ECONOMIC ANALYSIS OF USING POULTRY LITTER IN CATTLE FEEDLOTS: SONORA, MEXICO.

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ECONOMIC ANALYSIS OF USING POULTRY LITTER IN CATTLE FEEDLOTS: SONORA, MEXICO

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ABSTRACT

A computerized linear programming model was used to calculate diets for steers weighing 200, 300 and 400 kgs, and gaining 0.9, 1.1 and 1.2 kgs/day respectively. A prototype diet was calculated for each combination of weight and weight gain. Later, nine kinds of poultry litters were made available, varying in their protein and energy content. Results showed that poultry litter can substitute economically for protein, energy, roughages and mineral sources. The least cost level of poultry litter in diets ranged from 7.17 to 19.99 percent for 200 kgs steers, 3.21 to 9.89 percent for 300 kgs steers, and 3.21 to 9.89 percent for 400 kgs steers.

Besides the savings obtained when poultry litter cost was $3,000 pesos/metric ton, it was found that the use of poultry litter in the diets was relatively insensitive to price changes.

I. INTRODUCTION

According to the Secretaria de Agricultura y Recursos Hidaulicos the State of Sonora, Mexico, produced approximately 72,000 metric tons of poultry litter in 1983 from intensive broiler units. About 48 percent of the 72,000 metric tons was from the region of Hermosillo County. Thus, about 34,560 metric tons of poultry litter were available in the Hermosillo area to be used as a pollutant, as a fertilizer, or as a feedstuff for animals.

The first alternative represents water contamination, bad odors and flies which together with a strong social movement for a better environment will make the disposal of wastes a constitutionally regulated activity. In support of the environment, the Secretaria de Desarrollo Urbano y Ecologia is promoting the right of the Mexican people to have a better environmental quality as a constitutional amendment. This amendment gives local governments the opportunity to locally adopt the necessary measures to obtain the desired goals. The second option reflects a traditional method utilized to dispose animal wastes. However, the appearance of new and cheaper plant nutrients has made animal wastes a relatively expensive fertilizer.

Finally, using animal wastes as a feed ingredient represents a viable alternative which could solve pollution problems, substitute for other feeds and make animal production a more economically attractive activity.

The possibility of recovering the nutrients contained in animal wastes for animal production has been widely explored by many researchers, what is even more important some countries like Israel (Holzer, 1980), have made the utilization of animal wastes, and specifically poultry litter, a common practice in ruminants' nutrition.

In Mexico, some animal producers are using poultry litter as part of the diets for ruminants. These feedlot owners have concluded that the crude protein contained in other feedstuffs, and that poultry litter is an inexpensive substitute for other protein sources.

The chemical composition of poultry litter denotes differences that should be examined before any attempt is made to include the litter as a substitute for a specific ingredient. Poultry litter contains a considerable amount of crude protein. However, the litter also contains energy and minerals (mainly clacium and phosphorus) in proportions that makes this product different from other feedstuffs.

Once the chemical composition and costs of the feedstuffs used in the region of Hermosillo, and the nutrient requirements of steers of certain weights and expected rates of gain were obtained, a computerized linear programming model can be used to calculate the least cost diets for the animals in order to attain the following objectives:

1. Determine the level at which poultry litter can be included in the diets without affecting the nutrient requirement for the fattening steers.

2. Conduct a sensitivity analysis on the constraints and costs of the ingredients.

3. And finally, find out the potential demand for poultry litter.

This thesis contains several analysis designed to accomplish the above objectives.

II. CHEMICAL COMPOSITION OF POULTRY LITTER

Poultry litter, as used here, refers to the manures from houses where chickens are kept on litter. The product includes bedding material such as peanut hulls, wood shavings, corn cobs, wheat straw and oat straw, etc., in addition to the feces, urine, wasted feed, and feathers. Poultry litter can be distinguished from poultry waste in that the latter is a product from caged laying hens which does not contain bedding material.

Tables 1 and 2 show that poultry litter, according to the mean values, is high in crude protein, calcium and phosphorous, also a significant amount of energy is present. Table 1 was obtained from the United States of America wile Table 2 presents data collected from the State of Sonora, Mexico. Less information is given in Table 2 due to the unavailability of data with respect to the mean values for digestible protein (DP), digestible energy (DE) and metabolized energy (ME), besides the range values marked as n.a. (not available).

The wide variability of poultry litter chemical composition, under standard management systems, results from many factors, The most important sources of variation include the type of bedding material used, the composition of the diet fed, and the method of processing and handling of the litter (Bhattacharya and Taylor, 1975; Bhattacharya and Fontenot, 1966; Lucas, et al. 1975; Arndt, et al. 1979).

Since rumen microorganisms can convert nonprotein nitrogen into microbian protein, ruminants seem to be better adapted to utilize poultry litter than other kinds of animals.

More that 50 percent of the nonprotein nitrogen in poultry litter is present in the form of uric acid (Bhattacharya and Taylor, 1975). Keonig, et al. (1978) demonstrated that rumen microorganisms were able to fully utilize uric acid from an adaptation period of two to three days; furthermore, once the microbes are adapted to uric acid, the rumen microflora will degrade it in about a six-hour incubation period. Pearce (1979) states that according to published reports, the level of crude protein in poultry litter could range from 7.5 percent to 41.8 percent. This wide variability comes from the factors mentioned above.

Energy content is one important factor to be considered during the evaluation of feedstuffs. Moreover, the digestibility coefficient for gross energy should be determined in order to better judge the energy value of poultry litter. As stated by McDonald, et al. (1973) higher digestibility coefficients mean that more energy has been absorbed by the animals and less of it has been wasted through the feces.

Table 1

Chemical Composition of Poultry Litter
in the United States

Composition of Dry Matter	Poultry Litter Mean	Poultry Litter Range
Crude Protein (CP)	26.8	19.4 - 40.0
Digestible Protein (DP) (Ruminants)(%)	22.6	21.6 - 23.5
Energy (Kcal/kg)		
Gross Energy (GE)	3652	3250.0 - 3862.0
Digestible Energy (DE) (Ruminants)	2440.0	n.a*
Metabolizable Energy (ME) (Ruminants)	1627.0	1100.0 -2181.0
Minerals		
Ash (%)	18.6	9.5 - 30.7
Calcium (Ca) (%)	2.6	1.6 - 6.07
Phosphorus (P) (%)	1.81	0.89 - 2.86

Source: Martin, et al. (1983a).

* not available

Table 2

Chemical Composition of Poultry Litter
in Sonora, Mexico

Composition of Dry Matter	Poultry Litter	
	Mean*	Range**
Crude Protein (CP) (%)	24.1	12.1 - 32.5
Digestible Protein (DP)	n.a.	n.a.
Energy (Kcal/kg)		
Gross Energy (GE)	3251	2906 - 4010
Digestible Energy (DE)	n.a.	n.a.
Metabolizable Energy (ME)	n.a.	n.a.
Minerals		
Ash	20.42	n.a.
Calcium (Ca) (%)	3.10	n.a.
Phosphorous (P) (%)	1.85	n.a.

Source: *Unpublished data from the Centro de Investigaciones Pecarias del Estado de Sonora, (1983).

**Coronado (unpublished paper, 1979).

Brugman, et al., (1967) found a 59.15 percent digestion coefficient for energy in poultry litter. Ray (1978) indicated that energy digestibility of poultry litter ranged from 64.84 percent to 79.96 percent depending on the litter base used. In Ray's study, he found that wheat bran litter, cotton boll hull litter, and sage grass litter were better digested than cottonseed hull litter, rice hull litter and wood shaving litter. Ray also reported a high correlation between digestible dry matter and digestible energy, concluding that digestible dry matter can be accurately used as a measure of energy digestibility.

It can be concluded that poultry litter is high in crude and digestible protein, calcium, and phosphorus and gross energy. However, digestible energy is low. Also, poultry litter will have a wide variation in the chemical composition, particularly protein, and energy, ash, calcium and phosphorus, as a result of the origin and management practices (see Tables 1 and 2).

III. EFFECTS OF HANDLING AND PROCESSING ON THE NUTRITIVE VALUE OF POULTRY LITTER

The effects of handling and processing on the nutritive value of poultry litter are almost the same as for poultry waste; for this reason, some experiments involving poultry waste were considered to be applicable in poultry litter management.

After the excreta is voided its quality may be changed by diverse factors before feeding. In many cases, poultry litter has been dehydrated in order to obtain a product with less moisture and almost free of pathogenic microbials. Manoukas, et al. (1964) recorded nitrogen losses of 7.1 percent to 15.2 percent when poultry litter was dried in an oven at 65°C for 24 hours. Fontenot, et al. (1971) found 19 percent of the total nitrogen lost as a result of heating poultry litter at a temperature of 150°C for four hours. In some special cases, like the one reported by Brugman, et al. (1967), no nitrogen differences were found when poultry litter was heat treated at 135°C temperature for a period of 11 hours, but, the authors reported that crude protein digestibility was depressed by 7.6 percent. Long, et al. (1969) notices an inverse relationship between the temperature at which poultry waste was treated and the total crude protein of the final manure.

Ensiling has been a process widely used to preserve and add palatability to feedstuffs. Harmon, _et al_. (1975) found that ensiling poultry litter with high moisture corn grain at a 1:2 ratio resulted in a small nitrogen loss compared to heat treated poultry litter at 260°C for a period of 30 minutes.

Storing poultry litter can have detrimental effects on its chemcial composition. Large nitrogen losses can be expected as a result of the conversion of uric acid to ammonia which is lost via volatilization. As reported by Flegal, _et al_. (1972), the nitrogen content of poultry waste during the first 28 days of storage, after voiding, changed very little. However, from the 28th to the 98th day, 40 percent of the crude protein was lost.

Handling of poultry litter can result in serious contamination of the product. The utilization of poultry litter from unpaved poultry units will tend to be high in ash content due to the inclusion of soil and other foreign materials.

In the Hermosillo area, poultry litter is usually taken directly from the poultry units to the feedlots. However, after the litter is bought, it is stored in the same manner as low quality roughages. Unpaved and exposed areas are used to store poultry litter. Since feed mixes are usually prepared on day-by-day basis, not all the poultry litter will be used in a short period of time. Therefore, the litter left will be exposed to climatic factors like solar radiation, wind, rain, etc. and consequently, the quality of the litter used in different time periods will have different nutrient concentrations. Nitrogen losses can be expected. It is important, therefore, to consider these nutrient losses during the time of mixing poultry litter with the rest of the ingredients of the diet, or, manage the litter like other good quality feedstuffs. Poultry litter should be protected from contamination by soil and other foreign materials and exposure to undesirable climate factors until it is utilized. Lengthy storage should also be avoided.

IV. PERFORMANCE OF STEERS FED POULTRY LITTER

A summary of performance trials (Martin, et al. 1983b) where poultry litter was involved in feeding steers is presented in Table 3.

Based on Trials 1 and 2 feeding steers with 18.75 percent poultry litter, in substitution of cottonseed, decreased avarage daily gains and feed efficiency (Table 3). However, when the experimental groups were fed for equal energy intake with respect to the control, average daily gains were almost the same as shown on Trial 3, Table 3:

The effect of replacing cottonseed meal, bermuda grass hay and corn grain with poultry litter is displayed in Trial 4. When poultry litter was added at a portion of 9.9 percent of the diet, average daily gains and feed to gain ratios were only slightly affected for steers fed poultry litter (Table 3).

Including 25 percent of poultry litter instead of hay and soybean meal insignificantly reduced average daily gains, but feed efficiency was slightly improved as exhibited by Trial 5 (Table 3).

Two different control diets were used to find the effects of two distinct substitution levels of soybean meal. In Trial 6, average daily gains and feed efficiency were

Table 3

Performance of Steers Fed Unprocessed Poultry Litter

Trial #	Litter Content of Total Ration (%)	Average Daily Gain (kgs/day)	Feed to Gain Ratio (kgs of Feed/ kg of gain)	Feedstuff Reduced or Replaced in the Diet	Type of Litter
1	Control 0.0	0.97	10.79	-Cottonseed meal, molasses and corn	-Cane bagasse
	18.72	0.82	12.76		
2	Control 0.0	0.84	13.97		
	18.75	0.60	19.69		
3	Control 0.0	0.94	14.81		
	18.77	0.87	19.01		
4	Control 0.0	0.97	11.27	-Snapped corn, cottonseed meal and bermuda grass hay	-Ground corn cobs
	9.9	0.94	12.08		
	19.8	0.93	12.16		
5	Control 0.0	1.30	11.15	-Hay and soybean meal	-Peanut hulls, wood shavings
	25.0 hulls	1.28	10.08		
	25.0 wood	1.20	10.75		
6	Control 0.0	1.29	7.78	-Peanut hulls and soybean meal	-Wood shavings
	20.0	1.18	8.52		
7	Control 0.0	1.16	8.53		
	20.0	1.18	8.52		

Source: Martin, et al. (1983b).

reduced. However, in Trial 7, where the level of soybean meal was higher than for Trial 6, average daily gains and feed efficiency were slightly decreased for the control diets.

In general, average daily gains and feed to gain ratios could be decreased as the level of poultry litter is increased. The substitution of oil meals with poultry litter, based on crude protein content, could be misleading. Most of the tests done have considered iso-nitrogenous diets without regard to the energy level. Thus, at least protein and energy should be considered when comparing average daily gains and feed to gain ratios among diets in order to define the real potential of poultry litter as a substitute of other feedstuffs.

The above information relates to technical substitutions such as soybean meal for poultry litter, cottonseed meal for poultry litter or various feedstuffs for poultry litter. On the other hand, economic substitution involves changes in costs and returns which will be discussed in the next chapter.

V. THE ECONOMIC MODEL

When animal producers use protein sources, it is assumed that the feed ingredients can be substituted one for another. For example, in the series of experiments shown in Table 3 (Chapter IV), it is assumed that poultry litter can substitute for cottonseed meal, soybean meal or other feeds without affecting the level of output. In economic theory, (Ferguson and Maurice, 1978; Calkins and DiPietre, 1983), this interpretation can be explained by the use of the following production function with two variable inputs:

$$\bar{y} = f(X_1, X_2/\bar{X}_3,\ldots,\bar{X}_n).$$

Where $\bar{y}$ is the desired level of output, X_1 and X_2 are the variable inputs and $\bar{X}_3,\ldots,\bar{X}_n$ are the fixed inputs used in the production process. In animal feeding there are many combination of feeds that can achieve a desired level of weight gain. For instance, using cottonseed meal (CSM) and poultry litter (PL) as variable inputs and the rest of feeds as fixed inputs the following production function results:

100 Kgs of gain = f(CSM,PL/Sorghum grain,...Premix).

In this case, cottonseed meal (CSM) and poultry litter (PL) are substitutes that can be mixed in various combinations and obtain one hundred kilograms of gain from the animals being fed. This relationship between variable inputs is illustrated in Figure 1. Q_1 is the isoquant curve which shows all possible combinations of CSM and PL that can produce one hundred kilograms of gain. The rate at which one input is substituted for another along the isoquant curve is called the Marginal Rate of Technical Substitution (MRTS) which can be expressed as:

$$MRTS = \frac{CSM}{PL}$$

That is, Marginal Rate of Technical Substitution (MRTS) is equal to the change in quantity of Cottonseed meal divided by the change in quantity of poultry litter (PL).

In order to determine the least cost combination of cottonseed meal and poultry litter, the concept of isocost curves must be defined. Isocost curves are lines showing the various combinations of variable resources cottonseed meal and poultry litter that may be purchased with a given cash outlay. The isocost curve is represented by C_1 in Figure 1. To attain a least cost combination of the variable inputs, the MRTS must be equal to the negative inverse ratio of prices for cottonseed meal and poultry litter. That is:

$$MRTS - \frac{\text{Price of PL}}{\text{Price of CSM}}$$

or

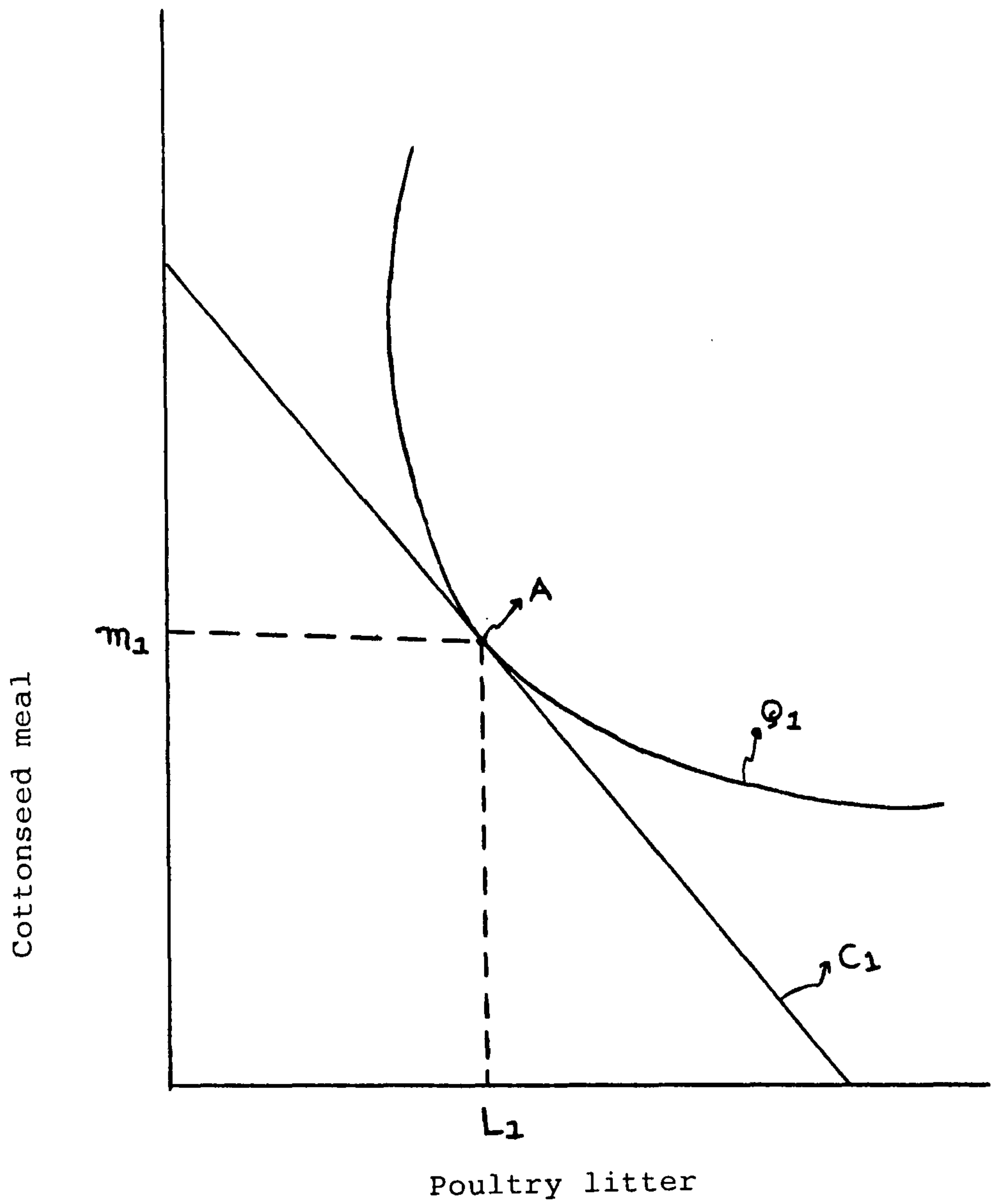
$$\frac{CSM}{PL} - \frac{\text{Price of PL}}{\text{Price of CSM}}$$

In the case of Figure 1, the least cost combination results at the point of tangency of the isocost and isoquant shown by point A, and M_1 quantity of cottonseed meal plus L_1 of poultry litter will be used.

In the development of Figure 1 it has been assumed that cottonseed meal and poultry litter are imperfect substitutes where increasing amounts of cottonseed meal must be added to replace equal reductions in poultry litter (or vice versa). Unfortunately, none of the experiments illustrated in Chapter IV (Table 3) show different combinations of poultry litter and cottonseed meal (or other feedstuff) for a given level of output. It seems that these experiments have been developed to find the maximum level of poultry litter and to completely replace other feedstuffs in animal diets. In this case the isoquant is a straight line (Constant Marginal Rate of Technical Substitution).

Using the information given, Trial 3, Table 3 discussed in the previous chapter and assuming that only cottonseed meal was completely replaced, Figure 2 can be developed to explain the consequences of having an isoquant with a Constant Marginal Rate of Technical Substitution. A Q_2 average daily gain can be obtained when 3.57 kgs of cottonseed meal is included in the ration or if this quantity is replaced completely with 6.85 kgs of poultry litter. The least cost combination will depend on how the

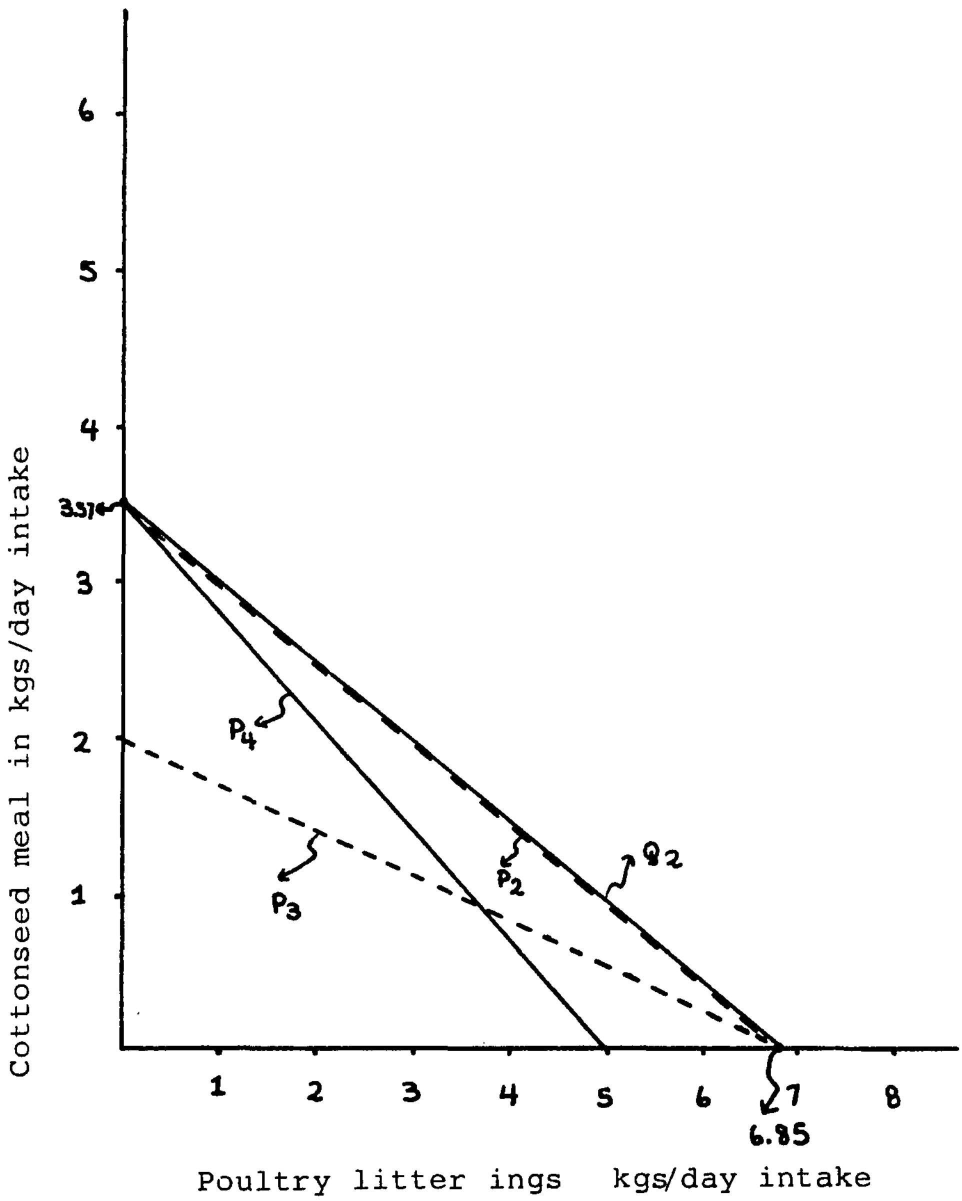
Figure 1



Hypothetical Isoquant and Isocost Curves for
Cottonseed Meal and Poultry Litter: Imperfect Substitutes

price ratio is related to the isoquant curve. If the price ratio of poultry litter to cottonseed meal is equal to 0.52 (the MRTS) or 3.57 ÷ 6.85), an infinite number of combinations can be obtained without affecting the cost of the feed mix. This possibility is demonstrated by dotted line P_2 in Figure 2. On the other hand, if price ratio is greater than 0.52 (i.e., the price of poultry litter increases while the price of cottonseed meal stays the same), only cottonseed meal will be included in the ration (see dotted line P_3). Finally, if the price ratio is less than 0.52, only poultry litter will be used (see line P_4). The principle is the same when more than two feed ingredients are involved and linear programming is a useful technique to find the least cost combination of feedstuffs given certain constraints to avoid changes in animal performance (Bernard and Nix, 1973).

Figure 2



Isoquant and Isocost Curves for
Cottonseed Meal and Poultry Litter:
Perfect Substitutes

VI. THE MATHEMATICAL MODEL

According to Budnick, et al. (1977), the mathematical statement of the linear programming model can be expressed as:

$$\text{Minimize } Z = \sum_{j=1}^{n} CjXj$$

Subject to:

$$\sum_{j=1}^{n} aijXj \ (\leq, \geq, =)\ bi, \ i = 1,2,\ldots,m$$

$$Xj \geq 0, \ j = 1,2,\ldots,n$$

Where Xj = Quantity of the jth feed ingredient

Cj = Costs of the jth feed ingredient

aij = Coefficient of the ith constraint for the jth feed ingredient or other activity

bi = Right hand-side constant for the ith constraint

n = number of ingredients

m = number of structural constraints

Given the information about the technical coefficients in the available information on chemical composition exhibited in Tables 6 and 7, the nutrient requirements for steers (Table 8), the costs of the available ingredients (Table 9) and other structural constraints, the matrix for least costs diets is shown in Table 4. Table 5 was developed to illustrate the different right hand-side values that will be used to calculate the least cost diets for different body weights for fattening steers.

The following symbols and definitions are used in the matrix and in presenting the results:

SOR = Sorghum grain

MOL = Cane molasses

CSM = Cottonseed meal

URE = Urea

WHS = Wheat straw

CSH = Cottonseed hulls

CAL = Calcium carbonate

DIC = Dicalcium phosphate

PRE = Premix

SAL = Salt

PLX = Poultry litter type, X = 1,2,3,4,5,6,7,8, and 9, depending on the type of litter available for feed mixing

DML = Dry matter level which is equal to 1 in all diets to make one metric ton of feed mix

PRO = Protein restriction level

NEm = Net energy for maintenance restriction level

NEg = Net energy for gain restriction level

CRL = Calcium restriction level

PRL = Phosphorus restriction level

The values for PRO, NEm, NEg, CRL, and PRL vary according to body weight and rate of gain of steers. Minimum levels were established.

URL = Urea restriction level. The restriction for urea was supposed to be less than or equal to 1 percent, to avoid poisoning problems or reductions on intake (Church, 1979).

SRL = Salt restriction level. A 0.1 percent salt level was considered to be acceptable to meet the animal requirements in all diets.

PRE = Premix restriction level. A quantity of 0.5 percent of premix was also considered appropriate for all diets.

MRL = Molasses restriction level. According to Cullison (1979) no more than 15 percent of molasses should be added in diets to avoid gastro-intestinal problems in steers.

PLL = Poultry litter restriction level. In concordance with Smith, et al. (1929) no more than 20 percent of poultry litter should be added to diets for steers to avoid changes in animal performance.

a = Chemical conpositon of poultry litter by type. (PRO, NEm and NEg).

RHS = Right hand-side or structural constraints.

b = Right hand-side values according to body weight and rate of gain of steers

Signs:

(=) Equal to

(≤) Less than or equal to

(≥) Greater than or equal to

Table 4

Matrix For Least Cost Diets For Fattening Steers

	Xi	SOR	MOL	CSM	URE	WHS	CHS	CAL
OBJECT	Cj	14200	5015	2550	14346	5000	4500	1862
	aij							
DML		1.00	1.00	1.00	1.00	1.00	1.00	1.00
PRO		10.30	2.30	44.80	281.00	3.60	4.30	0.0
NEm		1.85	2.27	1.69	0.0	0.99	0.94	0.0
NEg		1.23	1.48	1.11	0.0	0.10	0.03	0.0
CRL		0.03	1.19	0.17	0.0	0.17	0.16	38.00
PRL		0.31	0.11	1.31	0.0	0.08	0.10	0.0
URL		0.0	0.0	0.0	0.0	0.0	0.0	0.0
SRL		0.0	0.0	0.0	0.0	0.0	0.0	0.0
PEL		0.0	0.0	0.0	0.0	0.0	0.0	0.0
MRL		0.0	1.00	0.0	0.0	0.0	0.0	0.0
PLL		0.0	0.0	0.0	0.0	0.0	0.0	0.0

Continued...

Table 4 Continued ...

Matrix For Least Cost Diets For Fattening Sters

	Xi	DIC	PRE	ORT	SAL	PLX	SIGN	RHS
OBJECT	Cj	37000	60000	38000	7000	3000	---	---
	aij							
DML		1.00	1.00	1.00	1.00	1.00	(=)	100.00
PRO		0.0	0.0	0.0	0.0	a	(≥)	b
NEm		0.0	0.0	0.0	0.0	a	(≥)	b
NEg		0.0	0.0	0.0	0.0	a	(≥)	b
CRL		24.00	0.0	20.00	0.0	3.10	(≥)	b
PRL		19.00	0.0	20.00	0.0	1.85	(≥)	b
URL		0.0	0.0	0.0	0.0	0.0	(≤)	1.00
SRL		0.0	0.0	0.0	1.00	0.0	(=)	0.10
PEL		0.0	1.00	0.0	0.0	0.0	(=)	0.50
MRL		0.0	0.0	0.0	0.0	0.0	(≤)	15.00
PLL		0.0	0.0	0.0	0.0	1.0	(≤)	20.00

Note: See text, pp. 22-24 for definitions

Table 5

Right Hand Side (RHS) Value for
Different Body Weight (BW) and
Daily Gains (DG) in kgs for Steers

Constraint	Sign	BW=200 DG=0.9	BW=300 DG=1.1	BW=400 DG=1.2
DML %	(=)	100.00	100.00	100.00
PRO %	(≥)	12.30	10.30	10.00
NEm Mcal/kg	(≥)	1.70	1.81	1.81
NEg Mcal/kg	(≥)	1.10	1.18	1.18
CRL %	(≥)	0.47	0.33	0.27
PRL %	(≥)	0.37	0.29	0.25
URE %	(≤)	1.00	1.00	1.00
SAL %	(=)	0.10	0.10	0.10
PEL %	(=)	0.50	0.50	0.50
MRL %	(≤)	15.00	15.00	15.00
PLL %	(≤)	20.00	20.00	20.00

Note: See text, pp. 22-24 for definitions

Table 6

Chemical Composition of Traditional Feed Ingredients Used in Cattle Feeding

Ingredient	Crude protein (%)	NEm	NEg	Ca (%)	P (%)
		(Mcal/kg)			
Sorghum grain	10.30	1.85	1.23	0.03	0.31
Molasses cane	2.30	2.27	1.48	1.19	0.11
Cottonseed meal	44.80	1.69	1.11	0.17	1.31
Urea	281.00	---	---	---	---
Wheat straw	3.60	0.99	0.10	0.17	0.08
Cottonseed hulls	4.30	0.94	0.03	0.16	0.10
Calcium carbonate	---	---	---	38.00	---
Dicalcium phosphate	---	---	---	24.00	19.00
Premix	---	---	---	---	---
Orthophosphate	---	---	---	20.00	20.00

Source: NRC (1976)

Table 7

Chemical Composition of Nine Types of Poultry Litters

Poultry Litter	Code	Crude Protein	NEm* Mcal/kg	NEg* Mcal/kg	Calcium (%)	Phosphorus (%)
Poultry litter 1	(PL1)	20.00	0.89	0.00	3.10	1,85
Poultry litter 2	(PL2)	25.00	0.89	0.00	3.10	1.85
Poultry litter 3	(PL3)	30.00	0.89	0.00	3.10	1.85
Poultry litter 4	(PL4)	20.00	1.00	0.12	3.10	1.85
Poultry litter 5	(PL5)	25.00	1.00	0.12	3.10	1.85
Poultry litter 6	(PL6)	30.00	1.00	0.12	3.10	1.85
Poultry litter 7	(PL7)	20.00	1.14	0.42	3.10	1.85
Poultry litter 8	(PL8)	25.00	1.14	0.42	3.10	1.85
Poultry litter 9	(PL9)	30.00	1.14	0.42	3.10	1.85

Note: *The Net Energy for maintenance(NEm) and Net Energy for gain (NEg) values were obtained using the method described by Lofgreen and Garret (1968), and officially utilized by the NRC (1976). (See Appendix)

Table 8

Nutrient Requirements for Steers

Body Weight (kgs)	Daily gain (kgs)	Crude Protein (%)	NEm (%)	NEg (%)	Ca (%)	P (%)
200	0.90	12.3	1.70	1.10	0.47	0.37
300	1.1	10.8	1.81	1.18	0.33	0.29
400	1.2	10.2	1.81	1.18	0.27	0.25

Source: NRC (1970)

Note: See text pp 21-24 for definitions

Table 9

Cost of Ingredients Used in Cattle Feeding

Ingredient	Code	Cost* (Pesos/Metric Ton)
Sorghum grain	(SOR)	14200.00
Molasses cane	(MOL)	5015.00
Cottonseed meal	(CSM)	25500.00
Urea	(URE)	14346.00
Wheat straw	(WHS)	5000.00
Cottonseed hulls	(CSH)	4500.00
Calcium carbonate	(CAL)	1862.00
Dicalcium phosphate	(DIC)	37000.00
Premix	(PRE)	60000.00
Orthophosphate	(ORT)	38000.00
Poultry litter (9 types)	(PLXj)	3000.00

Note: *The prices are for August 1983. The costs of the ingredients were obtained from feedlot owners. Costs include a $1000.00 peso-charge for handling and transportation of the feedstuffs from the poultry farm to the feedlot.

VII. RESULTS

The linear programming model as discussed in the previous Chapter was utilized and several alternatives are analyzed. First, three least cost rations were calculated for fattening steers weighing 200, 300 and 400 kgs, and gaining 0.9, 1.1 and 1.2 kgs/day respectively, but without considering poultry litter as an available feedstuff. Second, nine different least cost diets were calculated for steers weighing 200 kgs and gaining 0.9 kgs/day using the nine different poultry types available, but only one type of poultry litter was made available for each diet. Finally, for steers weighing 300 and 400 kgs, the same procedure explained for steers weighing 200 kgs was used and under the assumption that nine poultry litter types were available.

Ingredient Composition of Diets for Steers Using Traditional Feedstuffs

The ingredient compositon of the three least cost diets for fattening steers are displayed in Table 10. Cottonseed meal and urea, which are protein sources, were included at a level of 3.78 percent and 1.0 percent respectively, in the least cost diet number 1 for steers weighing 200 kgs and gaining 0.9 kgs/day. In the same table, under

The name of diet number 2, the ingredients that will be in the least cost diet for steers weighing 300 kgs and gaining 1.1 kgs/day are shown. Fir this diet, no cottonseed meal was included and the lever of urea was 0.79 percent. The results for steers weighing 400 kgs and gaining 1.2 kgs/day are shown under diet number 3. Cottonseed meal was excluded from the solution and 0.52 percent of urea was included. Small difference in costs for the three diets were obtained, being $12,511 pesos per metric ton for diet 1, $12,554 for diet 2 and $12,446 for diet 3.

It can be concluded from the information presented in Table 10 that as the protein requirement decreased less cottonseed meal and urea were included, and the difference in costs for the three diets were small.

Ingredient Composition of Diets for Steers Using Traditional Feedstuffs and Poultry Litter

The optimal soltuions for all diets where the different kinds of poultry litters were made available (one kind of litter for each diet only) are shown on Tables 11, 12, and 13. The litters were permitted to change on their crude protein, maintaining the energy level constant, or keeping the crude protein constant and varying the energy level. Considering that the responses are applicable to the three tables, even though the magnitude of the response is different, an explanation of the results will

Table 10

Least Cost Diets for Steers Using Traditional Feedstuffs

Ingredients	Diet 1	Diet 2 (%)	Diet 3
Sorghum grain (SOR)	67.70	77.75	77.37
Molasses cane (MOL)	15.00	15.00	15.00
Cottonseed meal (CSM)	3.78	0.00	0.00
Urea (URE)	1.00	0.79	0.52
Cottonseed hulls (SCH)	11.11	5.50	0.00
Wheat straw (WHS)	0.00	0.00	6.36
Calcium carbonate (CAL)	0.37	0.22	0.15
Dicalcium phosphate (DIC)	0.44	0.14	0.00
Salt (SAL)	0.10	0.10	0.10
Premix (PRE)	0.50	0.50	0.50
Total	100.00	100.00	100.00
Body weight in kgs	200	300	400
Daily gain in kgs	0.90	1.10	1.20
Diet cost in peso/ metric ton	12,511.44	12,544.49	12,446.26

be described for the data shown on Table 13. When poultry litter 1, which contains 20 percent crude protein, 0.89 Mcal/kg of net energy for maintenance and 0,0 of net energy for gain, was available as a feed ingredient 3.21 percent of litter and 0.64 percent of urea entered in the optimal solution. Containing the same energy level than for poultry litter 1, but with 25 percent crude protein, poultry litter 2 entered in the solution at 3.21 percent level, same than before but decreasing the level of urea to 0.58 percent. Furthermore, when poultry litter 3, which contains the same energy level than poultry litter 1 and 2, but with 30 percent crude protein, was accessible 6.32 percent of litter was included in the diet displacing most of the urea (0.19 percent entered) and totally calcium carbonate. The same outcome results for the other poultry litters; that is, as the level of crude protein in litters increases, the level of urea in the solution decreases, and the level of poultry litter increases.

When poultry litter is permitted to vary on its energy level and the crude portein is maintained constant, the litter tends to substitute for sorghum grain, calcium carbonate, dicalcium phosphate and urea. This can be observed analyzing poultry litter 1, 4 and 7. Poultry litter 1 has a 20 percent crude protein, 0.89 Mcal/kg of net energy maintenance and zero net energy for gain. The level

Table 11

Least Cost Diets for Steers Using Traditional Feedstuffs and Poultry Litter: Steers Weight = 200 Kgs

Diet #	Ingredient	Sorgum grain (%)	Mola-sses (%)	Poultry litter (%)	Urea (%)	Cal-cium (%)	Salt (%)	Premix (%)	Total (%)
4	Poultry litter 1	71.38	15.00	8.96	1.00	3.06	0.10	0.50	100.00
5	Poultry litter 2	71.38	15.00	7.17	1.00	4.85	0.10	0.50	100.00
6	Poultry litter 3	71.38	15.00	12.74	0.28	0.00	0.10	0.50	100.00
7	Poultry litter 4	70.05	15.00	13.63	0.72	0.00	0.10	0.50	100.00
8	Poultry litter 5	70.02	15.00	13.93	0.45	0.00	0.10	0.50	100.00
9	Poultry litter 6	69.99	15.00	14.24	0.17	0.00	0.10	0.50	100.00
10	Poultry litter 7	64.90	15.00	18.97	0.53	0.00	0.10	0.50	100.00
11	Poultry litter 8	64.71	15.00	19.55	0.14	0.00	0.10	0.50	100.00
12	Poultry litter 9	64.63	15.00	19.77	0.00	0.00	0.10	0.50	100.00

Table 12

Least Cost Diets for Steers Using Traditional Feedstuffs and Poultry Litter: Steers Weight = 300 kgs

Diet #	Ingredient	Sorghum grain (%)	Molasses (%)	Poultry litter (%)	Urea (%)	Dicalcium (%)	Salt (%)	Premix (%)	Total (%)
4	Poultry litter 1	77.89	15.00	3.21	0.64	2.66	0.10	0.50	100.00
5	Poultry litter 2	77.89	15.00	3.21	0.58	2.72	0.10	0.50	100.00
6	Poultry litter 3	77.89	15.00	6.32	0.19	0.00	0.10	0.50	100.00
7	Poultry litter 4	77.23	15.00	6.76	0.41	0.00	0.10	0.50	100.00
8	Poultry litter 5	77.21	15.00	6.91	0.28	0.00	0.10	0.50	100.00
9	Poultry litter 6	77.20	15.00	7.07	0.14	0.00	0.10	0.50	100.00
10	Poultry litter 7	74.67	15.00	9.42	0.31	0.00	0.10	0.50	100.00
11	Poultry litter 8	74.57	15.00	9.70	0.12	0.00	0.10	0.50	100.00
12	Poultry litter 9	74.51	15.00	9.89	0.00	0.00	0.10	0.50	100.00

Table 13

Least Cost Diets for Steers Using Traditional Feedstuffs and Poultry Litter: Steers Weight = 400 kgs

Diet #	Ingredient	Sorghum grain (%)	Mola-sses (%)	Poultry litter (%)	Urea (%)	Cal-cium (%)	Salt (%)	Premix (%)	Total (%)
4	Poultry litter 1	77.89	15.00	3.21	0.35	2.95	0.10	0.50	100.00
5	Poultry litter 2	77.89	15.00	3.21	0.58	2.72	0.10	0.50	100.00
6	Poultry litter 3	77.89	15.00	6.32	0.19	0.00	0.10	0.50	100.00
7	Poultry litter 4	77.19	15.00	7.11	0.10	0.00	0.10	0.50	100.00
8	Poultry litter 5	77.18	15.00	7.22	0.00	0.00	0.10	0.50	100.00
9	Poultry litter 6	77.18	15.00	7.22	0.00	0.00	0.10	0.50	100.00
10	Poultry litter 7	74.51	15.00	9.89	0.00	0.00	0.10	0.50	100.00
11	Poultry litter 8	74.51	15.00	9.89	0.00	0.00	0.10	0.50	100.00
12	Poultry litter 9	74.51	15.00	9.89	0.00	0.00	0.10	0.50	100.00

included in the diet for poultry litter 2 is 3.21, sorghum grain 77.89 percent, urea 0.64 percent and 2.66 percent dicalcium phosphate. For poultry litter 4, which contains the same level of crude protein than litter 1, but the energy level is 1.0 Mcal/kg for net energy for maintenance and 0.12 Mcal/kg of net energy for gain, the level in the optimal solution is 6.76 percent, sorghum grain 77.23 percent, 0.41 percent urea and dicalcium decreased to 0.0 percent. When poultry litter 7, which contains 20 percent crude protein and higher energy values than poultry litter 1 and 4, was made available the diet calculated contains 9.42 percnet poultry litter, 74.67 percent sorghum grain and 0.31 percent urea. It is apparent that the same conclusions can be applied to the rest of the litters. It also seems that as the level of energy is increased a tendency to substitute sorghum grain with litter is more obvious.

Sensitivity Analysis of Diets for Steers With Different Kinds of Poultry litter Available

The calculated least cost diet in Tables 11-13 could be sensitive to changes in the parameters used to obtain the mix. It is important, therefore, to analyze the effects of these parameters on the optimal solution. Changes in the cost of the ingredients, changes in the constraints utilized and changes in the technical coefficients could affect the optimal solution in such a way that an activity (feeds, slack and surplus variables) already in the least cost mix could leave or decrease its contribution to the optimal solution, making room for other activities to enter in the new solution and probably changing the contribution of other activities in the diet. However, in practice, once the least cost diet is developed, feedlot operators are more concerned about cost increases in the feeds than in the other parameters. Thus, the focus of this section will be on the effect of feed cost changes on the optimal solution. Before starting the explanation, it is important to clarify that changes in the optimal solution refer to changes in the actual contribution of the activities already in the diet, and not only to changes in cost of the feed mix. Also, it is important to note that an ingredient will leave the basis or the optimal solution partially or completely. This is something that sensitivity analysis does not normally specify.

The least cost diet for steers weighing 200 kgs is summarized in Table 41 (Diet #4 in Table 11). The solution for this diet will be examined in some detail. However, for the rest of the diets less explanation will be given.

The optimal diet shown in Table 14 includes 71.38 percent of sorghum grain (SOR), 15.0 percent molasses (MOL), 8.96 percent poultry litter 1 (PL1), 1.0 percent salt (SAL), and 0.50 percent premix (PRE). This diet has a cost of $11,665 pesos per metric ton. Activities with a minus sign (-) refer to equal to or greater than restrictions that were exceeded in the optimal solution (surplus variable). That is, calcium (-CAL), phosphorus (-PRL) and net energy for maintenance (-NEm) values were exceeded by 1.20 percent, 0.03 percent and 0.041 Mcal/kg, respectively. Activities with a plus sign (+) represents less than or equal to restrictions that were not binding. In this diet 11.04 percent of the poultry litter (+PLL) is left unused from the less than or equal to restriction of 20 percent.

As shown in Table 15 all the nutrient requirements and feed restrictions were met, or their values were exceeded as is the case of -PRO, -NEm, -CRL, and -PRL.

Diet #4 is optimal based on the ingredient costs from Table 9. However, if there are changes in feeds costs the solution might remain unchanged or change, depending on the cost variations. Table 16 contains information about how sensitive or insensitive the current optimal solution is to changes in feed costs. The original 8.96 percent of poultry litter 1 will remain in the diet as long as the cost does not exceed $8,905 pesos per metric ton (upper limit column). If the cost of the litter is greater than $8,905 pesos, its percentage will be decreased in the diet and cottonseed meal (CSM) will enter the new solution. Urea

Table 14

Diet 4 - Least Cost Diet for Steers
Weighing 200 kgs and gaining 0.9 kgs/day

Ingredient	Quantity (%)	Other activities (Slack or surplus variables)	Quantity
Sorghum grain (SOR)	71.38	-CRL %	1.20
Molasses (MOL)	15.00	-PRL %	0.03
Poultry litter 1 (PL1)	8.96	-NEm Mcal/kg	0.041
Urea (URE)	1.00	+PLL %	11.04
Calcium carbonate (CAL)	3.06		
Salt (SAL)	0.10		
Premix (PRE)	0.50		
Total	100.00		

Diet Cost = $11,664.74 pesos/metric ton

Table 15

Diet 4 - Right Hand-side Values and Amount Used

Restrictions	Right hand-side	Amount Used
Dry matter level (SML) %	100.00	100.00
Protein (-PRO) %	12.30	13.30
Net energy for maintenance (-NEm) Mcal/kg	1.70	1.741
Net energy for gain (-NEg) % Mcal/kg	1.10	1.10
Calcium restriction level (-CRL) %	0.47	1.60
Phosphorous restriction level (-PRL) %	0.37	0.43
Urea restriction level (+URL) %	1.00	1.00
Salt restriction level (SRL) %	0.10	0.10
Premix level (PEL) %	0.50	0.50
Molasses restriction level (+MRL) %	15.00	15.00
Poultry litter level (+PLL) %	20.00	8.96

*No sign ( ) = should be equal to

- sign (-) = should be greater or equal to

+ sign (+) = should be less than or equal to

Table 16

Diet 4 - Cost Stability of the Optimal Solution

Ingredient	Current cost from Table 11	Upper limit	Entering Activity
Poultry litter 1 (PL1)	3000.00	8905.37	CSM
Urea (URE)	14346.00	17850.00	+URL
Calcium carbonate (CAL)	1862.00	2130.57	+URL
Sorghum grain (SOR)	14200.00	25816.83	CSM
Salt (SAL)	7000.00	999999.00	UNBOUNDED
Premix (PRE)	60000.00	999999.00	UNBOUNDED
Molasses (MOL)	5015.00	16133.40	+MRL

will remain in the diet as long as its cost does not exceed $17,851 pesos its contribution will decrease and the corresponding urea restriction level of (+URE) will enter in the solution (slack variable). The cost of calcium carbonate could go up to $2,131 pesos per metric ton without leaving the current optimal solution. However, if the cost of calcium carbonate is greater than $2,131 pesos it will leave the diet, and the urea restriction level will enter the new solution. Salt and premix costs could go up to infinite without being forced out of the diet because their levels were set at equal to the desired quantities. Molasses will remain in the diet as long as its cost does not exceed $16,133 pesos per metric ton. If the cost of molasses is greater than $16,133 pesos it will be replaced by the molasses restriction level (+MLL). In general, the magnitude of a cost increase needed to force an ingredient out of the solution, indicates that feeds already in the solution are very stable.

Using the penalty costs exhibited in Table 17, it is possible to analyze the effect on the cost of the diet if one of the ingredients not included in the present solution is not added. The penalty cost is different from the cost of the ingredient. When a unit of a feed is not included in the diet is added, one or various ingredients will be forced out such that the diet constraints may be met.

If one percent of cottonseed meal is added, the cost of the diet will increase by $104.84 pesos per metric ton. If one percent of wheat straw is forced in the final solution, the cost of the diet will increase by $19,38 pesos per metric ton. A one percent cottonseed hulls level could be added, however, the cost of the diet will increase by $21.07 pesos per metric ton. Similar data are given for cottonseed hulls (CSH), dicalcium carbonate (DIC) and orthophosphate (ORT).

The stability of the solution due to changes in the restriction levels (Right hand-side) can be examined using the data in Table 18. This table gives information about the upper and lower values of the restrictions at which the solution will remain unchanged and the levels at which the basis will change. It also should be noted that changes in the restrictions could affect slack or surplus variables (shown as "other activities" in the solution) in the current optimal solution (Table 14). The restriction level for dry matter (DML) could go from 96.9 percent to infinity without changing the optimal solution, but if the restriction for dry matter is less than 96.9 percent calcium carbonate (CAL), will leave the basis. No change in the optimal solution is expected if the restriction level for crude protein (-PRO) is between the range of 11.9 to 12.9 percent. However, if the restriction level is greater than 12.9 percent calcium

Table 17

Diet 4 - Penalty Costs for Ingredients not in the Optimal Solution

Ingredient	Penalty cost (per 1 percent added to the diet)*
Cottonseed meal (CSM)	104.84
Wheat straw (WHS)	19.38
Cottonseed hulls (CSH)	21.07
Dicalcium phosphate (DIC)	351.38
Orthophosphate (ORT)	361.38

* Penalty cost refers to how much the cost of one metric ton will increase as a result of 1 percent addition of a feed that is not in the optimal solution.

carbonate will leave the optimal solution. On the other hand, if the crude protein restriction level (-PRO) is less than 11.9 percent the excess crude protein level will leave the basis. The net energy for maintenance restriction level (-NEm) could be between zero and 1.741 Mcal/kg without affecting the actual diet components. However, if the level of net energy for maintenance is greater than 1.741 Mcal/kg, the exceeded net energy for maintenance (-NEm) level already in the solution will leave the basis. The poultry litter restriction (+PLL) could be fixed at a level greater than 20 percent without affecting the current optimal solution (since some poultry litter is already left). If the restriction level is less than 8.96 percent all the restriction level would be used. Sensitivities of the remaining constraints are interpreted in a similar manner using the information in Table 18.

A summary of cost stability for poultry litter is depicted in Tables 19, 20, and 21. As can be seen in Table 19, poultry litter 1 (PL1) will remain in the optimal solution as long as its price does not exceed $8,905 pesos per metric ton. Otherwise, if the price of the litter is greater than $8,905 pesos per metric ton the actual percentage of poultry litter will leave the basis and cottonseed meal (CSM) will enter in the new solution. The 7.17 percent of poultry litter 2 (PL2) will remain in the optimal solution

Table 18

Diet 4 - Sensitivity Analysis on Constraints

Constraint	Right hand side	Upper limit	Leaving activity	Lower limit	Leaving activity
DML	100.00	999999.00	UNBD	96.90	CAL
-PRO	12.30	12.90	CAL	11.90	-PRO
-NEm	1.70	1.741	-NEm	999999.00	UNBD
-NEg	1.10	1.164	-PRL	1.063	-NEm
-CRL	0.47	1.61	-CRL	999999.00	UNBD
-PRL	0.37	0.43	-PRL	999999.00	UNBD
+URL	1.00	1.10	-PRL	0.80	CAL
SRL	0.10	3.20	CAL	0.00	SAL
PEL	0.50	3.60	CAL	0.00	PRE
+MRL	15.00	25.00	CAL	10.00	-PRL
+PLL	20.00	999999.00	UNBD	8.96	+PLL

as long as the price of the litter is equal or less than $10,666 pesos per metric ton. However, if the price of poultry litter is greater than this amount the optimal solution will change, entering cottonseed meal and poultry litter 2 leaving the basis. The actual percentage of poultry litter 3 (PL3) will stay in the optimal solution if the price of the litter is less than or equal to $3,195 pesos per metric ton. Otherwise, the optimal solution will change, making room for calcium carbonate (CAL) to enter in the solution. The same explanation could be given for poultry litter 5, 6, 7, 8, and 9, but the difference relies on different cost increases that are necessary to force a change on the optimal solution (refer to Table 19).

Table 20 refers to the stability of the optimal solutions as a result of changes in costs of the different kinds of poultry litters when they are available to calculate diets for steers weighing 300 kgs and gaining 1.1 kgs per day. it should be noted that if one compares this table with Table 19, the only differences are for poultry litter 1 and poultry litter 2. Poultry litter 1 will remain in the optimal solution as long as its price does not exceed $4,851 pesos per metric ton. Otherwise, the litter leave the actual basis and wheat straw (WHS) enter in the new solution. On the other hand, poultry litter 2 will stay in the basis as long as its price is less than or equal to

$5,073 pesos per metric ton. However, if the price of the litter exceeds this amount, wheat straw will enter in the new solution and poultry litter 2 will leave the basis. For the rest of the litters the upper limit in costs and the entering activities are the same asfor Table 19.

In Table 21, information about the stability of poultry litter is given in case that cost increases occur when the different kinds of litters are made available for diets that should meet the requirements for steers weighing 400 kgs and gaining 1.2 kgs per day.

Since in none of the calculated least cost diets cottonseed meal was included penalty costs are displayed in Table 22. The penalty cost represents the increase in cost of a metric ton of mix in case that one percent of cottonseed meal in the diet (one percent in the diet = 10 kgs in one ton) will increase the cost of the feed mix in diet #4, for steers weighing 200 kgs and gaining 0.9 kgs, by $104.83 pesos. In diet #5 the inclusion of one percent cottonseed meal will increase the cost of the diet by $108.87 pesos per metric ton. The same explanation could be given for the rest of the diets noting that only small changes occur. Except in diet 4 and 5 for steers weighing 200 kgs and gaining 0.9 kgs per day, there are no differences in penalty costs for the same diet and different steers characteristics when cottonseed meal is included.

Table 19

Cost Stability for Poultry Litter on the Optimal Solutions in Diets for Steers Weighing 200 kgs and Gaining 0.9 kgs/day

Poultry litter kind	Current cost (pesos)	Upper limit	Enter Activity
Poultry litter 1 (PL1)	3,000.00	8,905.54	CSM
Poultry litter 2 (PL2)	"	10,666.22	CSM
Poultry litter 3 (PL3)	"	3,194.81	CAL
Poultry litter 4 (PL4)	"	3,909.60	CAL
Poultry litter 5 (PL5)	"	4,131.74	CAL
Poultry litter 6 (PL6)	"	4,353.86	CAL
Poultry litter 7 (PL7)	"	6,807.26	CAL
Poultry litter 8 (PL8)	"	7,029.40	CAL
Poultry litter 9 (PL9)	"	6,074.98	CAL

Table 20

Cost Stability for Poultry Litter on the Optimal Solutions in Diets for Steers Weighing 300 kgs and Gaining 1.1 kgs/day

Poultry litter Kind	Current cost (pesos)	Upper limit	Enter Activity
Poultry litter 1 (PL1)	3,000.00	4,850,56	WHS
Poultry litter 2 (PL2)	"	5,072,69	WHS
Poultry litter 3 (PL3)	"	3,194.81	CAL
Poultry litter 4 (PL4)	"	3,909.60	CAL
Poultry litter 5 (PL5)	"	4,131.74	CAL
Poultry litter 6 (PL6)	"	4,353.86	CAL
Poultry litter 7 (PL7)	"	6,807.26	CAL
Poultry litter 8 (PL8)	"	7,029.40	CAL
Poultry litter 9 (PL9)	"	6,074.98	CAL

Table 21

Cost Stability of Poultry Litter in the Optimal Solutions in Diets for Steers Weighing 400 kgs and Gaining 1.2 kgs/day

Poultry litter kind	Current cost (Pesos)	Upper limit	Enter activity
Poultry litter 1 (PL1)	3,000.00	4,850.56	WHS
Poultry litter 2 (PL2)	"	5,072.60	WHS
Poultry litter 3 (PL3)	"	3,194.81	CAL
Poultry litter 4 (PL4)	"	3,909.60	CAL
Poultry litter 5 (PL5)	"	4,131.74	CAL
Poultry litter 6 (PL6)	"	4,353.86	CAL
Poultry litter 7 (PL7)	"	6,807.26	CAL
Poultry litter 8 (PL8)	"	7,029.40	CAL
Poultry litter 9 (PL9)	"	6,074.98	CAL

Table 22

Penalty Costs in pesos/metric ton per 1 Percent Added of Cottonseed meal in All Diets

Poultry litter kind	Diet #	Body Weight		
		200 kgs	300 kgs	400 kgs
PL1	4	104.83	109.21	109.21
PL2	5	108.87	109.27	109.26
PL3	6	109.21	109.21	109.21
PL4	7	108.95	108.95	108.95
PL5	8	108.86	108.86	108.86
PL6	9	108.78	108.78	108.78
PL7	10	107.44	107.44	107.44
PL8	11	107.27	107.27	107.27
PL9	12	129.59	129.59	129.59

Table 23

Diet Costs When Poultry Litter Was Included

	Cost in pesos per metric ton	Cost in pesos per metric ton	Cost in pesos per metric ton
Diet #	Body weight = 200 kgs	Body weight = 300 kgs	Body weight = 400 kgs
4	11,664.74	12,356.47	12,320.93
5	11,644.34	12,349.33	12,349.33
6	11,617.57	12,336.14	12,336.14
7	11,518.39	12,286.91	12,248.27
8	11,484.75	12,270.22	12,235.63
9	11,449.62	12,252.78	12,235.63
10	10,920.13	11,989.98	11,936.37
11	10,854.63	11,957.47	11,936.22
12	10,830.04	11,936.22	11,936.22

In general, it is demonstrated by Table 23 that when the quality of the litter increases, in terms of higher protein and energy content, the contribution of poultry litter in the diet also increases. At the same time an increase in poultry litter in the diet tends to decrease its cost. If we go back to Table 10 where a least cost diet was calculated for steers weighing 200 kgs and gaining 0.9 kgs, where no poultry litter was available, a cost of $12,511 pesos per metric ton of feed mix was obtained. Comparing the cost of this diet with the cost of nine diets obtained for the same steer, using different poultry litter qualities, savings that could range form $876.10 up to $1,681.40 pesos per metric ton are achieved. However, as the nutrient requirement for protein and minerals are decreased and more energy is demanded, less poultry litter is included in the diets and the savings obtained before are decreased. It could be seen by comparing the cost $12,544 pesos per metric ton in the diet for steers weighing 300 kgs and gaining 1.1 kgs per day with the diets calculated for these animals when poultry litter was included savings from $198.02 up to $618.27 pesos could be obtained when poultry litter is in the diets. For steers weighing 400 kgs and gaining 1.2 kgs, a cost saving in their diets could be achieved if poultry litter is used. These savings could range form $125.33 to $510.04 pesos per metric ton of feed mix, taking into consideration that the cost of the diet calculated with traditional feed ingredients had a cost of $12,356 pesos per metric ton.

Quantity Demanded For Poultry Litter

The quantity demanded for poultry litter is able to be determined using the information given by the linear programming model on cost stability of the different kinds of litters used to calculate the diets for the various types of steers. However, only the quantity demanded for poultry litter 5 will be determined by utilizing the three different types of steers. The data used to obtain the quantity for poultry litter 5 demand comes from Tables 11, 12 and 13. Considering the actual price of $3,000.00 pesos per metric ton of poultry litter, its percentage contribution in the different kinds of steers, the intake of the feed mix recommended by the NRC (1976) to achieve the desired rate of gain and the steer population on feedlots given by the Union Ganadera Regional de Sonora (1983). The total quantity demanded of poultry litter 5 could be calculated by following the next procedure: Steers weighing 200 kgs and gaining 0.9 kgs per day will need 4.10 Mcal of net energy for maintenance (NEm) and 2.81 Mcal of net energy for gain (NEg). On the other side, the diet for these steers has 1.77 Mcal/kg of NEm and 1.10 Mcal/kg of NEg. Therefore, it the total quantity of NEm requirements is divided by the quantity of NEm contained in the feed mix, it will give the quantity of feed mix necessary for maintenance. That is, quantity of feed mix for maintenance = $\frac{4.10 \text{ Mcal}}{1.77 \text{ Mcal/kg}}$ = 2.32 kgs. Thus 2.32 kgs of this feed mix will be necessary to maintain the animals. On the other hand, if the quantity of NEg required by the steers is divided by the NEg contained in the diet, the result will be the quantity of the feed mix to gain the prior mentioned daily gain.

Quantity of feed mix for gain = $\frac{2.81 \text{ Mcal/kg}}{1.10 \text{ Mcal/kg}}$ = 2.56 kgs. The summation of 2.32 kgs and 2.56 kgs gives 4.88 kgs of feed mix which is the expected intake of the diet for the steers to gain 0.9 kgs per day. This ration of 4.88 kgs of feed mix multiplied by the 13.93 percent of poultry litter in the diet will give 0.68 kgs of litter intake per day per steer. Assuming that the population is constant for the whole year, 1/3 of the 75,000 animals have an average weight of 200 kgs. Thus, 25,000 steers will consume 17 metric tons pf poultry litter per day. During the year the quantity demanded for poultry litter will be 6,205 tons (17 tons X 365 days). The same procedure was applied to determine the quantity demand for steers weighing 300 kgs and 400 kgs with their respective daily gains of 1.1 kg and 1.2 kgs per day. Quantity of poultry litter demanded for steers

NEm requirements = 5.5 Mcal

NEg requirements = 4.78 Mcal

NEm in feed mix = 1.84 Mcal/kg

NEg in feed mix = 1.18 Mcal/kg

Total feed mix intake one day/animal =7.07 kgs

Percent of poultry litter in the feed mix = 6.91 percent

Poultry litter intake/animal/day = .488 kgs

Numbers of steers = 25,000 steers

Total poultry litter intake/day = 12.2 tons

Given this data a quantity of 5445.3 tons of poultry litter will be demanded.

Quantity of poultry litter demanded for steers weighing 400 kgs and gaining 1.2 kgs/day.

NEm requirements = 6.89 Mcal

NEg requierments = 6.55 Mcal

NEm in feed mix = 1.84 Mcal/kg

NEg in feed mix = 1.18 Mcal/kg

Total feed mix intake/day/animal = 9.33 kgs

Percent of poultry litter in the feed mix = 7.12 percent

Poultry litter intake/animal/day = .66 kgs

Number of steers = 25,000 steers

Total poultry litter intake/day = 16.5 tons

Given this information, a quantity of 5022.5 metric tons of poultry litter will be demanded.

The summation of the quantities demanded in the three feeding periods will be of 16,672 metric tons. Therefore, if we consider the quantity available of poultry litter is approximately of $34,560 metric tons per year an excess of 17,888 metric tons will be still available for other uses. The supply, however, is not a function of the price that feedlot operations could pay for the litter. Its quantity is related to the population of birds in production units and only the quality of the litter could be affected by making it a marketable product.

Poultry Litter Demand Schedule

Once the quantities demanded for poultry litter 5 (PL5) for the different types of steers were calculated, changes in the "upper limit" price of PL5 were introduced to find if PL5 will leave the diet completely and if not to derive the demand schedule. The results are shown in Table 24 for steers weighing 200 kgs, in Table 25 for steers weighing 300 kgs and in Table 26 for steers weighing 400 kgs.

According to the results, in order to completely remove PL5 form the diets for 200 kgs steers, the price of PL5 must be greater than $14,408 pesos per metric ton. However, in the price interval of $3,000.00 to $14,408 pesos per metric ton less quantity of PL5 is demanded and calcium carbonate, cottonseed meal, orthophosphate and cottonseed hulls tend to replace the PL5. In Table 25, the price of

PL5 can go up to $7,408 pesos per metric ton without completely removing the litter from the diet. Calcium carbonate and orthophosphate tend to replace PL5. In order to completely remove PL5 from the diet for steers weighing 400 kgs (Table 26), the price of the litter would have to be greater than $9,241 pesos per metric ton. In this case, as the percentage of poultry litter 5 in the diet decrease, calcium carbonate, wheat straw, cottonseed hulls and orthophosphate will enter in the diet.

In general, (except for Table 24, where cottonseed meal substituted poultry litter), there is a tendency to replace poultry litter 5 with mineral sources and low quality roughages. Large increases in poultry litter prices are necessary to completely remove PL5 form the diets for the three kinds of steers.

Poultry litter is usually collected and transported from poultry units by feedlot owners. The price of $3,000.00 pesos per metric ton represents approximately the costs of collecting and transporting. The poultry unit owners do not receive a specific payment for the litter, instead they get a free cleaning of the units which in turn represents savings in their operating costs.

The variability in chemical composition makes poultry litter an unstable product. Feedlot owners have to constantly analyze the product in order to be sure of its

Table 24

Demand Schedule for Poultry Litter 5:
Steers' Weight = 200 kgs

Price range (pesos/metric ton)	Quantity of PL5 (% of the diet)	Entering feedstuff
0-4,316	13.93	---
4,317-11,515	7.47	Calcium carbonate
11,516-13,545	7.31	Cottonseed meal
13,546-14,408	4.70	Orthophosphate
14,408	0.00	Cottonseed hulls

Table 25

Demand Schedule for Poultry Litter 5:
Steers' Weight = 300 kgs

Price range (pesos/metric ton)	Quantity of PL5 (% of the diet)	Entering feedstuff
0-4,130	6.91	---
4,131-7,418	6.16	Calcium carbonate
7,418	0.00	Orthophosphate

Table 26

Demand Schedule for Poultry Litter 5:
Steers' Weight = 400 kgs

Price range (pesos/metric ton)	Quantity of PL5 (% of the diet)	Entering feedstuff
0-4,130	7.22	---
4,131-6,064	3.49	Calcium carbonate
6,065-8,434	1.71	Wheat straw
8,435-9,241	1.68	Cottonseed hulls
9,241	0.00	Orthophosphate

chemical profile and make changes in the animal diets each time a different poultry litter is brought to the feedlot. This fact causes feedlot owners to avoid the use of poultry litter in place of other feedstuffs.

The possibility of having a homogeneous product is of great importance for animal producers, but it is difficult for feedlot owners to mix the product since they have to buy poultry litter from different sources and do the mixing. This job, however, could be done by intermediaries. Having a homogeneous product implies monitoring the chemical composition of different poultry litter sources which can be done easier by intermediaries than by feedlot producers.

The demand schedules depicted in Tables 24, 25, and 26 showthat poultry litter price can be significantly raised and have a small effect on quantity demanded. This gives the possibility to intermediaries to pass monitoring and mixing costs to feedlot owners without substantial effects on poultry litter quantity demanded. However, if the product is made homogeneous the future price is not known. Therefore, further analysis will have to be done to obtain the price of the homogeneous product.

CONCLUSIONS

The chemical profile of poultry litter indicates good characteristics as a feed ingredient for animal production. However, the nutrient composition, and mainly the non-protein nitrogen content, makes the litter more suitable for ruminants nutrition. Performance trials using poultry litter demonstrated that it could be added up to a level of 20 percent without significantly affecting average daily gain and feed to gain ratio.

The quality of poultry litter in terms of protein and energy content affects the level at which poultry litter can be added to ruminant diets. As the level of protein in the litter increases, holding the energy constant, the amount of poultry litter in the diet increases, substituting mainly for cottonseed meal and urea. As the level of energy in the litter increases, holding the protein level constant, the quantity of poultry litter in the diet increases forcing cottonseed meal, urea and grain sorghum levels to decrease.

The level of poultry litter in diets for steers weighing 200 kgs and gaining 0.9 kgs per day ranged from 7.17 to 19.77percent and for the other two the levels (300 and 400 kg steers) ranged from 3.21 percent to 9.89 percent of the diets.

Considering the actual cost of poultry litter ($3,000.00 pesos per metric ton) significant savings could be obtained when the litter is included in the dietsd. Higher savings occurred in diets for steers weighing 200 kgs and gaining 0.9 kgs per day where savings ranged from $867.10 to $1,681.40 metric ton of feed mix. Lower savings, however, resulted for steers weighing 300 kgs and gaining 1.1 kgs per day: $198.02 to $618.27 pesos per metric ton. For steers wieghing 400 kgs and gaining 1.2 kgs per day, less saving was obtained ranging from $125.33 to $510.04 pesos per metric ton. Savings were directly related to the amount of litter in the diet when compared to traditional feed mix.

The estimated aggregate quantity demanded of 15,608.5 metric tons of poultry litter represents approximately 44 percent of the total quantity available in the Hermosillo area. Therefore, using poultry litter in feeding cattle appears to be a good alternative that could have a beneficial effect onthe environment without imposing law enforcement rules to dispose poultry litter.

APPENDIX

Table 8 was generated using the values described in Table 2. Nine different poultry litter types were classified according to their crude protein and energy content. The gross energy content of poultry litters 1, 2 and 3 was held constant with a value of 2.906 Mcal/kg of dry matter, while, the crude protein was permitted to change to 20 percent, 25 percent and 30 percent for litters 1, 2 and 3, respectively. For poultry litters 4, 5 and 6, a gross energy value of 3.521 Mcal/kg of dry matter was used. Poultry litter 4 had a crude protein value of 20 percent dry matter, poultry litter 5 a crude protein content of 25 percnet, and for poultry litter 6 a crude protein value of 30 percent was considered. For poultry litters 7, 8 and 9, a 20 percent, 25 percent and 30 percnet crude protein levels were utilized respectively, and 4.010 Mcal/kg of dry matter was used in the three litters.

A digestibility coefficient of 59.15 percent, as reported by Brugman, et al. (1964), was used to convert from gross energy (GE) values to their respective digestible energy (DE). Once the digestible energy was calculated, the metabolizable energy (ME) content of the litter was computed utilizing the formula suggested by the NRC (1976):

ME (Mcal/kg for cattle) = DE (Mcal/kg) x 0.82

where

DE = Digestible energy which is determined by deducting the energy of the feces from the gross energy.

ME = Metabolizable energy which is determined by deducting from gross enregy the energy of the feces, urine and methane.

Finally, the net energy for maintenance (NEm) and net energy for gain (NEg) values were computed using the method described by Lofgreen and Garret (1968) and officially utilized by the NRC (1976):

$$\text{Log } F = 2.2577 - 0.2213 \text{ ME}$$

$$\text{NEm} = 77/F$$

$$\text{NEg} = 2.54 - 0.0314F$$

Where F is the feed required for energy equilibrium, given in grams/day per kilogram of metabolic weight (W^{75}).

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