we must first know how many units of each enterprise can be produced with each resource. By dividing the total amount of each available resource by the amount required per unit of livestock in Table 1, we learn that the operator has enough:

(a) Feed grain to produce	180 head of hogs	(2700 ÷ 15)
(b) Feed grain to feed	60 head of cattle	(2700 ÷ 45)
(c) Labor to raise	250 head of hogs	(600 ÷ 2.4)
(c) Labor to raise	50 head of cattle	(600 ÷ 12)

If the operator were to raise all hogs, he would have enough grain to feed 180 head. He would use all of his grain, but retain 168 hours of unused labor (180 head x 2.4 hours = 432 hours of labor required). His net return from all hogs would be \$4,500. In this case, feed grain is limiting production.

If he decided to raise all beef steers, he would have enough labor to produce 50 head of cattle. He would exhaust his labor but retain 450 bushels of unused feed (50 x 45 = 2,250 bushels of grain required). His net return from the cattle would be \$3,950. In this case, labor becomes the limiting resource. This information is shown in Table 2.

Note that the **most limiting resource** is **not** the same for each enterprise. If we had discovered that the same resource (say grain) was the scarce or limiting one for both enterprises, the highest profit solution would have been simple. The enterprise giving the most returns by using up all of the grain would give the greatest income and no combination of enterprises would increase income. This assumes, of course, that none of the other resources could be substituted for labor and that the supply of labor could not be increased.

Table 2. Production possibilities from labor and feed showing returns and unused resources.

Resources available	600 hours labor	2,700 bushels feed
Number of feeder cattle possible	50 head	60 head
Number of hogs possible	250 head	180 head
Maximum return from all cattle	\$3,950	
Maximum return from all hogs		\$4,500
Unused resource—all cattle		450 bushels feed
Unused resource—all hogs	168 hours	

So far, we have used simple arithmetic in a budgeting procedure. In our example, if the operator had no preference for cattle or hog production and wanted to choose the one enterprise that would give him the most profit, he would raise hogs. Producing 180 head of hogs with 2,700 bushels of grain would give a net income of \$4,500, compared to \$3,950 profit from feeding 50 steers, the maximum possible with 600 hours of labor.

But the solution to our problem is not so simple. Producing all hogs will leave 168 hours of unused or excess labor. It would appear, then, that some combination of hogs and cattle might produce more net income.

Second Step: To determine the combination of enterprises that will give the most income, we resort to graphic presentation. By plotting cattle numbers on one side and hog numbers on the other side of a graph we can show the number of hogs and cattle that can be produced with 600 hours of labor and with 2,700 bushels of grain. In the follow-

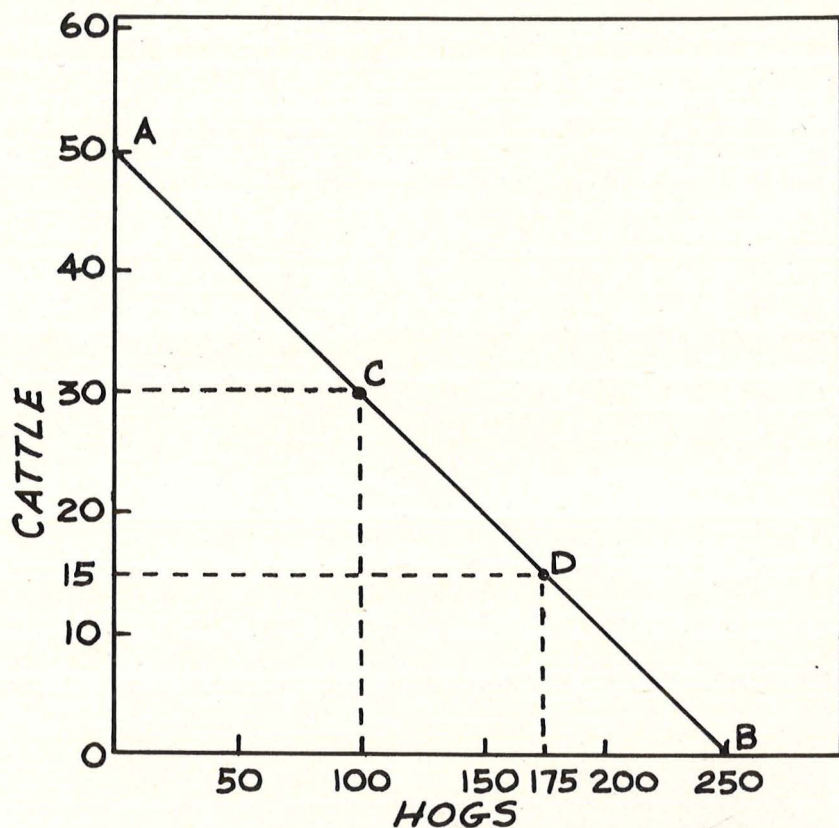


Figure 2. All possible combinations of hog and cattle production using 600 hours of labor.

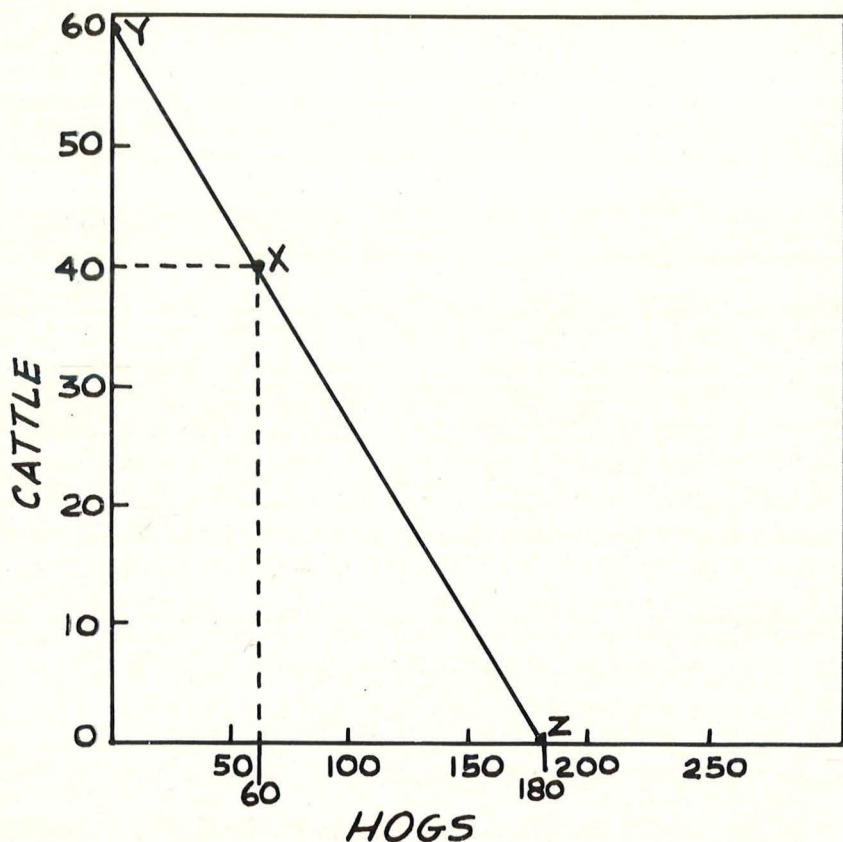


Figure 3. All possible combinations of hog and cattle production using 2,700 bushels of grain.

ing graphs, cattle numbers have been plotted on the vertical axis and hog numbers on the horizontal axis.

1—All combinations of production of the two livestock enterprises for labor are shown in Figure 2. If all of the labor was used in cattle production, 50 head of cattle and no hogs could be produced. This possibility is indicated at point A. If the entire 600 hours of labor was used in hog production, 250 hogs and no cattle could be produced. This is indicated at point B. The straight line connecting these two points indicates all the production combinations possible from the use of this resource. At point C, 30 cattle and 100 hogs could be produced. At point D, 15 cattle and 175 hogs would be possible.

2—Now consider the other resource—grain. As indicated in Table 2, 60 cattle or 180 hogs could be produced with the 2,700 bushels of grain. These items are charted in Figure 3 as points Y and Z. The line connecting these points indicates all possible production points for this

resource. For example, point X indicates that 40 cattle and 60 hogs would use all grain resources.

Third Step: The two graphs, Figures 2 and 3, indicate the number of cattle and hogs which can be produced from each individual resource. They do not tell us how many cattle and hogs can be produced from labor and grain together. To do this, the figures must be combined. This has been done in Figure 4.

Figure 4 shows the greatest production possibilities for each resource. It also shows the most production possible when the two resources are combined. This is indicated by the line connecting points A, K and Z.

Any combination of hogs and cattle above or to the right of line A, K and Z is not possible. At the two extremes: (1) if no hogs are produced, cattle production is limited to 50 head (point A) because of limited labor; and (2) if no cattle are produced, hog production is

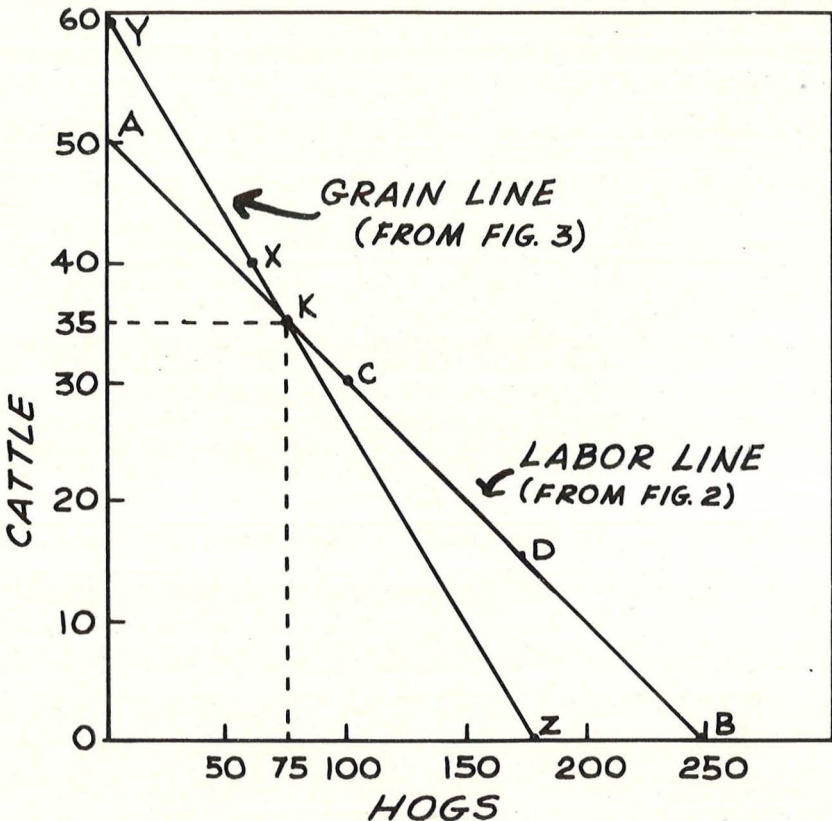


Figure 4. All possible combinations of hogs and cattle which can be produced from 600 hours of labor and 2,700 bushels of grain.

limited to 180 head (point Z) because of limited feed. All combinations of livestock production, as indicated by points Y, X, C, D and B are not possible when the 600 hours of labor and 2,700 bushels of grain are used together.

Point X indicates that a combination of 60 hogs and 40 cattle will use all the grain. However, these amounts of livestock require 624 hours of labor, or 24 more than are available ($60 \text{ hogs} \times 2.4 \text{ hours}$, plus $40 \text{ cattle} \times 12 \text{ hours} = 624 \text{ hours}$). At point D, there is sufficient labor to produce 175 hogs and 15 cattle. So far, so good! But this much livestock requires 600 more bushels than the available 2,700 bushels ($175 \text{ hogs} \times 15 \text{ bushels}$, plus $15 \text{ cattle} \times 45 \text{ bushels} = 3,300$ bushels of grain).

In Figure 5, only those combinations of production possible from using labor and grain together are shown. Note that the curve is not smooth or straight, but is made up of two straight sections: AK and KZ. The point K, where the slope of the lines changes, indicates the

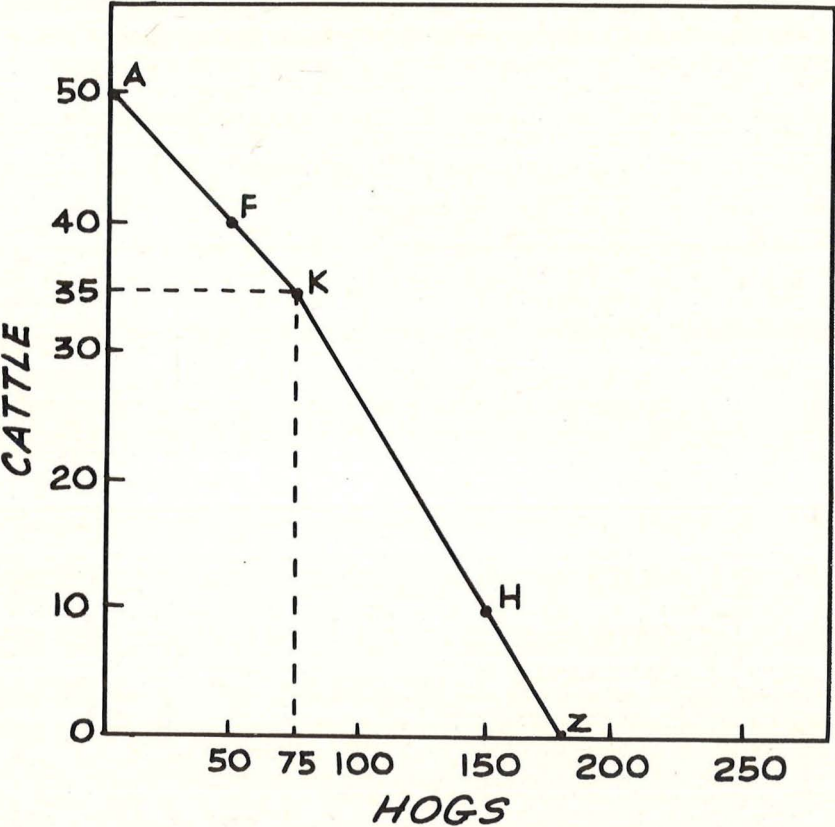


Figure 5. All possible combinations of hogs and cattle which can be produced from 600 hours of labor and 2,700 bushels of grain (production possibility curve).

Table 3. Resources used in production of hogs and cattle as indicated in Figure 5.

	Labor (hr.)	Grain (bu.)
Total resources available	600	2,700
Resource use—at point F		
40 cattle	480	1,800
50 hogs	120	750
	600	2,550
Resource use—at point K		
35 cattle	420	1,575
75 hogs	180	1,125
	600	2,700
Resource use—at point H		
10 cattle	120	450
150 hogs	360	2,250
	480	2,700

combination of hogs and cattle that completely uses up all feed grain and labor. At this point, 35 cattle and 75 hogs can be produced. The operator **could** produce at levels where only one resource is exhausted. At point F, 40 cattle and 50 hogs are produced, or at point H, 10 cattle and 150 hogs are raised. Neither combination exhausts all of the labor and all of the grain (see Table 3). Only at point K is it possible to combine hog and cattle production in such manner as to completely exhaust the supply of labor and grain.¹

Fourth Step: To determine the most profitable organization of cattle and hogs, we must know the return per unit of livestock. For this example, returns per unit were \$25 for hogs and \$79 for cattle (See Table 1). Charges for grain and labor have not been subtracted from these returns and as a result, these figures should be considered as net returns to labor, grain and fixed costs. The return per unit of livestock is used to compare incomes from livestock production at points A, K and Z shown in Figure 5. For determining profits, these points are the only ones that need to be considered. All other points shown on the line can be ignored.² At each of these points a different organization is indicated.

- (1) Point A—50 cattle, no hogs.
- (2) Point Z—no cattle, 180 hogs.
- (3) Point K—35 cattle, 75 hogs.

¹ At first it might appear most profitable to completely utilize both resources. However, there is a possibility that a resource can be so completely utilized that profits are reduced. In economic terms this is called "negative net marginal productivity." It will be seen later that it may be necessary to leave some resources idle in order to maximize income.

² Income will be greatest at those points where the line begins or changes slope. More profits can be obtained by moving to the left or right of a point along the line. A slight possibility exists that a point along a line might be equally profitable to a beginning or corner point. Nonetheless, profits along the line would never exceed those at a corner. Hence, for all practical purposes, we will consider only points where the line begins and where the line changes slope as rational points.

The resulting income from each organization is as follows:

$$\text{Point A: } (50 \text{ cattle} \times \$79) + (0 \text{ hogs} \times \$25) = \$3,950$$

$$\text{Point Z: } (0 \text{ cattle} \times \$79) + (180 \text{ hogs} \times \$25) = \$4,500$$

$$\text{Point K: } (35 \text{ cattle} \times \$79) + (75 \text{ hogs} \times \$25) = \$4,640$$

Thus, for returns of \$25 and \$79 per unit of hogs and cattle respectively, point K indicates the most profitable combination of hogs and cattle in use of resources.

Changes in farm prices or costs may change the optimum point of production. For comparison with the above example, consider returns per unit of livestock at \$60 for cattle and \$10 for hogs. In this case the net returns would be at point A, $\$60 \times 50 = \$3,000$; point K, $\$60 \times 35 \text{ plus } \$10 \times 75 = \$2,850$; and at point Z, $\$10 \times 180 = \$1,800$. In this case, the greatest profit will result from feeding all cattle (point A).

As another example, we might assume a net return per unit of \$72 for cattle and \$20 for hogs. Under these circumstances, the incomes are: point A = \$3,600; point K = \$4,020; point Z = \$3,600. In the latter case A and Z are equal in their use of resources, but K makes the best use of resources. As shown above, any prices may be applied to the example, and the livestock combination giving the greatest profits can be determined quickly.

CONSIDERING MORE THAN TWO RESOURCES

Our example can be expanded to include other resources as well as labor and grain. Suppose that plenty of housing is available for cattle but present facilities for hogs limit the herd to 150 head. How will this affect the best use of resources? Figure 6 shows the original production possibility curve with the restriction on hog housing added. Point Z is no longer a reasonable point for production. At point Z, 180 hogs would be produced. However only enough housing is available for the production of 150 hogs. Our new points include E and H. The best organization at point E is 150 hogs and no cattle, and at point H, 150 hogs and 10 cattle. Actually, point E would not be considered as long as feeding cattle results in a positive net return.

Now let us consider operating capital as a resource. Suppose that there is sufficient capital to feed 60 cattle or raise 300 hogs. How will this affect the best use of resources? In Figure 7, points Y and N indicate the numbers of all cattle or all hogs that can be produced with the available capital. Since hog housing is limited, only combinations of hogs and cattle indicated on the capital line to the left of point O would be possible. At point O, the intersection of the hog housing and capital lines, 150 hogs and 30 cattle could be produced. But we saw from the previous example, when 150 hogs are produced, other resource limitations restricted cattle feeding to 10 head (as indicated by point H). In this case, capital is not considered a scarce or limiting

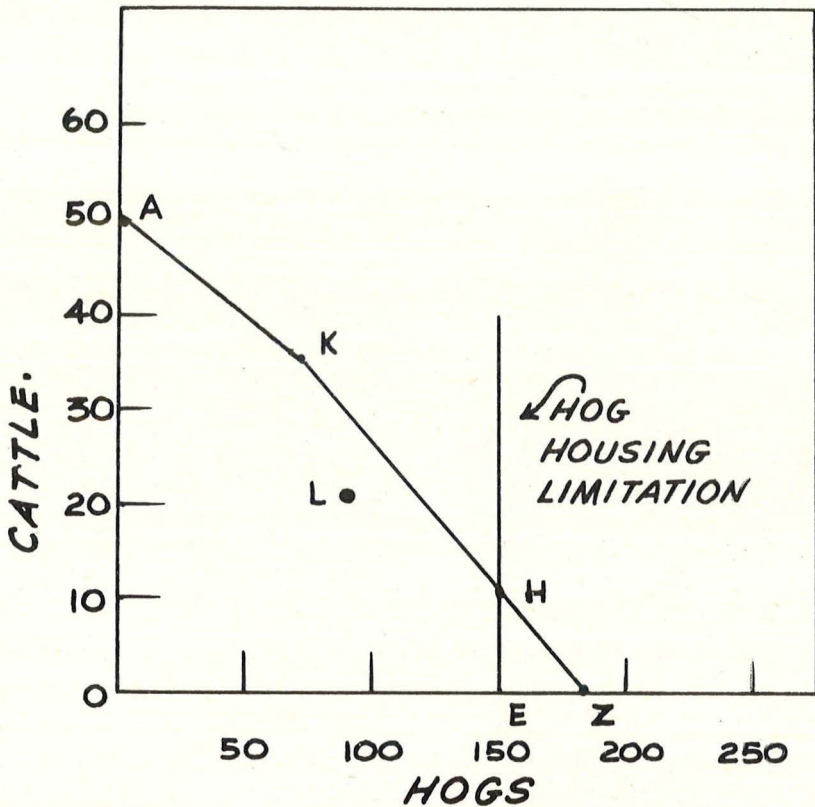


Figure 6. All possible combinations of hogs and cattle which can be produced from labor and grain with limited hog housing space.

resource; production of cattle and hogs will be limited by the amount of available housing, feed grain and labor.

We can consider using excess or unused capital (as indicated in Figure 7) to hire additional labor and/or to buy additional grain. Assume that \$9,000 of capital is available (see Table 4). By using all of the capital, 60 cattle or 300 hogs could be produced, as shown by points Y and N in Figure 7. But we are restricted to 150 hogs because of a lack of housing space, and cattle production is limited to 50 head because of labor restrictions. At point K, all of the present labor and feed grain is used; at point H, all of the feed grain is used, but there are 120 hours of unused labor ($600 - 480 = 120$). At point G, there is sufficient housing and labor to produce 150 hogs and 20 cattle, but we would need 3,150 bushels of grain ($20 \text{ cattle} \times 45 \text{ bu.} + 150 \text{ hogs} \times 15 \text{ bu.} = 3,150$). With only 2,700 bushels of grain available, we would need to buy extra grain to use all of the available labor. This is true for any combination of hogs and cattle along the line between points

Table 4. Production possibilities using capital to buy additional grain.*

Requirements per unit:	Cattle	Hogs
Grain (bu)	45	15
Labor (hr)	12	2.4
Capital	\$150	\$30
Returns per unit of livestock	\$ 79	\$25

Maximum production possible:

	Cattle	Hogs	Net Return	Capital Required	Labor Required	Feed Required
Point A	50	\$3,950	\$7,500	600	2,250
Point K	35	75	4,640	7,500	600	2,700
Point H	10	150	4,540	6,000	480	2,700
Point G	20	150	4,880	7,950	600	3,150

* Resources available: 2,700 bushels grain, 600 hours labor, \$9,000 capital and hog housing limited to 150 head.

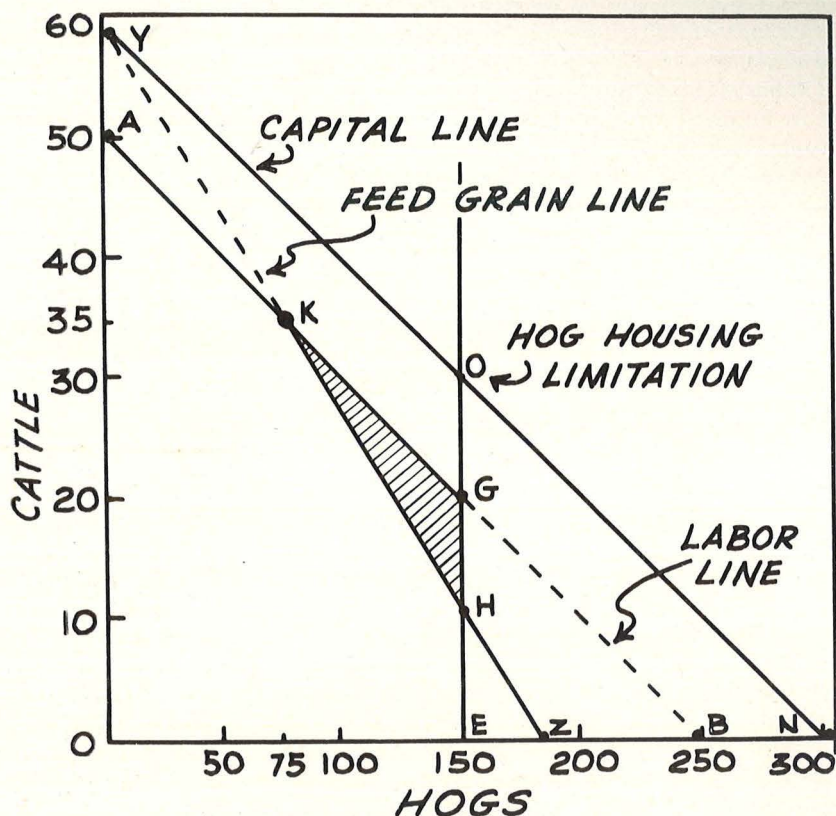


Figure 7. Combinations of hogs and cattle which can be produced when operating capital is used to buy grain with limited hog housing.

K and G. The shaded area in the triangle KGH indicates an area of excess labor and feed grain shortage.

It would be reasonable to assume that additional feed grain could be purchased to feed more cattle and make use of the excess labor indicated by the shaded area. If we were to buy additional grain to feed more cattle, how many more could we feed with the 120 hours of unused labor? Would there be sufficient capital to fully use the extra labor?

When compared with point H (Figure 7), there would be sufficient labor at point G to feed 10 more cattle ($120 \text{ hours} \div 12 = 10$). These additional cattle would require \$1,500 more capital ($\$150 \times 10 = \$1,500$) and 450 bushels of additional grain ($45 \times 10 = 450$). With feed grain valued at \$1.00 per bushel, we would have to buy \$450 of grain. When compared with point H, \$1,950 of additional capital (see Table 4) would be required to buy the additional 10 cattle, pay operating expenses and buy additional feed required. With \$7,950 required for production at point G, we still have \$1,050 of capital left. The balance of capital could be used to secure **both** more labor and grain to expand production still more.

What effect would feeding 20 cattle and 150 hogs (indicated by point G in Figure 7) have on returns? At point H, income is shown as \$4,540 from 10 cattle and 150 hogs. Adding 10 more cattle will increase returns by \$790 ($10 \times \79), but we will have to buy \$450 of grain. Thus, the net return is \$340 more than was realized at point H and \$240 more than at point K, which previously was the "high returns" combination of livestock (see Table 4).

This example shows that capital, if plentiful, can be used to buy grain. We could have considered hiring labor to increase production, or even using some of the excess capital to expand hog housing facilities. At any rate, this example should indicate that one resource can often be substituted for another.

APPLYING LINEAR PROGRAMING TO FARM PROBLEMS

The example presented in the previous section is a simplified presentation of linear programing. Because many resources and enterprises are considered at the same time, the form used in research work is a great deal more complicated. However, the graphic analysis described can be used by agricultural leaders in counseling with farm operators.

In applying this technique to solve problems concerning farm organizations, several points must be considered:

1. Several resources can be considered at one time to determine enterprise combinations, but only two enterprises can be compared at a time, since graphic analysis is limited to two dimensions—vertical and horizontal. This is not a serious limitation in examining the organization of livestock enterprises. Most farmers are not concerned with the production of more than two major livestock enterprises (example: beef feeding and hogs; dairy cattle and hogs).

2. An indication of the resources currently used on any given farm can be obtained by first budgeting the present cropping system and livestock organization. (Extension Circular, E.C. 58-810, entitled, "Greater Returns From Your Farm" can be used as a guide for budgeting.) By following this procedure, the supply of feed grain, forage, labor and capital can be determined. This information can be used in determining an alternative livestock organization by graphic analysis. If you find that feed grain and/or forage are limiting or scarce resources, adjustments in the cropping system can then be made to increase livestock production.

3. Use production information which is best adapted to the individual farm situation. Detailed information about the farm business under consideration would be best. In the absence of such information, use production standards obtained through experiment station information and data from detailed farm costs studies, but adjusted to individual farm conditions.

4. After the first solution of farm organization and income is obtained, alternative programed plans can be compared with it. Your comparisons should show **changes** in net income, rather than **total** net income. In most cases, the farm operator is concerned with the effect a change in organization will have on his income.

5. Consider changes in resource requirements as well as changes in organization. As a farmer increases from 40 head of feeder steers to 100 head, the labor required per steer will be less. The same is true for virtually all livestock enterprises.

6. Resources often can be substituted for one another, or additional resources may be purchased. Corn can be sold and the income used to hire labor; corn can be made into silage to replace or supplement hay; more hay and less grain may be used in a ration; capital can be used to buy labor or to buy labor-saving equipment to substitute for labor.

7. Remember that an answer obtained by linear programing or budgeting is only as good as the data used. It is not a substitute for precise data, management or judgment. Linear programing is only an aid to sound farm management.

INFORMATION NEEDED FOR APPLICATION TO FARM MANAGEMENT PROBLEMS

To determine the best organization of an individual farm by linear programing, we must first take a look at the present situation.

a. How many acres of crop land are available? How many acres are irrigated and how many acres are dryland? How intensively should the land be cropped?

b. What level of crop yields can be expected? How much feed grain, hay, silage and pasture will be available for livestock?

c. What livestock facilities are or could be available? What kind of feeding program for each livestock enterprise is anticipated?

d. How much capital and labor is available for use in farming?
How is the labor supply distributed throughout the year?

e. What is the expected net return or income per unit of production?

f. How much feed is required per unit of livestock produced?

g. How much capital is required for each unit of production?

h. How much labor is required per litter of hogs; per milk cow; per feeder heifer or steer; per acre of wheat; per acre of corn, etc.?

All of these questions must be answered to supply information needed in either budgeting or linear programming.

Ordinarily, levels of crop yields and other information concerning crop production are easy to obtain. The farmer usually has first-hand knowledge about crop yields. If you are familiar with local conditions, the level of cropping efficiency can be determined rather easily.

The efficiency of livestock production is more difficult to determine. Few farmers have adequate records to supply such information. In addition, the usual records do not show income and cost figures for each enterprise, but only give an analysis of the overall farming business. As a result, it is difficult (if not impossible) to get a good look at the efficiency levels for the individual livestock enterprises on the farm.

By examining past business records for the farm, some idea is obtained of the number of acres of different crops raised, the number of different kinds of livestock produced, and an overall picture of the amount of capital, labor and feed used annually. This information can then be supplemented with information obtained from various bulletins and publications released by the University of Nebraska.

SOME USES OF LINEAR PROGRAMING IN RESEARCH

Determining most profitable cropping and livestock systems

Solving minimum resource requirements for given farm incomes

Testing stability of farm organizations through changing prices and costs

Determining least cost livestock feed rations

Determining fertilizer programs which meet requirements at minimum cost

Solving least cost transportation routes among regions for agricultural products

Appraising productivity of resources

Determining supply responses for farm products

Testing efficiency of farm leasing arrangements

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