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Feeding



# An Interregional Analysis of Livestock Use of Selected Feed Ingredients

by

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## Introduction

This is a report on a project conducted cooperatively by ERS/USDA and Purdue University.[1/] The study was an analysis of the use of feed grains and soybean meal in livestock and poultry feeds and concentrated on three aspects of the feed grain-livestock sectors of the economy--the regional location of feed grain supplies, regional requirements for livestock and poultry feeds, and briefly on requirements for export grains and soybean meal. A national, interregional, linear programming model was used; the model included interdependencies between the feed grain and livestock feeding sectors.

The major emphasis of this study was to develop an economic model of the principal forces in the livestock-feed grain economy. Within this context, specific objectives of the study were as follows:

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1/ Rodney C. Kite, An Interregional Analysis of Livestock Use of Selected Feed Ingredients, Unpublished Ph.D. Thesis, Purdue University, May 1973.

(1) To develop a feed grain-livestock feeding model with sufficient flexibility to facilitate analysis of situations faced by policy makers at the firm and national level.

(2) To develop an automated, computer version of this model.

(3) To estimate livestock/poultry feed use of seven feed ingredients: corn, barley, wheat, oats, rye, sorghum and soybean meal. Five categories of livestock were included in the analysis: dairy, beef, swine, poultry, and sheep.

(4) To determine interregional equilibrium values for feed ingredients and livestock/poultry feeds.

The model for the study consisted of 16 domestic regions and 9 export points (Tables 1 and 2). Estimates of interregional grain movements were obtained for the seven feed ingredients as they were transferred between regions to meet livestock/poultry feed and export requirements. A set of equilibrium ingredient prices, consistent with the interregional transfers, was obtained. In addition, equilibrium values for 16 livestock/poultry feeds were obtained for each of the 16 regions. Estimated use of the ingredients in the 16 feed types was aggregated into use by the five livestock/poultry types.

## Major Components of the Model

The model contains six major components: locations and quantities of feed ingredient supplies, locations and numbers of animals on feed, export and import of feed ingredients, formulation of animal feeds, human and industrial use of feed grains, and the transportation facilities connecting ingredient supplies to the locations at which they would either be used domestically or exported.

Table 1. Designation of Domestic Regions with Origin and Destination Points.

| | Region | Ingredient | Origin Point | Destination Point |
|---|---|---|---|---|
| | Maine | Corn | Keene, N.H. | Keene, N.H. |
| | New Hampshire | Barley | Keene, N.H. | Keene, N.H. |
| 1 | Vermont | Sorghum | Keene, N.H. | Keene, N.H. |
| | Connecticut | Wheat | Keene, N.H. | Keene, N.H. |
| | Rhode Island | Oats | Keene, N.H. | Keene, N.H. |
| | Massachusetts | Rye | Keene, N.H. | Keene, N.H. |
| | | Soybean Meal | Keene, N.H. | Keene, N.H. |
| | | Corn | Oneonta, N.Y. | Oneonta, N.Y. |
| | | Barley | Oneonta, N.Y. | Oneonta, N.Y. |
| | New York | Sorghum | Oneonta, N.Y. | Oneonta, N.Y. |
| 2 | New Jersey | Wheat | Oneonta, N.Y. | Lancaster, Pa. |
| | Pennsylvania | Oats | Oneonta, N.Y. | Oneonta, N.Y. |
| | | Rye | Oneonta, N.Y. | Oneonta, N.Y. |
| | | Soybean Meal | Oneonta, N.Y. | Oneonta, N.Y. |
| | | Corn | Bloomington, Ill. | Anderson, Ind. |
| | | Barley | Bedford, Ind. | Bellefontaine, Ohio |
| | Ohio | Sorghum | Centralia, Ill. | Anderson, Ind. |
| 3 | Indiana | Wheat | Lafayette, Ind. | Anderson, Ind. |
| | Illinois | Oats | Marion, Ind. | Anderson, Ind. |
| | | Rye | Lafayette, Ind. | Peoria, Ill. |
| | | Soybean Meal | Bloomington, Ind. | Anderson, Ind. |
| | | Corn | Mankato, Minn. | Mankato, Minn. |
| | Michigan | Barley | Detroit Lakes, Minn. | Wisconsin Dells, Wisc. |
| 4 | Wisconsin | Sorghum | Detroit Lakes, Minn. | Lansing, Mich. |
| | Minnesota | Wheat | E. Grand Forks, Minn. | Wisconsin Dells, Wisc. |
| | | Oats | Willmar, Minn. | Lansing, Mich. |
| | | Rye | Willmar, Minn. | Lansing, Mich. |
| | | Soybean Meal | Mankato, Minn. | Mankato, Minn. |
| | | Corn | Ames, Iowa | Ames, Iowa |
| | | Barley | Waterloo, Iowa | Columbia, Mo. |
| | Iowa | Sorghum | Sedalia, Mo. | Columbia, Mo. |
| 5 | Missouri | Wheat | Osceola, Iowa | Ames, Iowa |
| | | Oats | Waterloo, Iowa | Ames, Iowa |
| | | Rye | Rolla, Missouri | Columbia, Mo. |
| | | Soybean Meal | Ames, Iowa | Ames, Iowa |
| | | Corn | Valley City, N.D. | Mitchell, S.D. |
| | | Barley | Aberdeen, S.D. | Aberdeen, S.D. |
| | North Dakota | Sorghum | Gregory, S.D. | Gregory, S.D. |
| 6 | South Dakota | Wheat | Mobridge, S.D. | Mitchell, S.D. |
| | | Oats | Huron, S.D. | Mitchell, S.D. |
| | | Rye | Aberdeen, S.D. | Mitchell, S.D. |
| | | Soybean Meal | Valley City, N.D. | Mitchell, S.D. |
| | | Corn | Topeka, Kansas | Columbus, Nebr. |
| | | Barley | North Platte, Nebr. | North Platte, Nebr. |
| | Nebraska | Sorghum | Great Bend, Kansas | Great Bend, Kansas |
| 7 | Kansas | Wheat | Grand Island, Nebr. | Columbus, Nebr. |
| | Oats | Oats | Norfolk, Nebr. | Columbus, Nebr. |
| | | Rye | North Platte, Nebr. | Columbus, Nebr. |
| | | Soybean Meal | Topeka, Kansas | Columbus, Nebr. |
| | | Corn | Rocky Mount, N.C. | Fayetteville, N.C. |
| | Virginia | Barley | Winston Salem, N.C. | Fayetteville, N.C. |
| | West Virginia | Sorghum | Charlotte, N.C. | Fayetteville, N.C. |
| 8 | Maryland | Wheat | Fayetteville, N.C. | Fayetteville, N.C. |
| | Delaware | Oats | Durham, N.C. | Fayetteville, N.C. |
| | North Carolina | Rye | Annapolis, Md. | Fayetteville, N.C. |
| | | Soybean Meal | Rocky Mount, N.C. | Fayetteville, N.C. |

Table 1. Continued.

| | Region | Ingredient | Origin Point | Destination Point |
|---|---|---|---|---|
| | | Corn | Cordele, Georgia | Macon, Georgia |
| | | Barley | Macon, Georgia | Macon, Georgia |
| | South Carolina | Sorghum | Cordele, Georgia | Macon, Georgia |
| 9 | Georgia | Wheat | Macon, Georgia | Macon, Georgia |
| | Florida | Oats | Macon, Georgia | Macon, Georgia |
| | | Rye | Swainsboro, Ga. | Macon, Georgia |
| | | Soybean Meal | Cordele, Georgia | Macon, Georgia |
| | | Corn | Paris, Tenn. | Murfreesboro, Tenn. |
| | | Barley | Nashville, Tenn. | Murfreesboro, Tenn. |
| | Kentucky | Sorghum | Nashville, Tenn. | Murfreesboro, Tenn. |
| 10 | Tennessee | Wheat | Paris, Tenn. | Murfreesboro, Tenn. |
| | | Oats | Murfreesboro, Tenn. | Murfreesboro, Tenn. |
| | | Rye | Lexington, Ky. | Murfreesboro, Tenn. |
| | | Soybean Meal | Paris, Tenn. | Murfreesboro, Tenn. |
| | | Corn | Hoxie, Ark. | Little Rock, Ark. |
| | Alabama | Barley | Hoxie, Ark. | Little Rock, Ark. |
| | Mississippi | Sorghum | W. Memphis, Ark. | Little Rock, Ark. |
| 11 | Arkansas | Wheat | Blytheville, Ark. | Little Rock, Ark. |
| | Louisiana | Oats | Pine Bluff, Ark. | Little Rock, Ark. |
| | | Rye | Pine Bluff, Ark. | Jackson, Miss. |
| | | Soybean Meal | Hoxie, Ark. | Little Rock, Ark. |
| | | Corn | Waco, Texas | Oklahoma City, Okla. |
| | | Barley | Wichita Falls, Tex. | Oklahoma City, Okla. |
| | Oklahoma | Sorghum | Lubbock, Texas | Lubbock, Texas |
| 12 | Texas | Wheat | Enid, Oklahoma | San Antonio, Texas |
| | | Oats | Enid, Oklahoma | Oklahoma City, Okla. |
| | | Rye | Amarillo, Texas | Ft. Worth, Texas |
| | | Soybean Meal | Waco, Texas | Oklahoma City, Okla |
| | | Corn | Miles City, Mont. | Casper, Wyo. |
| | | Barley | Havre, Mont. | Casper, Wyo. |
| | Montana | Sorghum | -- | Casper, Wyo. |
| 13 | Idaho | Wheat | Havre, Mont. | Lewiston, Mont. |
| | Wyoming | Oats | Lewiston, Mont. | Twin Falls, Idaho |
| | | Rye | Havre, Monte. | Lewiston, Mont. |
| | | Soybean Meal | Miles City, Mont. | Casper, Wyo. |
| | | Corn | Spring Valley, Ariz. | Denver, Colo. |
| | Colorado | Barley | Boulder, Colo. | Denver, Colo. |
| | New Mexico | Sorghum | LaJunta, Colo. | Provo, Utah |
| 14 | Arizona | Wheat | Clovis, N. M. | Provo, Utah |
| | Utah | Oats | Salida, Colo. | Roswell, N. M. |
| | | Rye | Sterling, Colo. | Provo, Utah |
| | | Soybean Meal | Spring Valley, Ariz. | Denver, Colo. |
| | | Corn | Bend, Oregon | Ellensburg, Wash. |
| | | Barley | The Dalles, Oregon | Ellensburg, Wash. |
| 15 | Washington | Sorghum | -- | Bend, Oregon |
| | Oregon | Wheat | The Dalles, Oregon | Bend, Oregon |
| | | Oats | The Dalles, Oregon | Bend, Oregon |
| | | Rye | Salem, Oregon | Bend, Oregon |
| | | Soybean Meal | Bend, Oregon | Ellensburg, Wash. |
| | | Corn | Tracey, Calif. | Fresno, Calif. |
| | | Barley | Carson City, Nev. | Fresno, Calif. |
| | | Sorghum | -- | Fresno, Calif. |
| 16 | Nevada | Wheat | Winnemucca, Nev. | Fresno, Calif. |
| | California | Oats | Carson City, Nev. | Fresno, Calif. |
| | | Rye | -- | Fresno, Calif. |
| | | Soybean Meal | Tracey, Calif. | Fresno, Calif. |

Table 2. Designation of Export Points - All Ingredients.

| EXPORT POINT | DESCRIPTION |
|---|---|
| 1 | Superior, Wisconsin |
| 2 | Chicago, Illinois |
| 3 | Toledo, Ohio |
| 4 | Philadelphia, Pennsylvania |
| 5 | Norfolk, Virginia |
| 6 | New Orleans, Louisiana |
| 7 | Houston, Texas |
| 8 | San Francisco, California |
| 9 | Portland, Oregon |

It was obvious at the outset that a model including all of the relationships between and within the six components was beyond the scope of the study. Consequently, some elements of the system were taken as given. This procedure not only reduced the scope of the study, it also served to facilitate analysis of the impact, on animal-feed use of feed grains, of the exogenous components.

1. Supply and location of feed ingredients.

The locations and quantities of feed ingredients available were treated as exogenous to the model. From the view point of the study, a change in the feed grain program, for example, would be studied under the assumption that the goals of the program were attained, e.g., the production of corn was changed by a given amount. It would then be the function of the model to estimate the resulting patterns of ingredient use.

2. Locations and quantities of animals on feed.

The locations and numbers of livestock and poultry on feed were also taken as exogenous to the model. This approach was taken for two reasons: (1) The changes in location of livestock and poultry production are long term in nature and it is not the intent of this study to deal with the time horizon necessary to encompass this aspect of the feed grain-livestock economy, and (2) this approach would facilitate analysis of the impact of changes in the location and volume of animal feeding on ingredient use.

3. Export and import of feed ingredients.

Export, both volumes and points of departure, were assumed to be exogenous to the model. Imports were ignored. Domestic sources of ingredients for export are endogenous. To extend this to allow internal determination of final destination as well was considered beyond the scope of the study.

4. Human and industrial use of feed grains.

Human and industrial uses of feed grains were treated as exogenous to the model. This component of the model was treated differently from the other exogenous components in that human and industrial uses were taken from supplies. Net supplies were then used in the analysis and the human and industrial use component was dropped.

5. Ingredient transportation.

It was assumed that transport rates were known and fixed, and that there were no volume restrictions on point to point transfers. The transportation sector was assumed not to compete with the livestock feeding sector for resources. It was assumed that the transportation sector provides the service of moving ingredients from their point of production to where they would be used, at a constant unit cost, and at the time and in quantities required--subject only to limitations on ingredient availability.

6. Formulation of livestock and poultry feeds.

The major endogenous component of the model relates to the formulation of livestock and poultry feeds. Associated with the formulation component, and endogenous as well, was the determination of regional ingredient sources. This component of the model was constructed to insure that ingredients used for livestock and poultry feeds supplied the nutrients implied by the assumed total feed requirements. This was accomplished by formulating a number of least cost rations for each of the 16 feed types.2/

A total of 26 feed ingredients were used to formulate the feed rations (Table 3). The rations were then expressed as feed for the seven included ingredients and the remaining 19 were assumed to be available in the quantities needed to complete the feed rations.

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2/ The model might have been formulated including ingredient nutrient composition matrices and nutrient requirements for the various feed types. The resulting model would have been extremely large. The current formulation exploits the fact that the larger model could be solved using a Decomposition Algorithm. That is, that an optimum solution would then be some linear combination of possible solutions. Although the current model does not guarantee an optimal solution, some empirical evidence indicates that the loss in optimality is an acceptable trade for managability (11).

Table 3-4. List of Ingredients.

| Ingredient Number | Ingredient Description |
|---|---|
| (Included directly) | |
| 1 | Corn |
| 2 | Barley |
| 3 | Sorghum |
| 4 | Wheat |
| 5 | Oats |
| 6 | Rye |
| 7 | Soybean meal |
| (Included indirectly) | |
| 8 | Cottenseed meal Ex. 41 |
| 9 | Cottenseed meal S. 41 |
| 10 | Cottenseed meal Ex. 44 |
| 11 | Fishmeal Her. |
| 12 | Fishmeal Men. |
| 13 | Fishmeal Per. |
| 14 | Corn gluten meal |
| 15 | Corn gluten feed |
| 16 | Corn fermented soluables |
| 17 | Meat meal 55 |
| 18 | Meat and bone meal 50 |
| 19 | Feather meal |
| 20 | Poultry by-product |
| 21 | Animal fat |
| 22 | Vegetable and animal fat |
| 23 | Cane Molasses |
| 24 | Urea |
| 25 | Dry skim milk |
| 26 | Dry whey |

## The Mathematical Model

The mathematical model is expressed as relations (1) to (5).

The variables and parameters are defined:

| | |
|---|---|
| $P_j^k$ | Acquisition price for ingredient j in region k. |
| $t_j^{ik}$ | Transfer cost of ingredient j from region k to region i. |
| $y_j^{ik}$ | Quantity of ingredient j transferred from region k to region i. |
| $W_r^i$ | Lagrangian multiplier relating the value of feed r to region i. |
| $U_i^k$ | Lagrangian multiplier relating the value of ingredient j to region k. |
| $A_r^{\ell k}$ | Intensity of process $\ell$ in producing feed r in region k. |
| $f_{jr}^{\ell i}$ | Proportion of ingredient j used in process $\ell$ to produce feed r in region i. For a given $\ell$, i, and r, $(f_{1r}^{\ell i}, f_{2r}^{\ell i}, \ldots\ldots, f_{Jr}^{\ell i})$ is a single feed ration. |
| $X_j^k$ | Fixed quantity of ingredient j available in region k. |
| $Q^{ir}$ | Quantity of feed r required in region i. |
| I | Number of receiving regions. |
| K | Number of shipping regions. |
| J | Number of ingredients. |
| R | Number of feeds. |
| L | Number of processes, i.e. the number of alternative feed rations for each feed type. |

We wish to minimize total acquisition and transfer cost.[3/]

$$\sum_{i}^{I} \sum_{k}^{K} \sum_{j}^{J} (P_j^k + t_j^{ik}) y_j^{ik} \tag{1}$$

This objective is to be attained subject to four conditions.

(I) The quantity of feed r produced in region i must at least equal that region's requirement for r.

$$Q^{ir} \leq \sum_{\ell}^{L} A_r^{\ell i}, \quad r=1,R; \quad i=1,I. \tag{2}$$

(II) Shipments of ingredient j from region k must not exceed that region's initial supply of j.

$$\sum_{i}^{I} y_j^{ik} \leq X_j^k, \quad k=2,K; \quad j=1,J. \tag{3}$$

(III) Receipts of ingredient j by region i must at least equal that region's use.

$$\sum_{\ell}^{L} \sum_{r}^{B} A_r^{\ell i} f_{jr}^{\ell i} \leq \sum_{k}^{K} y_j^{ik}, \quad i=1,I; \quad j=1,J. \tag{4}$$

(IV) All $y_j^{ik}$ and $A_r^{\ell i}$ non-negative. (5)

Minimization of (1) subject to (2), (3), (4), and (5) results in the following relations:

(1) If condition (I) holds as an equality for i and r the implicit value of feed r in region i is greater than or equal to zero.

$$W_r^i \geq 0 \text{ if } Q^{ir} = \sum_{\ell}^{L} A_r^{\ell i}.$$

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3/ This objective function is formulated on the assumption that the cost of the indirectly included ingredients can be ignored.

(2) If condition (II) holds as an equality for region k and ingredient j the implicit value of ingredient j in region k is greater than or equal to zero.4/

$U_j^k \geq 0$ if $\sum_i^I y_j^{ik} = X_j^k$.

(3) If conditions (i) and (II) hold as inequalities $W_r^i$ and $U_j^k$ equal zero.

The mathematical model as expressed in relations (1) to (5) shows the relationships between the major components of the model. The empirical model however deviated slightly from the conceptual model. Total ingredient supplies were divided into two parts, current year's production and "free" carryover stocks. This adjustment had little effect on the conceptual model, beyond requiring a method for accounting for ingredient use from carryover stocks, and for adding a storage cost.

An example of the empirical model is shown in Figure 1. The example is for two domestic regions, two export points, three ingredients, and two types of animal feeds. The major components of the model are outlined as block-segments. The first 12 columns specify ingredient supplies, the first 6 are for current production and the next 6 are for free carryover stocks. Each of the first 12 columns is bounded at a region's supply of the appropriate ingredient. Columns 13 through 24 are for ingredient export, the following 12 are for domestic transportation and the remaining columns are for animal/poultry feeds. The last column in the figure specifies the "right-hand-side" or constraint levels assumed by the exogenous portions of the model.

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4/ Note that if $P_j^k > 0$, then $\mu_j^k \geq P_j^k$; this will also imply $w_r^i > 0$ if ingredient is employed in feed r.

The first 6 rows set the requirement that shipments not exceed supplies, the next 6 set the requirement that receipts at least equal domestic feed usage, the next 4 specify feed required, and the last 6 set export requirements. The last row represents the objective function. The first 6 columns of the objective function would contain ingredient costs, the next 6 would contain ingredient costs plus a storage charge. Columns 13 through 36 would contain point to point transfer costs. The remaining columns would contain the cost, in each alternative feed ration, of the implicitly included ingredients. Table 4 presents some statistics related to the actual model. That model contained a total of 3,679 columns and 507 rows. It was solved by the OPTIMA linear programming code on a CDC 6500 computer.

## Results

Two variants of the model were solved. The first, referred to as Model I, contained in the objective function all ingredient and transfer costs. For the second, referred to as Model II, the objective function contained only transfer costs. Model I would give estimates of interregional flows, regional ingredient use, and implicit values due to ingredient and transport cost differentials. Model II would give the same information due only to transport cost differentials. Model II would suggest values for a purely competitive ingredient procurement and distribution system. Model I would include some aspects of the real system. Both models were solved using data for 1971.

Figure 1. A Schematic Representation of the Full Model.

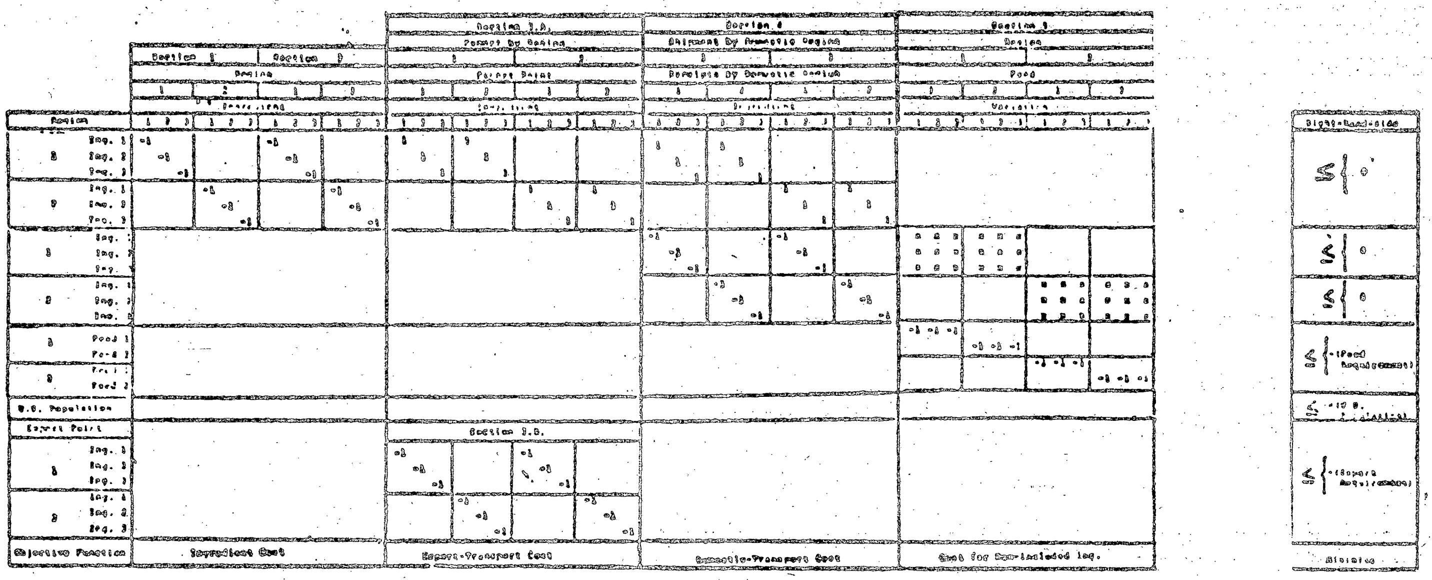

Table 4 . Maximum and Actual Number of Activities in the Model.

| Item | Maximum activities | Actual activities |
|---|---|---|
| Number of domestic shipping points. | 16 | 16 |
| Number of domestic receiving points. | 16 | 16 |
| Number of export points. | 9 | 9 |
| Number of feed ingredients. | 7 | 7 |
| Number or rows in model.1/ | 783 | 507 |
| Number of columns in model. | 5868 | 3679 |
| Current production | 112 | 95 |
| Carryover stocks | 112 | 93 |
| Export transportation | 1008 | 154 |
| Domestic transportation | 1792 | 493 |
| Feed rations | 2844 | 2844 |
| Density of Matrix (percent) | | .82 |
| Computer Processing time (seconds). | | |
| Generate matrix | | 68 |
| Solve from advanced basis | | 997 |
| Write reports | | 133 |
| Total processing | | 1198 |

1/The number or rows for the maximum includes the rows which would be eliminated by placing upper bounds on the production and carryover portions of the model.

A solution of the model produces a large output. Estimates are obtained for quantities of each ingredient shipped from each of the 16 domestic regions for domestic and export use. Estimates of the quantity of each of the 7 ingredients imported into each domestic region, and to each export point are also obtained. The output includes estimates of the quantity of each of the 7 ingredients used in each of the 16 feed types in each of the 16 domestic regions. The output also includes implicit values for each ingredient and feed type in each region. All of this information is too large a volume to discuss at this forum. Therefore, only the aggregate results will be discussed.5/

1. Ingredient shipment.

In terms of total shipments, estimated movement was greater for Model I than for Model II; 58.05 million tons for Model II and 69.15 million tons for Model I (Table 5). Corn was the ingredient shipped in greatest quantities, 29.6 million tons and 26.5 million tons for Models I and II respectively. Wheat was the ingredient shipped in the second largest quantities, mainly for export to the world market. Grain sorghum was the ingredient shipped in second largest amounts for domestic use, 13.3 million tons for Model I and 2.1 million tons for Model II.

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5/ The Appendix to this paper contains diagrams and tables which show some interregional results.

Table 5.--Total ingredient shipments - solutions from two models, 1971

| Ingredient | Shipment type | Model I | Model II |
|---|---|---|---|
| | | --------Million tons-------- | |
| Corn | Export | 14.1 | 14.1 |
| | Domestic | 15.5 | 12.4 |
| | Total | 29.6 | 26.5 |
| Barley | Export | 1.2 | 1.2 |
| | Domestic | 2.2 | .3 |
| | Total | 3.5 | 1.5 |
| Sorghum | Export | 3.2 | 3.2 |
| | Domestic | 13.3 | 2.1 |
| | Total | 16.5 | 5.3 |
| Wheat | Export | 18.0 | 18.0 |
| | Domestic | 1.1 | .2 |
| | Total | 19.1 | 18.2 |
| Oats | Export | .05 | .05 |
| | Domestic | 3.4 | .6 |
| | Total | 3.45 | .65 |
| Rye | Export | .2 | .2 |
| | Domestic | .5 | .1 |
| | Total | .7 | .3 |
| Soybean | Export | 4.5 | 4.5 |
| | Domestic | 1.8 | 1.1 |
| | Total | 6.3 | 5.6 |
| Total All Ingredients: | | 69.15 | 58.05 |

As would be expected, the regions having the largest supplies were the major shippers and the regions having the smallest supply/feed requirement ratio were the major importers. There were different indications by the two models as to which regions would be surplus or deficit for individual ingredients. In general, Model II indicated fewer deficit regions for individual ingredients than did Model I, and resulted in the lower total shipments observed from Model II.

2. Ingredient use.

Estimated total usage of the seven ingredients was larger from Model I than from Model II, 190.1 vs. 179.0 million tons. This is not a surprising result since the implicitly included ingredients did not have a cost attached under Model II. Thus, Model II will represent the estimated minimum use of the ingredients. We note from Table 6 that this does not mean that each ingredient will be used in a smaller amount, since the use of wheat for feed is more than doubled in Model II.

Corn was used in the largest quantities under both models, accounting for about 62 percent of total ingredient usage from Model I and 58 percent from Model II (Table 6). Swine feeds were estimated to account for the major usage of corn by both models (Tables 7 and 8). Sorghum was estimated to be used in the second largest quantities, 23.9 million tons for Model I and 16.0 million tons for Model II. Poultry feeds were the largest single user of sorghum in Model I and beef was the largest user in Model II.

Table 6.--Ingredients fed to livestock -- two models, 1971

| Ingredient | Model I | Model II | Model I | Model II | USDA estimate |
|---|---|---|---|---|---|
| | Mil. tons | Mil. tons | Pct. | Pct. | Mil. tons |
| Corn | 124.7 | 116.6 | 61.84 | 57.76 | 109.2 |
| Barley | 10.3 | 10.9 | 5.12 | 5.42 | 6.0 |
| Sorghum | 23.9 | 16.0 | 11.59 | 7.81 | 19.2 |
| Wheat | 5.7 | 12.5 | 2.84 | 6.22 | 6.5 |
| Oats | 15.3 | 13.0 | 7.61 | 6.47 | 11.6 |
| Rye | .9 | .6 | .45 | .30 | .4 |
| Soybean meal | 9.3 | 9.4 | 4.63 | 4.68 | 13.5 |
| Total | 190.1 | 179.0 | 94.03 | 88.61 | 166.4 |
| Calculated total requirements | 202.1 | 202.1 | 100.0 | 100.0 | |
| Supplied from implicitly included ingredients | 12.0 | 23.1 | 5.97 | 11.39 | |

Table 7.--Ingredient use by livestock in the U.S., Model I, 1971

| Ingredient | Dairy | Beef | Swine | Poultry | Sheep |
|---|---|---|---|---|---|
| | 1,000 ton | | | | |
| Corn | 17537.5 | 37528.8 | 53604.7 | 15372.1 | 658.2 |
| Barley | 190.1 | 7385.6 | 132.0 | 871.8 | 1698.6 |
| Sorghum | 0.0 | 8099.6 | 262.5 | 15518.7 | 0.0 |
| Wheat | 1188.6 | 724.9 | 3452.4 | 353.2 | 0.0 |
| Oats | 5992.8 | 759.9 | 3715.6 | 4794.0 | 0.0 |
| Rye | 0.0 | 0.0 | 847.1 | 18.3 | 0.0 |
| SBM | 765.1 | 412.3 | 6085.2 | 1935.1 | 116.5 |
| Total | 25674.1 | 54911.2 | 68099.7 | 38863.2 | 2473.3 |

Table 8.--Ingredient use by livestock in the U.S., Model II, 1971

| Ingredient | Dairy | Beef | Swine | Poultry | Sheep |
|---|---|---|---|---|---|
| | 1,000 ton | | | | |
| Corn | 14641.9 | 39282.5 | 41679.5 | 19977.4 | 1068.2 |
| Barley | 337.3 | 3676.6 | 4484.3 | 1168.1 | 1288.0 |
| Sorghum | 2599.8 | 7404.6 | 847.6 | 5119.1 | 0.0 |
| Wheat | 1580.1 | 3687.4 | 6191.9 | 1017.9 | 0.0 |
| Oats | 0.0 | 404.4 | 8266.1 | 4352.4 | 0.0 |
| Rye | 0.0 | 0.0 | 519.8 | 111.6 | 0.0 |
| SBM | 294.9 | 722.6 | 4881.1 | 3408.0 | 117.1 |
| Total | 19454.0 | 55178.2 | 66870.5 | 35154.5 | 2473.3 |

## Summary

This study was concerned with a spatial analysis of livestock use of seven feed ingredients: corn, barley, sorghum, wheat, oats, rye, and soybean meal. These seven ingredients were specified as the primary inputs into 16 types of livestock/poultry feeds. A national, interregional spatial equilibrium model was developed in a linear programming structure. Sixteen domestic ingredient producing and consuming regions, as well as nine ingredient export points, were included in the model to facilitate analysis of the interdependencies between feed ingredient producing regions, the transport system and feed consuming regions.

Two variants of the basic model were solved, each providing implicit values of each ingredient in each region. The solutions estimated optimal, least cost, ingredient movements between domestic regions and to export points. The solutions also provided estimates of ingredient use for each feed type in each domestic region; these estimates were aggregated and discussed under headings of dairy, beef, swine, poultry, and sheep. Ingredient identity with respect to both source and disposition was maintained throughout the system--providing detailed information about the source and use of individual feed ingredients, and the interactions between the location of supplies, the transport system and the points of consumption.

The analytic structure of the model is such that important information about the effects of interdependencies in the feed grain-livestock economy are obtained. This information will be valuable to both government policy analysts and business enterprises. (1) The results indicate where pressure is likely to be placed on the transport system. (2) The results indicate where significant ingredient deficits and surpluses are likely to occur. (3) The results provide guidelines for possible changes in the location of livestock feeding. (4) The results, by including the system interdependencies, provide measures of the relative competitive positions of the various geographic regions.

1. Summary results - Models I and II.

Model II differed from Model I in that the objective function for Model II contained only transportation costs while the objective function for Model I contained ingredient costs as well as transportation costs. The solution to Model II would be consistent with a wide variety of price structures because the equilibrium values obtained are price differentials. This means that the total price surface can be derived from one regional price. Since Model I contained ingredient prices the solution from it will embody some features of the real price structure which were not allowed to operate under Model II. The solutions show that these treatments of the price structure can produce different results.

Shipments of ingredients were consistently higher for Model I than for Model II, a total of 69.15 million tons for Model I and 58.05 million tons for Model II. This result follows the fact that costs for 19 ingredients, in addition to the seven studied, were included in Model I but not in Model II. The result was that these ingredients were substituted, as much as was allowed by the feed rations, for the seven included ingredients. Thus, Model II may be viewed as giving the minimum consumption of the seven ingredients. This does not mean that Model II provided the minimum consumption for individual ingredients. Despite the fact that total consumption for Model II was 21 million tons lower than for Model I (190.1 vs. 179.0 million tons) increases were noted in the consumption of barley, wheat, and soybean meal.

## Implications

The results obtained from this study have implications for four important aspects of the feed grain-livestock economy: The competitive structure, the price structure, the transportation network, and potential for regional growth. Each of these aspects is an important element in the environment of the firm and industry's relation to the total economy. This study can provide useful information for the analysis of each of these aspects.

1. Regional competition.

A purely competitive model was used in this report. In this form the results may be used to measure deviations by the real system from this "ideal" (subject to the existence of appropriate observations from the real world). However, the model was constructed in such a way that it can be used as a laboratory to analyze the implications of a less competitive system. This may be accomplished by placing bounds and/or ratio restrictions on some of the activities in the model.

2. Transportation.

The model may be used to analyze an entirely different question: that of failure to provide transportation facilities. Region 3 (Ohio, Indiana, and Illinois) was the source of corn for Region 1. If transportation facilities were not available to carry the quantity of corn currently estimated to move between the two regions, the cost to the system, at the margin, would be $4.30 per ton. This would indicate that the marginal value of an additional unit of transport facility would be $4.30. The use of bounds on the transport activities, and some sensitivity analysis would provide a more complete set of information.

3. Price structure.

The implicit prices provide information which is useful at both the firm and industry level. These prices may be used to analyze a variety of questions. For example, under Model II we found an expected equilibrium corn price differential of $13.20 between regions 1 and 3. This means that on the basis of the model assumptions we can expect the price of corn in region 1 to exceed the price in region 3 by $13.20. We conclude that region 3 has a competitive advantage over region 1. Alternatively we may conclude, for a firm in region 3, if corn can be sold in region 1 for a differential of more than $13.20 per ton it will be profitable to do so. On the other hand, region 1 can profit by obtaining corn in region 3 at a differential of less than $13.20. At a more aggregate level this data indicates some possibilities for reaction to national grain policies. If the corn support rate differential between regions 1 and 3 should exceed \$13.20 one might observe producers in region, in effect, selling their corn to the government and importing their needs from region 3. If the price differentials from Model II are used to set support rate limits we can suggest that it will be necessary to support corn prices at least at \$13.20 per ton (37 cents per bushel) more in region 1 than in region 3, if we are to expect to remove corn from the market in region 1.

4. Regional growth.

If additional data is combined with the implicit prices they may be used to form a guide to expected regional growth in ingredient, livestock, poultry, and feed production. Even without additional data the results can give initial guidelines. According to the results from Model II the equilibrium differential for swine feed (number 8 feed for example) is \$12.94 per ton higher in region 1 than in region 5. All other things equal, this implies that as long as the cost of transporting feed from region 5 to region 1 is less than \$12.94 per ton we can expect a growth in feed manufacturing in region 5 relative to region 1.

5. Alternative analytic possibilities.

A spatial equilibrium model has been used in this study. The structure of the model is such that, if additional data were available, temporal or temporal-spatial analyses could be performed. This can be achieved with little change to the basic structure of the model and would be especially useful when dealing with problems related to the scheduling of production, storage space and transportation facilities.

## Conclusions

The main conclusion to be drawn from this study is that the method and model can provide a wealth of information which is both useful and relevant. The information is consistent with some of the main economic decisions which policy analysts and business managers face. In particular, the model provides a mechanism through which one may investigate the impact of important economic forces.

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# APPENDIX

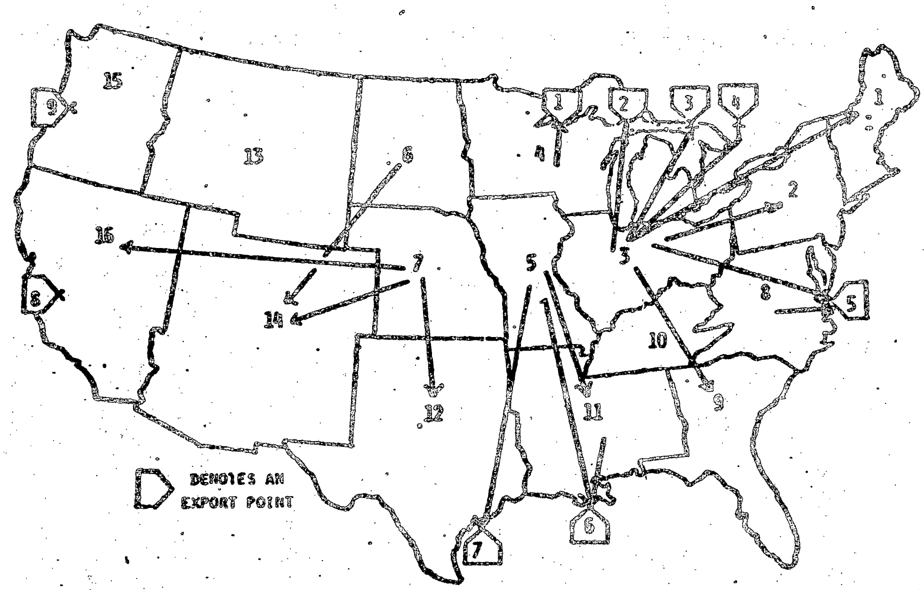


Figure 1. Interregional Movements of Corn - Model I, 1971.

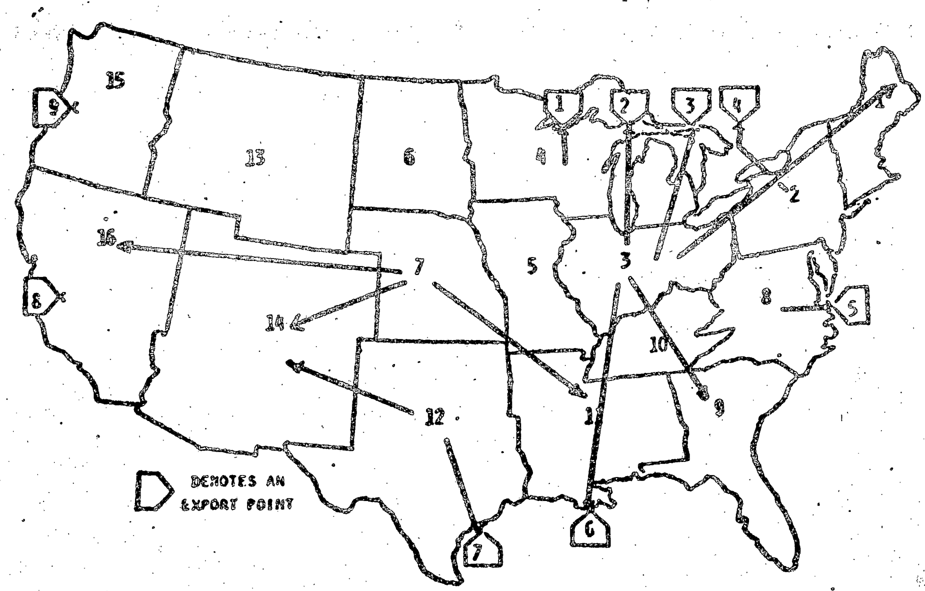


Figure 2. Interregional Movements of Corn - Model II, 1971.

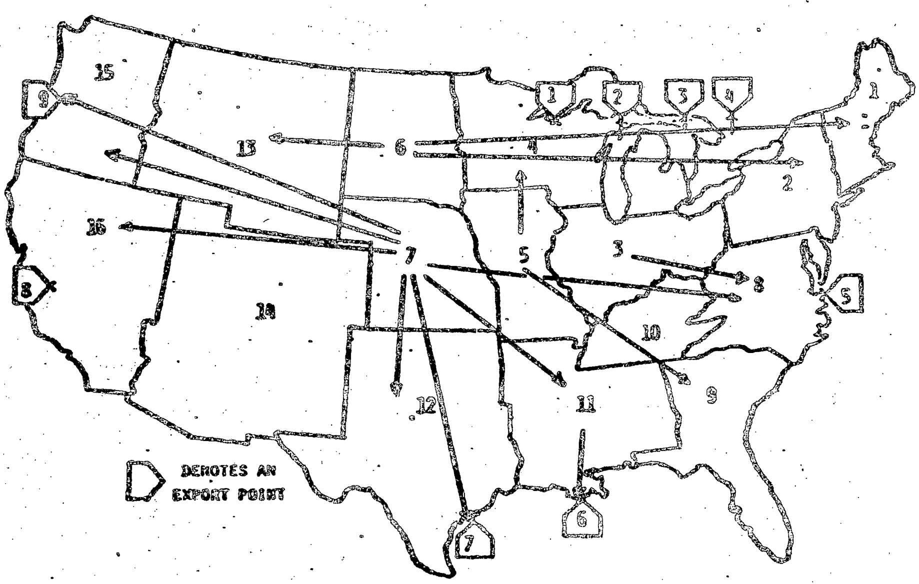


Figure 3. Interregional Movements of Sorghum - Model I, 1971.

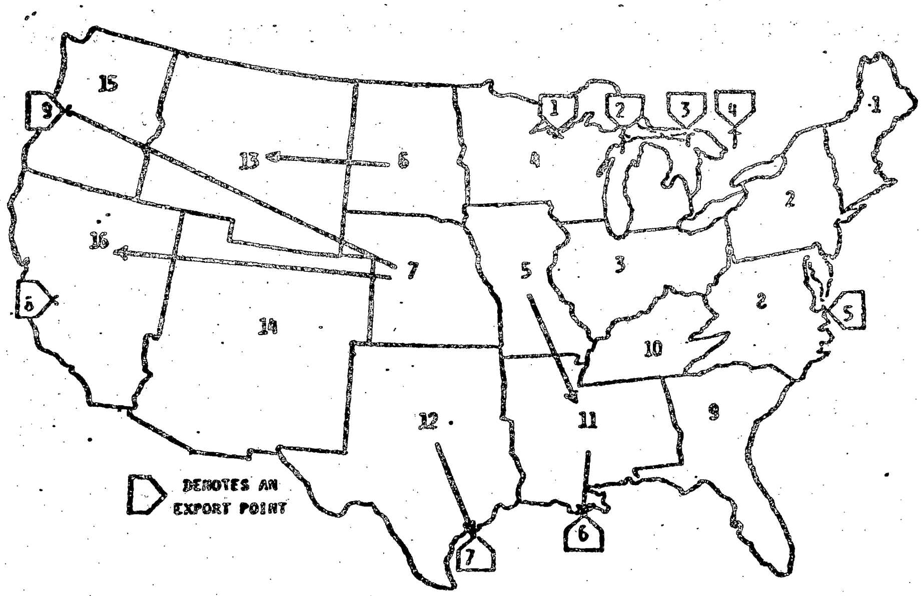


Figure 4. Interregional Movements of Sorghum - Model II, 1971.

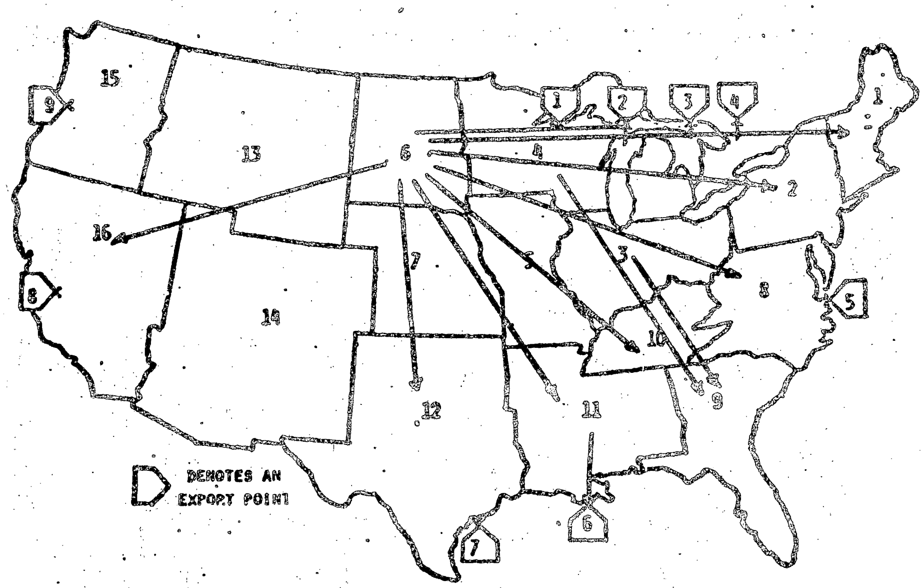


Figure 5. Interregional Movements of Oats - Model I, 1971.

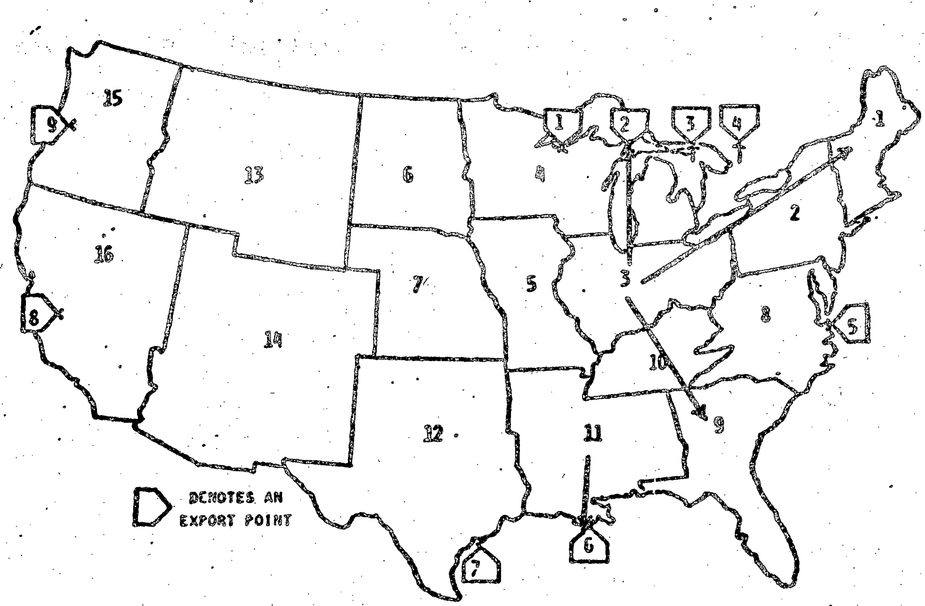


Figure 6. Interregional Movements of Oats - Model II, 1971.

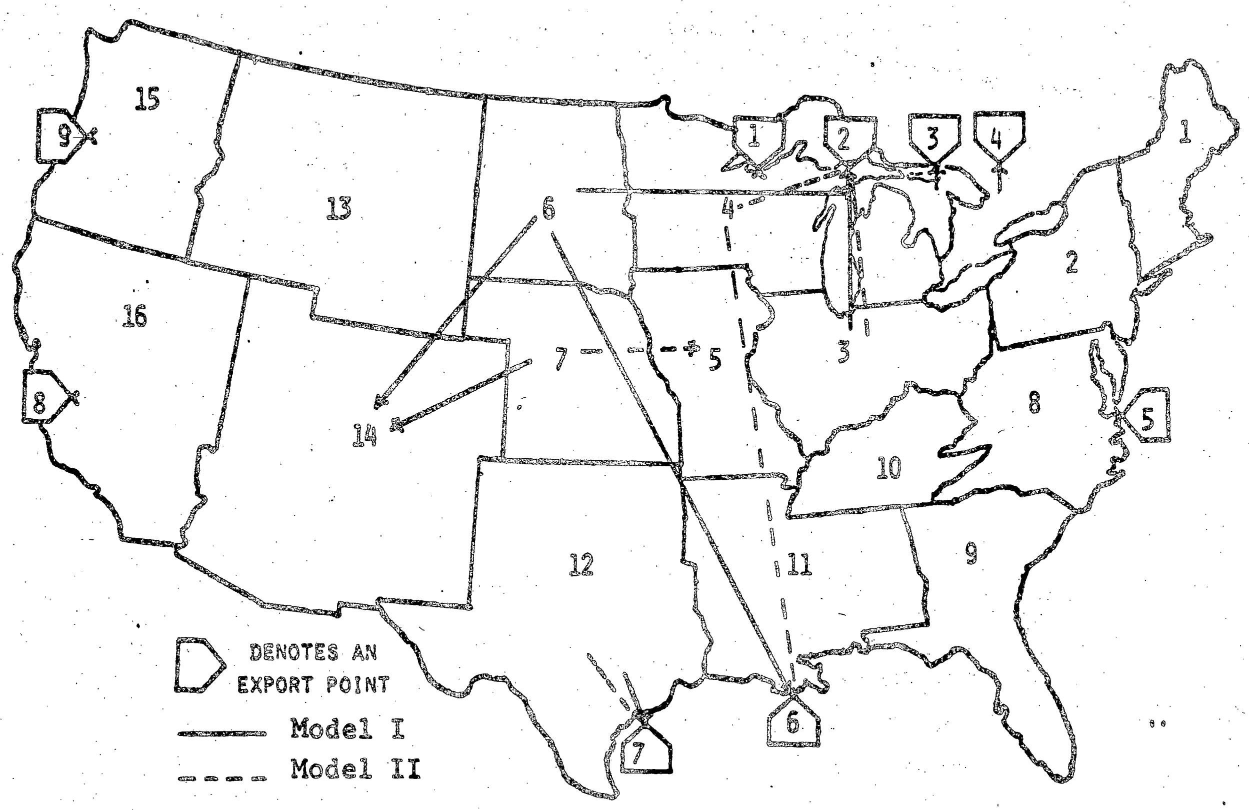


**Figure 7. Interregional Movements of Barley - Models I and II, 1971.**

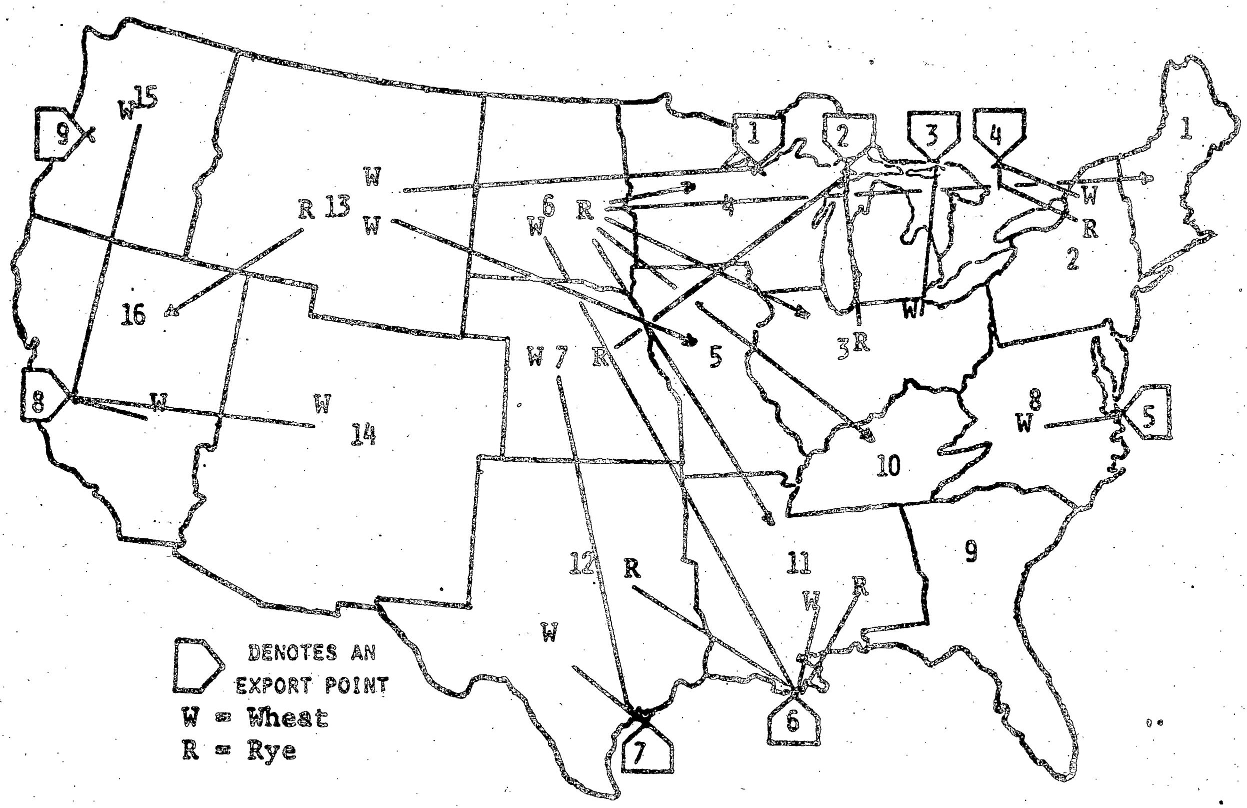


**Figure 8. Interregional Movements of Wheat and Rye - Model I, 1971.**

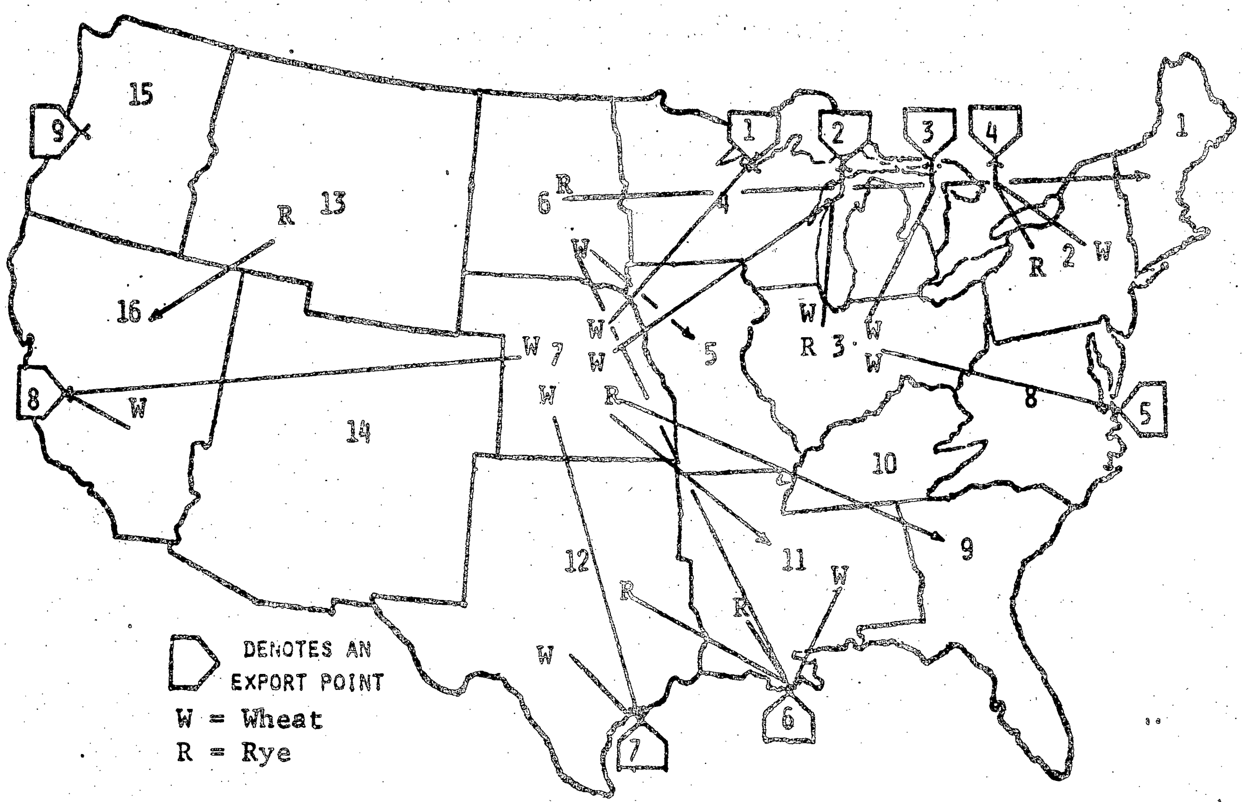


Figure 9. Interregional Movements of Wheat and Rye - Model II, 1971.

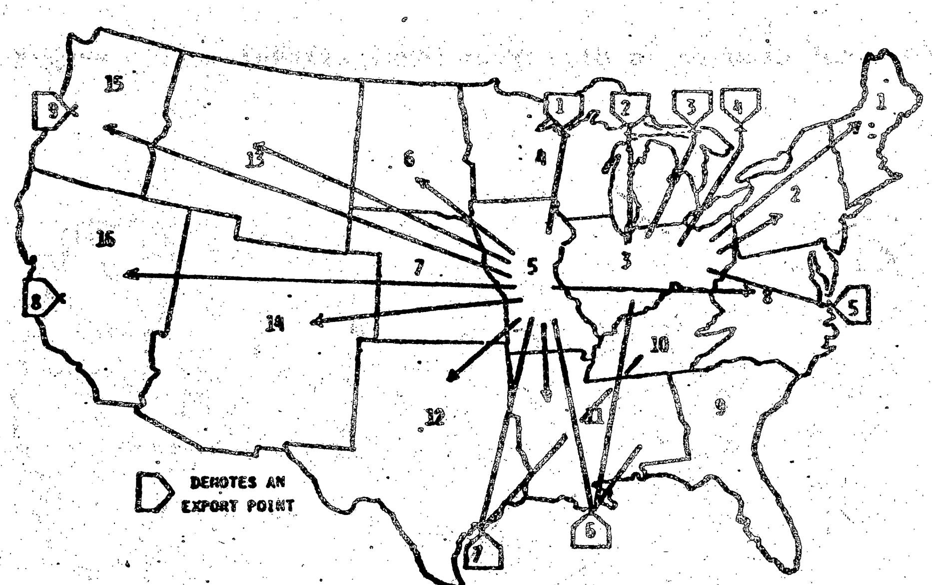


Figure 10. Interregional Movements of Soybean Meal - Model I, 1971.

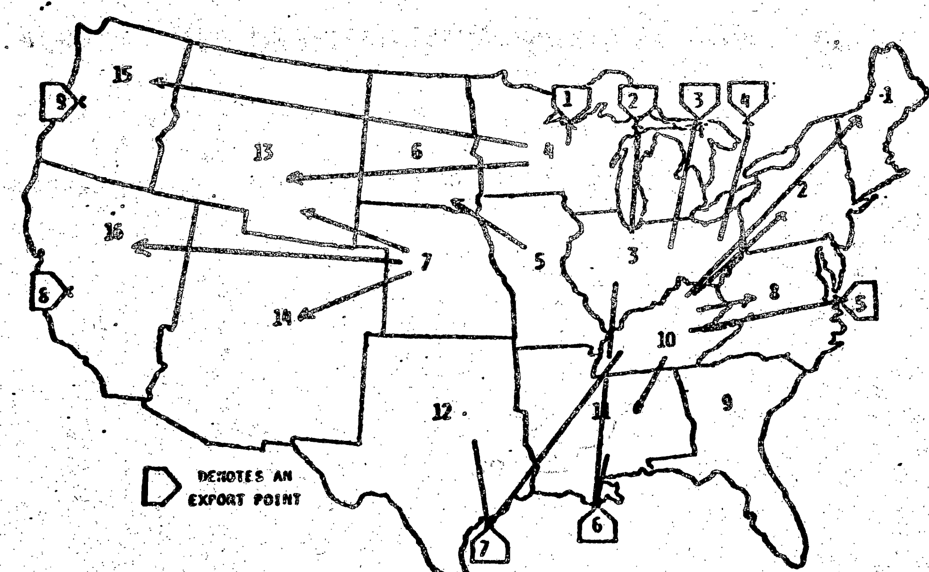


Figure 11. Interregional Movements of Soybean Meal - Model II, 1971.

Table 1. Supplies and Estimated Disposition of Corn, Models I and II, 1971.

| | | Model I | | | | | Model II | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Shipments | | | Fed to | | Shipments | | | Fed to | |
| Region | Supply | Received | Export | Domestic | Animals | Surplus | Received | Export | Domestic | Animals | Surplus |
| | | (Million Tons) | | | | | (Million Tons) | | | | |
| 1 | .011 | 1.945 | -- | -- | 1.957 | -- | 1.452 | -- | -- | 1.463 | -- |
| 2 | 4.709 | .265 | -- | -- | 4.974 | -- | -- | .652 | -- | 4.056 | -- |
| 3 | 73.372 | -- | 3.533 | 4.177 | 20.156 | 46.503 | -- | 10.706 | 3.040 | 18.291 | 42.334 |
| 4 | 32.567 | -- | 1.236 | -- | 17.125 | 14.205 | -- | 1.236 | -- | 16.405 | 14.925 |
| 5 | 57.406 | -- | 6.974 | 4.086 | 25.460 | 20.884 | -- | -- | -- | 26.617 | 30.788 |
| 6 | 5.671 | -- | -- | .989 | 2.740 | 1.942 | -- | -- | -- | 1.644 | -- |
| 7 | 25.266 | -- | -- | 6.220 | 19.044 | -- | -- | -- | 8.691 | 16.428 | .146 |
| 8 | 7.585 | -- | .441 | -- | 7.144 | -- | -- | 1.250 | -- | 6.335 | -- |
| 9 | 4.260 | 1.967 | -- | -- | 6.227 | -- | 1.588 | -- | -- | 5.847 | -- |
| 10 | 4.784 | -- | -- | -- | 4.031 | .752 | -- | -- | -- | 4.128 | .656 |
| 11 | 1.908 | 1.908 | 1.908 | -- | 4.086 | -- | 4.547 | -- | -- | 6.455 | -- |
| 12 | 1.807 | 1.807 | -- | -- | 4.664 | .458 | -- | .249 | .703 | .854 | -- |
| 13 | .201 | .201 | -- | -- | .201 | -- | -- | -- | -- | .201 | -- |
| 14 | 1.603 | 1.603 | -- | -- | 3.692 | -- | 1.137 | -- | -- | 2.741 | -- |
| 15 | .296 | .296 | -- | -- | .218 | .078 | -- | -- | -- | .296 | -- |
| 16 | 1.167 | 1.167 | -- | -- | 2.975 | -- | 3.711 | -- | -- | 4.879 | -- |
| Total | 223.622 | 15.475 | 14.095 | 15.475 | 124.701 | 84.825 | 12.436 | 14.095 | 12.436 | 116.649 | 88.850 |

Table 2. Supplies and Estimated Disposition of Sorghum - Models I and II, 1971.

| | | Model I | | | | | Model II | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Shipments | | Fed To | | | Shipments | | Fed To | |
| Region | Supply | Received | Export | Domestic | Animals | Surplus | Received | Export | Domestic | Animals | Surplus |
| | | (Million Tons) | | | | | (Million Tons) | | | | |
| 1 | .004 | .176 | -- | -- | .180 | -- | -- | -- | -- | .004 | -- |
| 2 | .004 | .166 | -- | -- | .170 | -- | -- | -- | -- | .004 | -- |
| 3 | .428 | -- | -- | .340 | .088 | -- | -- | -- | -- | .428 | -- |
| 4 | .006 | -- | -- | -- | .089 | -- | -- | -- | -- | -- | .006 |
| 5 | 1.731 | -- | -- | 1.117 | .613 | -- | -- | -- | 1.731 | -- | -- |
| 6 | .564 | -- | -- | .395 | .168 | -- | -- | -- | * | .109 | .455 |
| 7 | 15.647 | -- | 3.023 | 11.470 | 1.150 | -- | -- | .154 | .404 | .508 | 14.581 |
| 8 | .227 | 1.214 | -- | -- | 1.442 | -- | -- | -- | -- | .227 | -- |
| 9 | .079 | 1.034 | -- | -- | 1.114 | -- | -- | -- | -- | .079 | -- |
| 10 | .140 | -- | -- | -- | .140 | -- | -- | -- | -- | .140 | -- |
| 11 | .896 | 6.232 | .181 | -- | 6.947 | -- | 1.731 | .181 | -- | 2.445 | -- |
| 12 | 14.487 | .666 | -- | -- | 4.981 | 10.172 | -- | 2.869 | -- | 8.577 | 3.041 |
| 13 | -- | .053 | -- | -- | .053 | -- | -- | -- | -- | * | -- |
| 14 | 2.041 | -- | -- | -- | 2.041 | -- | -- | -- | -- | 2.041 | -- |
| 15 | -- | .207 | -- | -- | .207 | -- | -- | -- | -- | -- | -- |
| 16 | .999 | 3.491 | -- | -- | 4.490 | -- | .404 | -- | -- | 1.403 | -- |
| Total | 37.259 | 13.327 | 3.206 | 13.327 | 23.880 | 10.172 | 2.135 | 3.206 | 2.135 | 15.971 | 18.082 |

* Less than .0005 million tons

Table 3. Supplies and Estimated Disposition of Oats -- Models I and II, 1971.

| | | Model I | | | | | Model II | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Shipments | | Fed to | | | Shipments | | Fed to | |
| Region | Supply | Received | Export | Domestic | Animals | Surplus | Received | Export | Domestic | Animals | Surplus |
| 1 | .047 | .180 | -- | -- | .227 | -- | .293 | -- | -- | .340 | -- |
| 2 | .833 | .775 | -- | -- | 1.608 | -- | -- | -- | -- | .833 | -- |
| 3 | 2.141 | -- | -- | .763 | 1.378 | -- | -- | .040 | .627 | 1.472 | -- |
| 4 | 6.762 | -- | -- | .292 | 4.349 | 2.121 | -- | -- | -- | 4.403 | 2.359 |
| 5 | 1.637 | -- | -- | -- | 2.637 | -- | -- | -- | -- | 2.637 | -- |
| 6 | 5.508 | -- | .040 | 2.341 | 1.400 | 1.723 | -- | -- | -- | .321 | 5.187 |
| 7 | .950 | -- | -- | -- | .345 | .605 | -- | -- | -- | .950 | -- |
| 8 | .431 | .090 | -- | -- | .284 | .237 | -- | -- | -- | .431 | -- |
| 9 | .184 | 1.055 | -- | -- | 1.240 | -- | .334 | -- | -- | .519 | -- |
| 10 | .029 | .481 | -- | -- | .511 | -- | -- | -- | -- | .029 | -- |
| 11 | .163 | .279 | .006 | -- | .392 | .043 | -- | .006 | -- | .156 | -- |
| 12 | .444 | .256 | -- | -- | .256 | .444 | -- | -- | -- | .444 | -- |
| 13 | .544 | -- | -- | -- | -- | .544 | -- | -- | -- | .018 | .526 |
| 14 | .133 | -- | -- | -- | .133 | .133 | -- | -- | -- | .133 | -- |
| 15 | .187 | -- | -- | -- | .071 | .116 | -- | -- | -- | .187 | -- |
| 16 | .145 | .280 | -- | -- | .425 | -- | -- | -- | -- | .145 | -- |
| Total | 21.142 | 3.400 | .047 | 3.400 | 15.262 | 5.833 | .628 | .047 | .628 | 13.022 | 8.073 |

Table 4. Supplies and Estimated Disposition of Soybean Meal - Models I and II, 1971.

| | | Model I | | | | | Model II | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Shipments | | Fed To | | | Shipments | | Fed to | |
| Region | Supply | Received | Export | Domestic | Animals | Surplus | Received | Export | Domestic | Animals | Surplus |
| | | (Million Tons) | | | | | (Million Tons) | | | | |
| 1 | -- | .075 | -- | -- | .075 | -- | .081 | -- | -- | .081 | -- |
| 2 | | .405 | -- | -- | .405 | -- | .092 | -- | -- | .092 | -- |
| 3 | 4.388 | -- | 2.121 | .480 | 1.786 | -- | -- | 3.184 | -- | 1.204 | -- |
| 4 | 1.192 | -- | -- | -- | 1.192 | -- | -- | .452 | .038 | .625 | .077 |
| 5 | 3.719 | -- | .590 | 1.362 | 1.763 | -- | -- | -- | .066 | 2.252 | 1.401 |
| 6 | -- | .196 | -- | -- | .196 | -- | .066 | -- | -- | .066 | -- |
| 7 | .563 | -- | -- | -- | .563 | -- | -- | -- | .257 | .306 | -- |
| 8 | .544 | .143 | -- | -- | .688 | -- | .106 | -- | -- | .650 | -- |
| 9 | 1.338 | -- | -- | -- | .698 | .640 | -- | -- | -- | 1.338 | -- |
| 10 | 4.020 | -- | .346 | -- | .373 | 3.301 | -- | .438 | .763 | .464 | 2.355 |
| 11 | 1.445 | .337 | 1.445 | -- | .337 | -- | .484 | .423 | -- | 1.506 | -- |
| 12 | .394 | .126 | -- | -- | .520 | -- | -- | .005 | -- | .389 | -- |
| 13 | -- | .063 | -- | -- | .063 | -- | .025 | -- | -- | .025 | -- |
| 14 | -- | .243 | -- | -- | .243 | -- | .166 | -- | -- | .166 | -- |
| 15 | -- | .041 | -- | -- | .041 | -- | .015 | -- | -- | .015 | -- |
| 16 | .151 | .213 | -- | -- | .364 | -- | .087 | -- | -- | .238 | -- |
| Total | 17.759 | 1.846 | 4.504 | 1.846 | 9.314 | 3.941 | 1.125 | 4.504 | 1.125 | 9.423 | 3.833 |

Table 5. Implicit Values for Ingredients, Model I, 1971.

| REGION | CORN | BARLEY | SORGHUM | WHEAT | OATS | RYE | SBM |
|---|---|---|---|---|---|---|---|
| | ($/TON) | ($/TON) | ($/TON) | ($/TON) | ($/TON) | ($/TON) | ($/TON) |
| 1 | 62.10 | 70.80 | 67.83 | 67.56 | 66.72 | 71.17 | 135.20 |
| 2 | 60.50 | 60.50 | 66.23 | 64.40 | 65.12 | 61.93 | 133.60 |
| 3 | 48.90 | 58.20 | 56.84 | 62.68 | 55.76 | 74.88 | 122.00 |
| 4 | 49.00 | 49.05 | 63.53 | 61.54 | 48.42 | 64.37 | 140.18 |
| 5 | 46.00 | 58.02 | 51.3[illegible] | 67.52 | 64.23 | 636.47 | 120.24 |
| 6 | 48.00 | 45.84 | 45.33 | 56.70 | 41.72 | 45.27 | 130.24 |
| 7 | 48.56 | 51.15 | 47.2[illegible] | 6[illegible].60 | 50.00 | 62.28 | 151.94 |
| 8 | 56.30 | 57.34 | 63.22 | 61.44 | 65.12 | 64.67 | 132.08 |
| 9 | 57.76 | 60.95 | 62.14 | 6[illegible].77 | 64.18 | 74.98 | 116.48 |
| 10 | 51.08 | 51.08 | 54.61 | 63.90 | 58.54 | 62.79 | 122.00 |
| 11 | 54.00 | 59.14 | 56.03 | 67.80 | 58.72 | 83.39 | 128.24 |
| 12 | 53.12 | 53.22 | 52.0[illegible] | 6[illegible].79 | 59.80 | 62.39 | 127.86 |
| 13 | 57.28 | 46.52 | 51.97 | 44.52 | 45.32 | 49.40 | 146.94 |
| 14 | 55.94 | 55.94 | 54.63 | 55.98 | 58.34 | 55.18 | 134.94 |
| 15 | 62.90 | 50.74 | 64.0[illegible] | 51.78 | 51.24 | 51.54 | 146.94 |
| 16 | 65.36 | 65.42 | 64.03 | 72.78 | 69.02 | 75.90 | 146.94 |

Table 6. Implicit Values for Ingredients, Model II, 1971.

| REGION | CORN | BARLEY | SORGHUM | WHEAT | OATS | RYE | SBM |
|---|---|---|---|---|---|---|---|
| | ($/TON) | ($/TON) | ($/TON) | ($/TON) | ($/TON) | ($/TON) | ($/TON) |
| 1 | 13.20 | 14.57 | 13.77 | 14.58 | 12.16 | 25.90 | 13.20 |
| 2 | 2.70 | 2.95 | 6.4 | 2.98 | 2.78 | 2.74 | 11.60 |
| 3 | 0.00 | 10.33 | .1 | .38 | .56 | 12.61 | .85 |
| 4 | 0.00 | 0.00 | 0.0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5 | 0.00 | 15.25 | .67 | 14.00 | 17.81 | 467.21 | 0.00 |
| 6 | 0.00 | 0.00 | 0.0 | .00 | 0.00 | 0.00 | 10.06 |
| 7 | 0.00 | 5.83 | 0.0 | 0.00 | .01 | .01 | .09 |
| 8 | 4.12 | 5.61 | 5.5 | 5.85 | 6.04 | 5.88 | 10.20 |
| 9 | 8.86 | 9.21 | 9.4 | 9.78 | 8.98 | 17.50 | 1.15 |
| 10 | 0.00 | 0.00 | 0.0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 11 | 6.34 | 7.65 | 6.35 | 9.10 | 8.41 | 21.74 | 7.09 |
| 12 | .52 | .73 | 0.0 | 9.10 | .75 | .74 | 2.89 |
| 13 | 0.00 | 0.00 | 6.63 | 0.00 | 0.00 | 0.00 | 16.80 |
| 14 | 7.38 | 6.57 | 6.12 | 6.29 | 6.66 | 6.51 | 7.47 |
| 15 | 0.00 | 0.00 | 12.6 | 0.00 | 0.00 | 0.00 | 16.80 |
| 16 | 16.80 | 16.80 | 16.8 | 19.10 | 17.77 | 26.50 | 16.89 |

Table 7. Imputed Feed Values, All Regions, All Feed Types, Model I, 1971.

| REGION | Feed Type 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ($/TON) | | | | | | | | | | | | | | | |
| 1 | 65.42 | 65.42 | 58.77 | 62.40 | 70.26 | 76.17 | 70.42 | 69.21 | 71.44 | 78.80 | 82.39 | 77.54 | 88.71 | 84.35 | 80.91 | 0.00 |
| 2 | 63.82 | 63.[illegible]2 | 56.76 | 60.84 | 68.77 | 73.91 | 67.85 | 67.45 | 70.69 | 77.73 | 82.57 | 75.47 | 86.53 | 83.36 | 78.95 | 63.92 |
| 3 | 52.7[illegible] | 52.78 | 47.63 | 49.06 | 57.64 | 62.94 | 57.59 | 56.03 | 60.06 | 69.35 | 72.12 | 65.16 | 76.92 | 73.01 | 68.70 | 52.41 |
| 4 | 51.59 | 51.58 | 47.71 | 49.14 | 58.97 | 65.89 | 60.19 | 57.81 | 57.48 | 75.15 | 73.91 | 65.50 | 76.79 | 73.00 | 69.82 | 53.31 |
| 5 | 52.72 | 52.[illegible]0 | 45.63 | 46.21 | 54.9[illegible] | 6[illegible].23 | 71.29 | 53.25 | 58.42 | 64.66 | 69.71 | 62.94 | 74.88 | 71.58 | 66.81 | 49.57 |
| 6 | 48.91 | 48.87 | 42.31 | 46.97 | 57.62 | 61.82 | 55.15 | 55.99 | 53.79 | 59.46 | 66.76 | 61.17 | 70.86 | 67.47 | 64.37 | 49.78 |
| 7 | 52.01 | 52.[illegible]1 | 47.69 | 48.71 | 59.3[illegible] | 65.98 | 61.27 | 58.50 | 56.54 | 61.14 | 67.81 | 66.68 | 79.12 | 74.59 | 71.10 | 53.53 |
| 8 | 60.74 | 59.73 | 53.92 | 56.27 | 64.82 | 7[illegible].43 | 65.27 | 63.65 | 67.78 | 74.82 | 78.73 | 71.81 | 83.86 | 80.03 | 75.44 | 0.00 |
| 9 | 61.1[illegible] | 61.10 | 55.89 | 58.31 | 65.31 | 68.93 | 64.75 | 63.49 | 67.04 | 73.94 | 78.08 | 70.86 | 80.12 | 77.34 | 73.85 | 0.00 |
| 10 | 55.04 | 55.[illegible]4 | 50.47 | 51.78 | 59.83 | 64.22 | 59.61 | 57.96 | 61.06 | 67.47 | 73.42 | 65.29 | 77.00 | 72.94 | 68.66 | 0.00 |
| 11 | 57.34 | 57.34 | 51.31 | 54.59 | 62.52 | 66.16 | 62.41 | 61.12 | 63.58 | 68.64 | 74.02 | 69.06 | 91.28 | 76.99 | 72.61 | 0.00 |
| 12 | 56.73 | 56.73 | 50.64 | 53.53 | 61.77 | 66.19 | 61.67 | 60.35 | 60.80 | 65.18 | 71.58 | 67.80 | 79.71 | 75.84 | 71.37 | 56.71 |
| 13 | 49.67 | 51.48 | 44.46 | 51.67 | 63.34 | 67.11 | 51.84 | 50.41 | 60.35 | 65.41 | 71.88 | 0.00 | 0.00 | 0.00 | 0.00 | 51.21 |
| 14 | 58.89 | 58.89 | 52.67 | 56.31 | 65.69 | 68.77 | 61.40 | 60.16 | 63.28 | 67.74 | 74.05 | 72.50 | 85.24 | 80.95 | 76.29 | 59.63 |
| 15 | 55.31 | 55.92 | 48.48 | 56.39 | 69.[illegible] | 7[illegible].85 | 58.34 | 56.07 | 61.52 | 75.82 | 73.40 | 70.35 | 81.80 | 77.87 | 74.07 | 55.23 |
| 16 | 69.70 | 69.70 | 60.30 | 65.44 | 74.77 | 79.12 | 74.69 | 73.12 | 71.85 | 79.82 | 81.60 | 81.95 | 94.06 | 90.60 | 85.85 | 69.23 |

Table 8. Imputed Feed Values, All Regions, All Feed Types, Model II, 1971.

| REGION | Feed Type 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ($/TON) | | | | | | | | | | | | | | | |
| 1 | 8.95 | 6.20 | 9.92 | 10.59 | 12.47 | 11.10 | 10.00 | 12.94 | 9.66 | 9.96 | 9.18 | 10.94 | 10.12 | 9.88 | 9.08 | 0.00 |
| 2 | 1.03 | 1.27 | 2.17 | 2.16 | 3.15 | 3.32 | 2.43 | 2.62 | 2.47 | 2.64 | 2.24 | 2.48 | 3.21 | 2.53 | 2.26 | 3.12 |
| 3 | 0.00 | 0.00 | 0.00 | 0.00 | .06 | .16 | .41 | .08 | 0.06 | .09 | .08 | .14 | .16 | .11 | .11 | .04 |
| 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 6 | 0.00 | 0.00 | 0.00 | 0.00 | .64 | 1.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | .32 | 0.00 | .47 |
| 7 | 0.00 | 0.00 | 0.00 | 0.00 | .01 | .01 | .01 | .01 | 0.00 | 0.00 | 0.00 | .01 | .02 | .01 | .01 | .00 |
| 8 | 2.80 | 1.94 | 3.32 | 3.31 | 4.31 | 4.48 | 4.73 | 4.67 | 3.36 | 4.56 | 4.15 | 4.51 | 4.71 | 4.38 | 4.55 | 0.00 |
| 9 | 6.61 | 4.16 | 7.13 | 7.11 | 7.61 | 6.33 | 7.85 | 7.36 | 6.05 | 5.98 | 4.67 | 6.35 | 4.32 | 5.67 | 6.01 | 0.00 |
| 10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 11 | 4.13 | 2.94 | 5.10 | 5.09 | 6.04 | 6.02 | 6.52 | 6.35 | 4.68 | 5.39 | 5.06 | 5.56 | 5.10 | 5.64 | 5.64 | 0.00 |
| 12 | 0.00 | 0.00 | 0.00 | .14 | .54 | .49 | .62 | .65 | 0.00 | 0.00 | 0.00 | .61 | .84 | .67 | .61 | .63 |
| 13 | 0.00 | 0.00 | 0.00 | 0.00 | 1.15 | 1.86 | 0.00 | 0.00 | 0.00 | .58 | .40 | 0.00 | 0.00 | 0.00 | 0.00 | .79 |
| 14 | 3.81 | 2.78 | 5.29 | 5.92 | 6.67 | 5.52 | 5.60 | 5.84 | 5.32 | 4.85 | 4.56 | 5.53 | 5.48 | 5.42 | 5.41 | 6.61 |
| 15 | 0.00 | 0.00 | 0.00 | 0.00 | 1.15 | 1.86 | 0.00 | 0.00 | 0.00 | .83 | .40 | 0.00 | 1.67 | .53 | 0.00 | .79 |
| 16 | 10.92 | 7.56 | 13.52 | 13.48 | 13.84 | 14.49 | 14.32 | 14.93 | 12.36 | 13.93 | 12.40 | 14.14 | 12.91 | 13.75 | 13.80 | 16.00 |