Effects of Beef Feeding Practices and Conservation Farming Systems on the Interregional Pattern of Crop and Beef Production

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EFFECTS OF BEEF FEEDING PRACTICES AND CONSERVATION

FARMING SYSTEMS ON THE INTERREGIONAL PATTERN OF

CROP AND BEEF PRODUCTION

by

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I. INTRODUCTION

Beef cattle convert grass from U.S. rangelands and aftermath from crops into usable protein that otherwise would be unavailable for human consumption. They also are fed large quantities of grain in the United States. Intensive use of grain in the beef feeding industry results from the nation's large supplies and low real prices of feed grains.

The grain producing capacity of U.S. agriculture far exceeds the amount of cereals needed for domestic human consumption. Accordingly, a large amount of wheat is exported as a food crop while a large amount of feed grains is produced specifically for the nation's livestock industry. Only 3 percent of U.S. corn production is used for domestic human consumption. However, some people and groups have been concerned with the amount of grain fed to livestock in the United States while human hunger prevails over much of the world. They have been concerned especially about the amount of grain fed to beef cattle where the amount used to produce a pound of meat is greater than for hogs and poultry.

Various shifts could be made in cattle feeding to alter the amount of grain used for these purposes. Finishing cattle at different weights is one of them. Use of a greater proportion of silage is another. This study assumes that cattle will continue to be fed in feedlots and analyzes the impact of alternative finishing weights and silage feeding on U.S. and regional land use and crop production. It also analyzes the potential effects of a soil conservation alternative on crop and livestock production, land use and related variables.

The objective of this analysis is to evaluate the potential impact of alternative futures in beef production and soil conservation on agriculture as a whole and on the beef cattle industry in particular. Each future is specified in the model using different assumptions for the beef cattle industry and U.S. agriculture.

The alternative futures are:

1. The Base Alternative. It assumes that beef cattle will be finished on a conventional high concentrate ration and marketed at an average weight of 1,050 pounds. It has no requirements for attaining a greater level of conservation.

2. The 950 Alternative. It assumes that beef cattle also will be finished on a conventional high concentrate ration, but marketed at an average weight of 950 pounds. It has no requirements for soil conservation.

3. The 1150 Alternative. It assumes that beef cattle will be finished on a conventional high concentrate ration but marketed at an average weight of 1,150 pounds. It has no requirements on soil conservation.

4. The Silage Alternative. It assumes that beef cattle will be finished on a high silage ration and marketed at an average weight of 1,050 pounds. It has no requirements on soil conservation.

5. The Soil Conservation Alternative. It assumes that beef cattle will be finished on a conventional high concentrate ration and marketed at an average weight of 1,050 pounds. It requires agriculture to adopt

cropping practices that limit soil erosion to levels set by soil scientists as necessary if the productivity of the land is to be maintained.

The results obtained from the model for each of the alternative futures is used to assess the impact of the assumed conditions on U.S. agriculture and the beef cattle industry. Comparison of the results of the Base Alternative with the 950 Alternative and the 1150 Alternative provides information useful for identifying and appraising the impacts of changing feed efficiency as market weights vary (Chapter IV). Comparing the results from the Base Alternative with the results from the Silage Alternative provides a means of evaluating the impact of maximizing the number of animals fed per acre by using corn and sorghum silage instead of grain (Chapter V). Differences between the Base Alternative and the Soil Conservation Alternative reflect the result of requiring agriculture to conserve topsoil as crops are grown for livestock and people (Chapter VI). Since the Soil Conservation Alternative requires more forage in land use patterns, it interacts with the agricultural sector's ability and capacity to feed cattle.

Each alternative is analyzed relative to fixed levels of domestic and export demand. The alternatives are studied in terms of their impacts on farming practices, land and water use, interregional shifts in crop and livestock production patterns, inputs used in agriculture, the environmental impact, production costs, conservation practices and soil loss levels, export capabilities, and other variables potentially affected by the various assumptions for agriculture. The alternatives are studied by means of a national and interregional linear programming model of U.S. agriculture which expresses interdependence among all major producing regions of the nation.

II. THE MODEL

This section summarizes the specification and use of the linear programming model on which the analysis is based. The appendix includes a mathematical summary of the model. The model has four major sectors: (a) the land and water resources available to agriculture, (b) crop and livestock production activities for the transformation of these resources in agricultural commodities, (c) the commodity transportation network, and (d) the domestic and foreign demands for agricultural products. The model is solved with the objective of meeting the demands for agricultural products while minimizing the cost of producing and transporting the nation's agricultural products. The model assumes a competitive equilibrium with all resources used in agriculture, except land and water, receiving their market rate of return. Returns to land and water are determined endogenously in the model and may be higher or lower than prevailing market rates for a particular region.

Land resources in the model are divided into producing areas representing relatively homogenous production conditions. A large number of crop and livestock production activities is defined within each of these producing areas. The demands for the commodities are defined at demand centers within consuming regions over the United States based on projections of per capita consumption, population and export demands. When the model is solved, land in each producing area is brought into production under the criterion of minimum cost, i.e., the most productive land

is utilized first. This procedure allocates the production of crops and livestock consuming these crops to the producing areas to minimize the total cost of production and transportation incurred in meeting domestic and export demands for agricultural products.

Regions of the Model

Four sets of regions are used: (1) the data collection regions used in the development of the model's data base, (2) the regions or producing areas within which the production activities of the model are defined, (3) the market regions within which the demands for commodities are defined, and (4) the reporting regions into which the results are summarized.

The data regions, shown in Figure 1, are built on county approximations of the major land resource areas used for data collection by the Soil Conservation Service, U.S. Department of Agriculture [3]. These regions delineate the land of the United States into 156 areas based on dominant soil type and management characteristics. Weights are used to transfer data from these regions into the producing regions to generate coefficients needed in defining the model.

The 105 producing areas or regions shown in Figure 2 are derived from the Water Resources Council's 99 aggregated subareas [4]. The crop production sector and the land base of the model are defined within these regions. Water supplies for the western United States are defined for producing areas 48 to 105.

The 28 market regions shown in Figure 3 are aggregations of contiguous producing areas. Each market region functions in the model as a demand and transportation center. The metropolitan centers identified in each

Figure 1. The SCS data collection areas

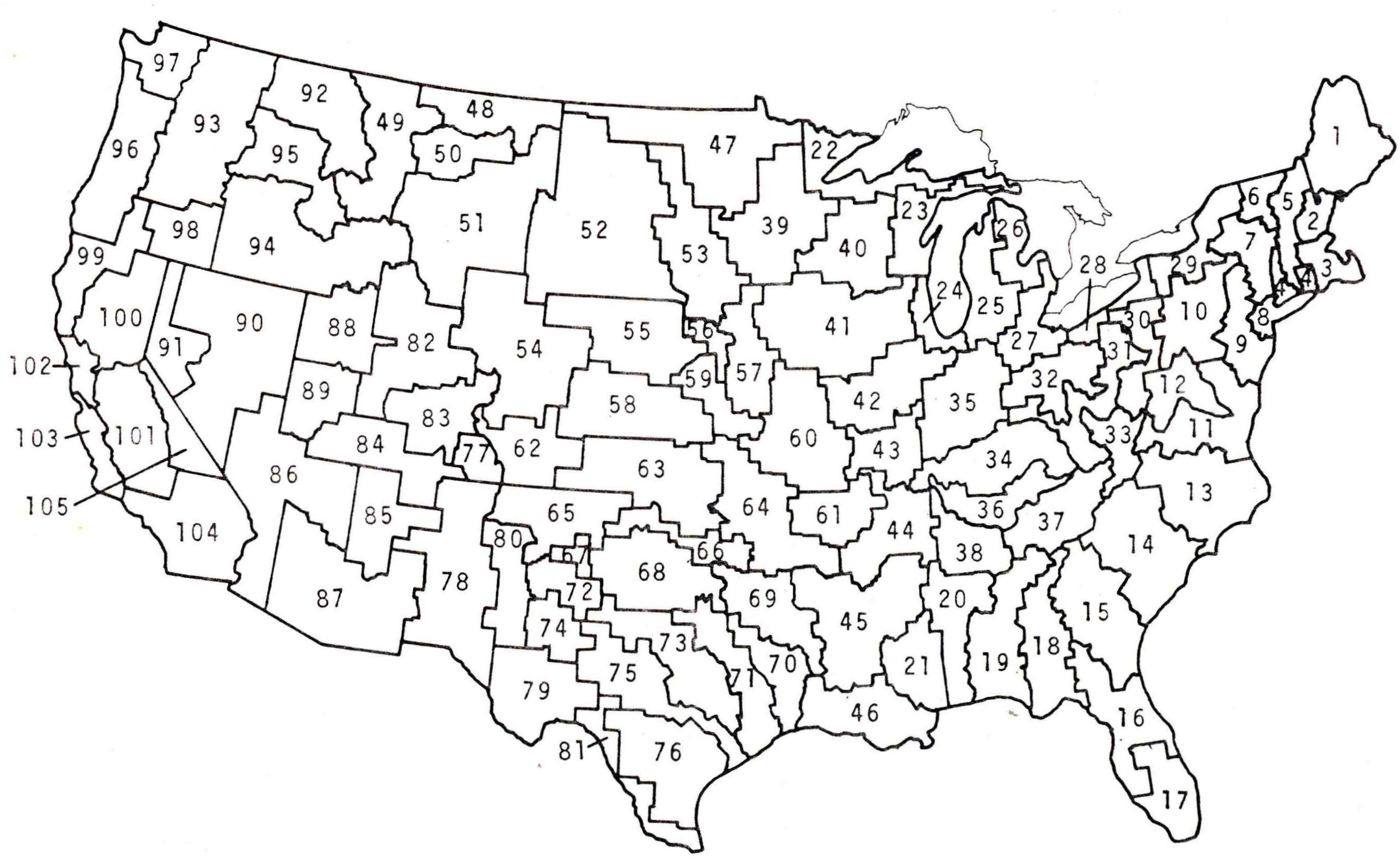

Figure 2. The 105 producing areas

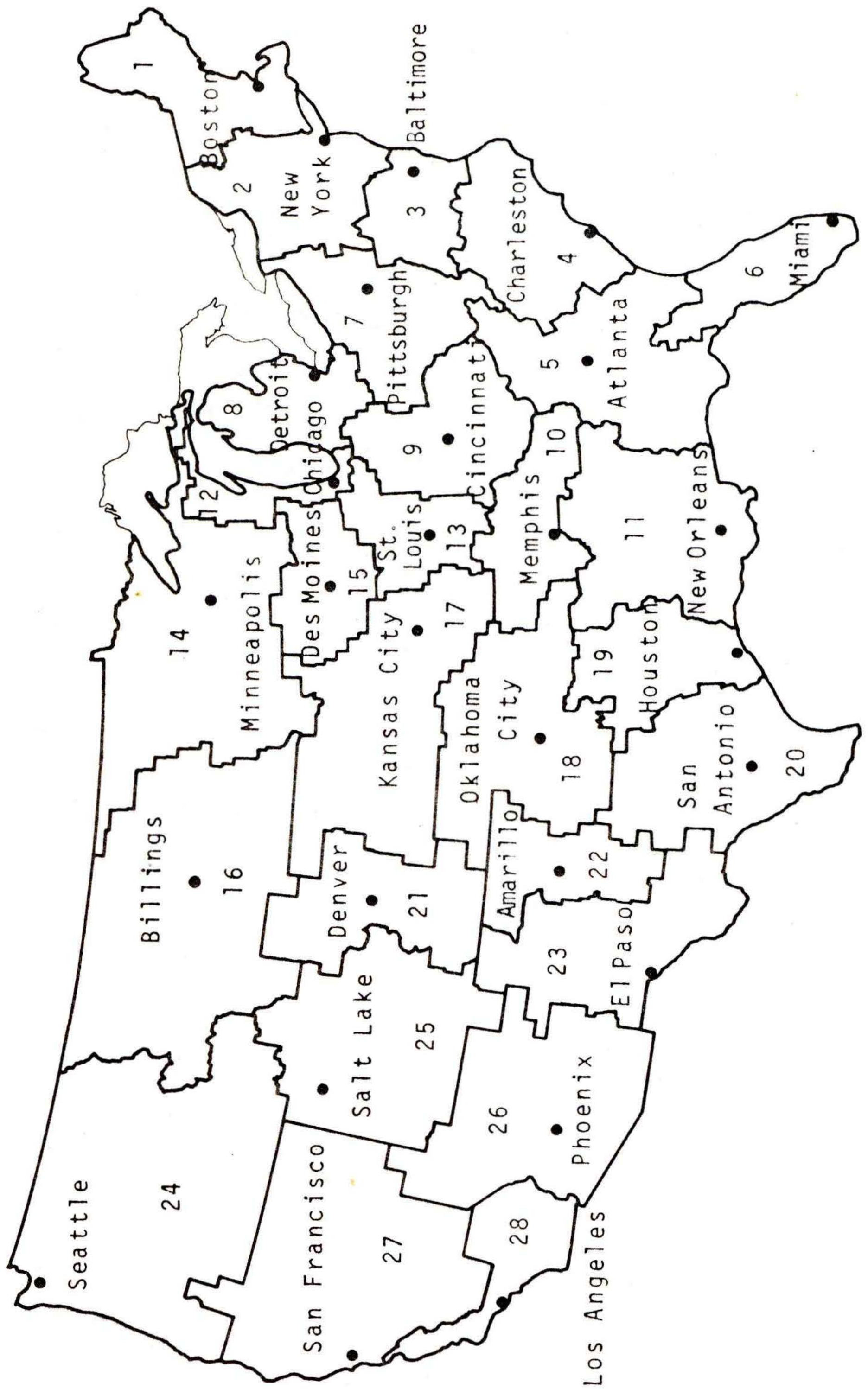

Figure 3. The 28 market regions

market region link the model's transportation sector. Transportation activities are defined to distribute commodities among these centers. The reporting regions shown in Figure 4 also are formed by aggregating contiguous producing areas.

Land Base

The model's land base was built from the Conservation Needs Inventory [2]. The Conservation Needs Inventory (CNI) reports acres of land by use and by agricultural capability class. Eight major capability classes are included in the CNI with classes II through VIII further subdivided to reflect the most severe hazard which prevents land from being available for unrestricted use. The subclasses reflect susceptibility to erosion, e, subsoil exposure, s, drainage problem, w, and climate conditions preventing normal crop production, c [2].

The county acreages are aggregated for dryland and irrigated uses to the 105 producing regions by the 29 capability class-subclasses. These 29 class-subclasses are then aggregated to give the five land quality classes shown in Table 1 to serve as the land base in the model.

Table 1. The five land quality classes used in the study and the land class and subclasses from which they are aggregated

Land Quality Class	Inventory Class-Subclasses	Acres
1	I, IIwa[a], IIIwa	64,596,000
2	rest of II, III, IV, all of V	213,385,000
3	IIIe	71,001,000
4	IVe	29,886,000
5	VI, VII, VIII	14,340,000

[a] wa means that drainage problems have been eliminated.

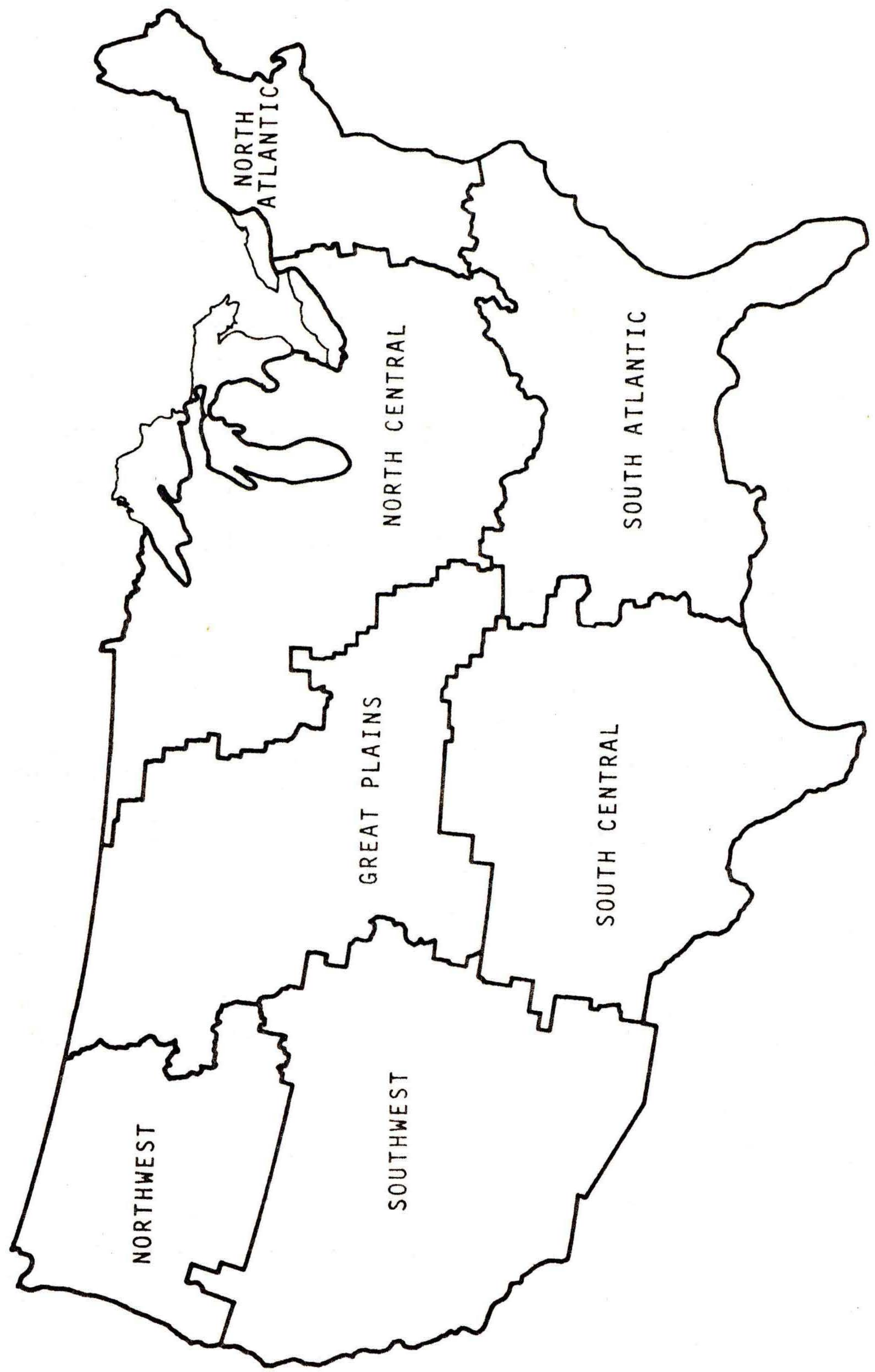

Figure 4. The 7 reporting regions

Additional information concerning the development of the land base, including adjustments to update the National Inventory data, can be found in Meister and Nicol [3] and Vocke, et al. [5].

Crop Production Sector

The endogenous crop production sector is defined on the land base of each producing region and includes alternative production activities for grain sorghum, sorghum silage, barley, corn, corn silage, cotton, legume and nonlegume hay, oats, soybeans, sugar beets, and wheat on each of the different land classes. Other crops enter the model on an exogenous basis. Unique activities are defined for each of the five land quality classes in each producing area and specify alternative rotations, tillage, and conservation practices for each crop and irrigated or dry-land farming. Each combination of these different components represents a crop management system or activity. Using the nitrogen, land, and water resources defined in the model, each system or activity produces commodities needed for livestock and consumer demands.

The procedure used to generate coefficients for crop rotations allows for interrelationships among crops. For example, following legume crops, nitrogen can be carried over to subsequent crops. Each rotation can be combined with any one of four conservation practices: straight row cropping, contouring, strip cropping, or terracing. Conservation practices are defined on the land quality classes according to recommendations given in the SCS Questionnaire [3]. A crop management system is completed by adding one of three tillage practices: conventional tillage with residue removed, conventional tillage with residue left, or reduced tillage. When they are adjusted to account for differences in production cost, fertilizer requirements, crop yields, water needs, and susceptibility to soil erosion by producing region, these crop management systems then become activities in the crop production sector. Further details can be found in Meister and Nicol [3]. Nitrogen is available to crops either from legumes, chemical fertilizers, or livestock manure.

Livestock

The livestock sector includes dairy, hogs, beef cows, beef feeding, broilers, turkeys, eggs, sheep and lambs, and a general category for other animals such as horses, mules, ducks, geese, and zoo animals. Separate livestock production activities are defined only for the endogenous livestock enterprises: hogs, beef cow, beef feeding, and dairying. Production coefficients for feed requirements and manure production are estimated for all categories, but cost data are needed only for the endogenous livestock.

Livestock rations are formulated within the model to allow endogenous substitution between grains, between roughages and grains, and between roughages. Hence, the model selects least-cost rations for the livestock in each region. The model also determines the type and amount of livestock to be produced in each region and the amount of grain transported to it. The nitrogen in the manure produced by livestock is transferred to the crop production sector where it is utilized as a fertilizer. Detailed discussion of the developemnt of these activities,

including specification of the alternative rations and the nutrient value of the animal manure can be found in Meister and Nicol [3].

Water Sector

The water sector of the model defines water availability in the western United States in producing areas 48 to 105. It also defines activities for the transfer of water between producing regions. Additional information about the water supplies and the transfer activities can be found elsewhere in Colette [1].

Transportation

The transportation routes, defined between all contiguous market regions, are measured by the distance between the metropolitan centers in each market region. Some heavily used long-haul routes between non-contiguous regions are defined if they reduce mileage by 10 percent over accumulated short-travel routes. Two activities are defined for each commodity over each route, one for shipment in each direction [3].

Time Horizon

Evaluation of policy impact alternatives within the limitations of the model requires that a sufficient time horizon be specified to allow for the implied adjustments to materialize. In this report, 1985 was selected as the year of projection. Alternatives defined in the model are designed to be consistent with projected and expected production alternatives available and demands prevailing in 1985.

Commodity Demands

The commodity demands in the model are either exogenous or endogenous. The endogenous commodity demands are the feed requirements of the endogenous livestock: hogs, beef cows, beef feeding, and dairying which can use many alternative rations. The exogenous commodity demands include the feed requirements of the exogenous livestock, projected domestic demands by consumers and industry, and export projections (Table 2). Outcomes would, of course, vary some for different export levels.

Table 2. Projected net export demands by commodity, U.S. totals (1,000 units)

Commodity	Unit	Quantity
Corn	bu.	2,030,995
Sorghum	bu.	270,002
Barley	bu.	24,994
Oats	bu.	19,000
Wheat	bu.	1,218,162
Oilmeal	bu.	791,374
Cotton	bu.	4,208

III. BASE ALTERNATIVE

In the Base Alternative, feedlot cattle are finished on a high concentrate ration and marketed at an average liveweight of 1,050 pounds. The regional distribution of livestock in the Base Alternative (stock cows, beef feeding, dairy, and hogs) is determined simultaneously with crop production patterns to minimize the total cost of raising and transporting both crop and livestock products to the demand centers explained elsewhere.

Crop Production Patterns

Output of individual crops in the Base Alternative is allocated to areas having a comparative advantage in production of each (Table 3). For example, about 65 percent of the corn and sorghum is produced in the North Central region. Over 50 percent of the soybean production is concentrated in the North Central region. Together, the North Central and Great Plains regions produce more than 60 percent of the small grains.

The utilization of the available cropland in each region varies from a low of 93 percent in the Southwest region to a high of 98 percent in the North Atlantic region (Table 4). For the entire United States, 96 percent of the cropland base which is not cropped is either not highly productive for crops or the cost of transporting its output to the demand centers is too high (or a combination of the two).

Beef Production Patterns

The regional distribution of beef production in the Base Alternative is determined simultaneously with regional crop production patterns (Table 5). The availability of corn and sorghum grain is an important determinant of the location of beef feeding operations. A second factor influencing the location of beef feeding is the availability of feeders from stock cow herds. The location of stock cows is partly determined by the availability of low cost roughage such as pasture and crop aftermath.

Table 3. Regional production by crop group in each reporting region in the Base Alternative

Region	Crop Production (1,000 units)					
	Corn and Sorghum Grain	Barley, Oats and Wheat	Soybeans	Cotton	Legume and Nonlegume Hay	Corn and Sorghum Silage
	(bushels)			(bales)	(tons)	
North Atlantic	483,924	255,833	10,651		5,948	5,323
South Atlantic	187,400	152,421	922,319	8,495		1,133
North Central	6,085,055	745,033	1,827,302		13,742	6,091
South Central	1,150,268	261,488	311,919	751	20,159	166,064
Great Plains	1,064,375	925,326	390,040		36,695	85,769
Northwest	244,115	306,082			6,846	1,070
Southwest	69,763	144,652		1,768	22,162	21,811
United States	9,284,906	2,790,845	3,461,793	11,015	105,522	287,263

Table 4. Percentage of available cropland used for crops in each region of of the Base Alternative

Region	Percent Utilization	Region	Percent Utilization
North Atlantic	98	Great Plains	94
South Atlantic	96	Northwest	97
North Central	97	Southwest	93
South Central	97	United States	96

Because of large supplies of low cost roughage, more than 70 percent of the feeders are raised in the South Central and Great Plains regions. In addition, corn and sorghum grain production in these two regions is more than adequate to feed out the feeders raised in them. Thus, in the Base Alternative, feeders from other regions can be profitably shipped to the South Central and Great Plains regions for feeding. As a consequence, more than 70 percent of the beef feeding is concentrated in these two regions under the Base Alternative.

Feed Consumption by Livestock

Livestock feed consumption in the Base Alternative is shown in Table 6. Nearly 70 percent of the corn and more than 80 percent of the sorghum is fed to livestock while only 3 percent of wheat production is consumed by livestock. Nearly 50 percent of the oilmeal output of agriculture in the Base Alternative is used as a protein source for livestock.

Table 5. Regional distribution and levels of various beef cattle activities in the Base Alternative (1,000 units)

Region	Feeders from Beef Cows (head)	Feeders from Dairy Cows (head)	Net Export of Feeders[a] (head)	Feeders Fed Out (head)	Corn and Sorghum Produced (tons)	Corn and Sorghum Consumed by Fed Beef (tons)	Corn and Sorghum Consumed by all Livestock (tons)
North Atlantic		979		979	13,550	1,559	17,451
South Atlantic	1,925	1,013	1,185	1,754	5,247	1,970	19,420
North Central	2,768	1,136	281	3,624	170,381	5,914	75,658
South Central	16,051	418	-1,185	17,655	32,207	24,671	31,775
Great Plains	11,434	201	-281	11,916	29,802	13,652	16,375
Northwest	1,467	101		1,568	6,835	2,372	4,588
Southwest	4,365	331		4,696	1,953	6,489	15,278
United States	38,013	4,182		42,195	259,977	56,627	180,545

[a]A positive value indicates feeder exports from the region. A negative value has the opposite meaning.

Table 6. Percentage of total U.S. output of crops consumed by livestock in the Base Alternative

Livestock	Crops				
	Corn Grain	Sorghum Grain	Wheat	Barley and Oats	Oilmeal
Endogenous livestock (hogs, fed beef, dairy, and stock cows)	53	69	1	46	25
Exogenous livestock	14	13	2	16	18
Total endogenous and exogenous livestock	67	82	3	62	43

Agricultural Inputs

The use of inputs in the Base Alternative varies considerably by crop (Table 7). Corn and sorghum grain production uses 27 percent of the cropland but requires almost 60 percent of all the nitrogen fertilizer. Pesticide usage also varies among crops and is concentrated primarily on corn and soybeans.

Soil Erosion

Because of differences in soil type and climate, the land in some of the reporting regions is more susceptible to erosion than others. These differences and the selection of crops, cropping practices, and conservation practices in each region determine the rate of soil erosion. Under the Base Alternative, the model selects the least-cost method of producing the needed crops without regard for any adverse effects on soil conservation and environmental quality. The average national rate of soil loss in the Base Alternative, including land in which erosion is nonexistent or not a hazard, is 5.51 tons per acre annually. Some land is level and does not have an erosion incidence. The rates for individual regions range from a low of less than 2 tons in the Southwest region to over 12 tons per year in the South Atlantic region (Table 8).

Table 7. Percentage of total inputs used in the Base Alternative by commodity group

Commodity Group	Percentage[a] Acres	Nitrogen Fertilizer	Pesticide Expenditures
Corn and sorghum grain	27	59	46
Barley, oats, and wheat	20	19	8
Cotton	2	4	8
Soybeans	28	4	33
Legume and nonlegume hay	8	5	2
Corn and sorghum silage	5	8	1

[a]Percentages do not sum to 100 because the table does not include all crops in the model.

Table 8. Average annual rates of soil erosion per acre for each major reporting region in the Base Alternative

Region	Soil Loss per Acre	Region	Soil Loss per Acre
	(tons)		(tons)
North Atlantic	5.35	Great Plains	4.36
South Atlantic	12.19	Northwest	3.40
North Central	4.77	Southwest	1.31
South Central	5.36	United States	5.51

Results from other alternatives are now compared with those from the Base Alternatives. The results from the Base Alternatives are not statistical predictions to 1985 but represent solutions which optimize relative to the restraints of the model and its objective function.

IV. ALTERNATIVE FINISHING WEIGHTS

As beef cattle are fed to heavier weights, feed efficiency declines. When fattening is carried to an extreme at heavier weights, excess fat on the animal's bodies must be trimmed from the carcass. To the extent this trimmed fat cannot be put to a valuable use, it represents a misallocation of the agricultural resources going into its deposition.

This study varies the finishing weight of fed beef cattle to analyze the interaction between resource use in American agriculture and the marketing weight of fed cattle. Besides changing total feed requirements for the fed beef industry, varying the market weight of the cattle implies an adjustment in stock cow numbers. When animals are marketed at a lighter than conventional weight, the number of animals slaughtered must increase to meet a given consumer demand for fed beef. This expansion of beef cow herds increases the resources needed to maintain the stock cow sector of the beef industry. Specifically, it also requires considerably more forage. Conversely, with heavier than conventional finishing weights, fewer cows are needed and hence, less resources are required for their maintenance.

Changes in the total feed requirements of both the stock cow herds and feeders as finishing weights are varied creates economic forces for interregional adjustments in the location of both feeder calf production and fattening. These changes also can have direct interregional impacts on the production of forages and thus indirectly on the production of feed grains. The nation's crop production thus should consist of a greater proportion of forages and a smaller proportion of feed grains. Various producing regions will be affected differently because they have different comparative advantages in producing these two major sets of crops. We analyze these effects to see if they are economically significant.

The Alternatives

Three alternative beef feeding sectors are defined using the data displayed in Table 9. The model alternative using a finishing weight of

950 pounds liveweight is referred to as the 950 Alternative. Similarly, the model alternative with a finishing weight of 1,150 pounds liveweight is called the 1150 Alternative. The Base Alternative uses a conventional finishing weight of 1,050 liveweight. The Base Alternative is used as the point of reference in interpreting the results of the alternative models.

Table 9. Meat yield and feed conversion rates used in the analysis of market weight of fed beef animals[a]

Market Weight[b]	Percent Marketable Meat[c]	Feed per Pound of Gain[d]
950	.308	7.73
1050	.306	8.41
1150	.304	9.19

[a]These data were provided by Dr. Gene Rouse of the Iowa State University Department of Animal Science.

[b]The listed market weight values are weighted averages of steers and heifers, where the weights are the relative proportions of each.

[c]Marketable meat is defined to be the boneless, closely trimmed, retail cuts from the round, loin, rib, and chuck. The percentage values account for both dressing percent and cutability.

[d]These values are average feed efficiency values over the whole feeding period from 450 pounds to (a) 950, (b) 1050, (c) 1150 pounds, respectively. Feed is in pounds of dry matter of all materials fed.

Feed Consumption in the 950 Alternative
and the Base Alternative

Marketing fed beef at an average finishing weight of 950 pounds liveweight in the 950 Alternative as compared to an average finishing weight of 1,050 pounds liveweight in the Base Alternative greatly increases feed efficiency. Total feed consumption by the U.S. cattle feeding industry declines 17 percent in the 950 Alternative as compared to the Base Alternative (Table 10).

Table 10. Percentage change in total consumption within the beef cattle industry in the 950 Alternative compared to the Base Alternative

Method of Measuring	Percent Change in Feed Consumption[a]		
	Beef Feeding Sector	Stock Cow Sector	Beef Cattle Industry
Consumption measured in net energy terms	-17	9	-1
Consumption measured in dollar terms	-17	10	1

[a]Positive values indicate a percentage increase in the 950 Alternative relative to the Base Alternative. Negative values have the opposite meaning.

Analysis of the entire beef cattle industry, including beef feeding and stock cows, however, reveals the impact of an expanded number of beef cows. To meet the meat demands incorporated in the model and to offset the lighter market weights, the 950 Alternative requires 9 percent more stock cows to produce calves than the Base Alternative. This larger population of stock cows consumes 9 percent more feed (Table 10)

with the additional forage coming out of the cropland base. When this increased consumption is balanced against savings in the feedlot, the result is a 1 percent savings of feed consumed in the 950 Alternative as compared to the Base Alternative.

When the feeds consumed by the cattle are priced according to their supply prices to give consumption in dollar terms, the results of the analysis are only slightly altered (Table 10).[1] Increased feed efficiency in the 950 Alternative lowers the total value of the feeds consumed by the beef feeding sector of the cattle industry. The total value of the various feeds consumed by the whole beef cattle industry is 1 percent higher in the 950 Alternative than the Base Alternative (Table 10). This slight increase, as compared to the decline when feed consumption is measured in net energy terms, results because the 950 Alternative raises the demand for pasture and roughages. The result of the higher demand is higher supply prices for both pasture and roughages. The higher supply prices slightly increase the cost of feeding the stock cows (Table 10). The result for the beef cattle industry is a higher total feed bill in the 950 Alternative as compared to the Base Alternative.

Feed Consumption in the 1150 Alternative
and the Base Alternative

Marketing fed beef at an average finishing weight of 1,150 pounds liveweight in the 1150 Alternative as compared to an average finishing

[1]The supply prices generated in the model were used in computing the dollar value of feed consumed. The supply price for that crop is that price required to produce a level of output sufficient to meet the demands of the model. The model selects the production cost of the highest cost producing area contributing towards total supply as the supply price.

weight of 1,050 pounds liveweight in the Base Alternative decreases feed efficiency. Total feed consumption by the beef feeding sector increases 18 percent (Table 11). Because fewer animals need to be slaughtered with the higher average finishing weight, the number of stock cows in the 1150 Alternative is 8 percent less than in the Base Alternative. Hence, total feed consumption by stock cows declines 7 percent. The result in the 1150 Alternative is a 2 percent increase in total feed consumption for the beef cattle industry.

With feeds consumed by the cattle priced according to their supply or shadow prices, the total value of feed consumption by the beef cattle industry increases 4 percent in the 1150 Alternative compared to the Base Alternative (Table 11). This 4 percent increase is the result of a 22 percent increase in the value for feed for cattle carried to the heavier finishing weight and a 5 percent decline in the value of the feeds consumed by stock cows. The explanation for the difference between an analysis of feed consumption on an energy basis as compared to a dollar basis is due to changing supply prices. Increasing the feed requirements of the beef feeding sector in the 1150 Alternative slightly raises the supply prices for the feeds. These higher supply prices exaggerate the impact of feeding cattle to the heavier finishing weight. The total cost of maintaining stock cows does not decline by the same proportion as cow numbers are reduced since the supply prices for pasture and roughages do not decline significantly.

Table 11. Percentage change in total consumption within the beef cattle industry in the 1150 Alternative compared to the Base Alternative

Method of Measuring	Percent Change in Feed Consumption[a]		
	Beef Feeding Sector	Stock Cow Sector	Beef Cattle Sector
Consumption measured in net energy terms	18	-7	2
Consumption measured in dollar terms	22	-5	4

[a]Positive values indicate a percentage increase in the 1150 Alternative relative to the Base Alternative. Negative values have the opposite meaning.

Location of Beef Feeding and Stock Cows in the 950 Alternative

The lighter finishing weight in the 950 Alternative has a significant interregional impact in the location of beef production. To compensate for lighter slaughter weights more feeders and more stock cows are needed. As shown in Table 12, stock cow numbers increase 17 percent in the South Central region in the 950 Alternative as compared to the Base Alternative. Also, the number of feeders finished in this region increases by 15 percent. Because of the increased efficiency of beef feeding in the 950 Alternative, the total quantity of corn and sorghum consumed by fed cattle declines by at least 20 percent in all regions except the South Central region. The increase in the number of fed cattle marketed from the South Central region in the 950 Alternative accounts for the relatively small decline in total consumption of corn and sorghum grain as compared to the Base Alternative.

Table 12. Percentage changes in the level of various beef cattle industry-related activities for the 950 Alternative compared to the Base Alternative[a]

Region	Feeders From Beef Cows	Feeders From Dairy Cows	Feeders Fed Out	Corn and Sorghum Produced	Corn and Sorghum Consumed by Fed Beef	Corn and Sorghum Consumed by All Livestock
North Atlantic	0	0	0	1	-23	-2
South Atlantic	3	0	3	0	-21	-2
North Central	3	0	2	-4	-22	-2
South Central	17	0	15	-8	-9	-7
Great Plains	2	0	2	-3	-23	-20
Northwest	4	0	4	-4	-20	-10
Southwest	6	0	6	-5	-24	-10
United States	9	0	8	-4	-17	-5

[a]Positive values indicate an increase in the level of activity in the 950 Alternative compared to the Base Alternative. Negative values have the opposite meaning.

Location of Beef Feeding and Stock Cows in the 1150 Alternative

As the finishing weight increases, the beef cattle industry in the Great Plains region is greatly disadvantaged in the 1150 Alternative compared to the Base Alternative. The number of stock cows and the number of feeders fed in the Great Plains region falls 17 and 16 percent, respectively (Table 13). The substantial decline of beef feeding in the Great Plains region is reflected in the relatively small increase in the consumption of corn and sorghum by fed cattle compared to the other regions in the model. Feed consumption increases because of reduced efficiency of feeding the cattle to the heavier finishing weight in the 1150 Alternative.

Parts of the Great Plains generally serve as "surplus" or "shifting" regions: If no special burden is placed on grain demand these areas of the Great Plains are not needed for grain can be used for forage. If grain demands are strong, these "shifting" areas move back into grain production in solution of interregional programming models. Hence, as more grain is used in the 1150 Alternative the "shifting" areas of the Great Plains move into grains.

V. HIGH SILAGE RATIONS FOR FED BEEF

If high silage rations were used more widely in beef feeding, some land could be shifted to producing food crops for humans. Silage produces more harvested output of feed nutrients per acre than does corn or sorghum grain.

In the Base Alternative beef feeding is limited to high concentrate rations. The alternative to be analyzed now includes high silage rations

Table 13. Percentage changes in the level of various beef cattle industry-related activities for the 1150 Alternative compared to the Base Alternative[a]

Region	Feeders From Beef Cows	Feeders From Dairy Cows	Feeders Fed Out	Corn and Sorghum Produced	Corn and Sorghum Consumed by Fed Beef	Corn and Sorghum Consumed by All Livestock
North Atlantic	0	0	-25	3	-14	-1
South Atlantic	-3	0	-4	0	23	2
North Central	-5	0	3	0	29	2
South Central	-4	0	-4	1	20	15
Great Plains	-17	0	-16	29	2	1
Northwest	0	0	0	-3	27	14
Southwest	-3	0	-3	-18	24	10
United States	-8	0	-7	3	16	5

[a]Positive values indicate an increase in the level of activity in the 1150 Alternative compared to the Base Alternative. Negative values have the opposite meaning.

for fed cattle. This alternative will be refered to as the Silage Alternative.

Land Use and Supply Price Changes

Substituting silage for concentrates has several important impacts (Table 14). With beef fed a high silage ration, 9.4 million acres are freed in the Silage Alternative compared to the Base Alternative. In addition to using fewer acres, extensive feeding of silage substantially lowers the supply prices of other crops (Table 15). The supply price for a particular commodity is determined, in meeting a given demand, by the per unit cost of production in the most expensive region where that crop is produced. Supply prices decrease under the Silage Alternative because fewer acres are needed to meet all the domestic and foreign demands as silage is substituted for concentrates in the fed beef ration. Because the model selects the least-cost organization of U.S. agriculture, those regions with less productive land, i.e., with the highest per unit production costs, are the first to be taken out of crop production. The result is lower supply prices for all commodities.

Table 14. Comparison of the percentage of net energy represented by each commodity group in the total net energy consumption in the Silage Alternative and the Base Alternative

Alternative	Corn and Sorghum Grain	Barley, Oats and Wheat	Oilmeal	Legume and Non-Legume Hay	Corn and Sorghum Silage
Base	67	8	3	14	8
Silage	3	6	6	4	80

Table 15. Percentage decrease in average supply prices for crops in the Silage Alternative as compared to the Base Alternative

Crop	Percentage Decrease	Crop	Percentage Decrease
Corn	10	Oilmeal	7
Sorghum	14	Legume hay	7
Barley	12	Silage	3
Oats	4	Cotton	0
Wheat	12		

The lower supply prices reduce feed costs for fed beef and the other classes of livestock as well. Total feed expenses for beef feeding declines 22 percent under the Silage Alternative in comparison with the Base Alternative. For dairying and hogs the decline is 7 and 9 percent, respectively, in the Silage Alternative compared to the Base Alternative.

Interregional Adjustments

The high silage ration favors certain interregional adjustments in agriculture relative to the Base Alternative (Table 16). Regions possessing a comparative advantage in beef cattle production can expand production at the expense of other regions because of increased production per acre.

The concentration of stock cows increases in the South Central region in the Silage Alternative compared to the Base Alternative. The concentration of cattle feeding in the South Central region also

Table 16. Percentage changes in the level of various beef cattle industry-related activities in the Silage Alternative as compared to the Base Alternative[a]

Region	Feeders Produced from Beef Cows	Feeders Produced from Dairy Cows	Feeders Fed Out	Corn and Sorghum Grain Produced	Corn and Sorghum Grain Consumed by Fed Beef	Corn and Sorghum Consumed by All Livestock
North Atlantic	0	0	0	-8	-95	-8
South Atlantic	0	0	67	-52	-88	-9
North Central	-8	0	-22	-13	-96	-16
South Central	10	0	2	-47	-95	-73
Great Plains	-8	0	-3	-31	-96	-39
Northwest	-13	0	-12	-17	-96	-50
Southwest	-4	0	-4	-56	-95	-42

[a]Positive values indicate a percentage increase in the level of activity in the Silage Alternative compared to the Base Alternative. Negative values have the opposite meaning.

increases following the increased availability of feed in the region when the high silage ration is used. The South Atlantic region also increases the size of its fed beef industry under the high silage rations as compared to the Base Alternative.

VI. SOIL CONSERVATION

The Base Alternative was formulated so that restrictions were not placed on the selection of cropping practices in relation to their effect on soil erosion. The Soil Conservation Alternative is formulated so that soil erosion rates will be less than the soil loss tolerance rates set by soil scientists as necessary to maintain the future productivity of land [6]. To develop the Soil Conservation Alternative, each crop management system in the Base Alternative is checked and only those systems whose erosion rate is less than the soil loss tolerance levels are allowed in the Soil Conservation Alternative. Thereafter, the model can select the rotation, tillage, method and conservation practices which are most efficient in meeting the soil loss restriction for each land class in each producing region.

A crop management system is defined as a unique combination of a rotation with a specific tillage and conservation practice on irrigated land or dryland. The crop rotations used in each production area are determined by combining the rotations recommended by the Soil Conservation Service [3]. Four conservation practices (straight row cultivation, contouring, strip cropping, and terracing) are allowed for each crop in

each producing area. Each conservation practice also can be used with three types of tillage practices: conventional tillage with residue removed, conventional tillage with residue left, and reduced tillage. The various combinations of crops, conservation practices, and tillage methods can be used for each land class in each producing area. Each rotation combined with a specific conservation practice and tillage practice defines a unique crop management system, programming activity, or variable. And, for each crop management system there is a specific soil erosion coefficient defined for each crop and land class in a particular region.

Soil erosion is influenced by many factors, such as land quality, slope gradient, length of slope, and rainfall. Erosion can be reduced by use of various tillage and conservation practices. Contouring reduces runoff by holding back water and allowing more time for penetration. Strip cropping is an effective means of spreading water. Terracing also reduces the velocity of water and disperses it. Reduced tillage represents the adoption of the most likely method of tillage in the area consistent with reduction in direct exposure of the soil surface to wind or running water.

Gross soil loss represents the number of tons of soil leaving the field over a one-year period. The soil loss is determined using the Universal Soil Loss Equation developed by Wischmeier and Smith [6]. The soil loss equation is expressed as:

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

where: A is the average annual per acre soil loss;

R is the rainfall erosive factor based on the local area;

K is the soil erodibility factor for the specific soil determined from its erosion under continuous fallow in a 9 percent slope, 92.6 feet long;

L is the slope length factor relative to 72.6 feet;

S is the slope gradient factor relative to a 9 percent slope;

C is the crop management factor which related to a particular crop rotation and tillage practice; and

P is the erosion control practice factor which relates to the conservation practice.

For producing areas in mountain valleys and on the West Coast, the data required for the soil loss equation have not been completely developed. An alternate procedure was used to estimate the soil loss from these lands. Soil Conservation Service (SCS) personnel estimated the tons of soil loss associated with each crop management systems on each of the land classes and subclasses defined in the SCS data area. For the purpose of the model, these estimates were treated as if they were developed from the soil loss equation [3]. Each activity representing production of irrigated crops is considered to have a soil loss level similar to the corresponding dry-land activity for similar land classes.

Changes in Soil Erosion Rates

Shifting crop production patterns and changing soil management practices to conform with the Soil Conservation Alternative result in substantial decreases in regional soil erosion rates compared to the Base Alternative (Table 17). The South Atlantic region is greatly affected by the soil conservation requirement due to normally high erosion rates

as a result of greater rainfall, more sloping land, and a lack of winter freezing over much of the region.

Table 17. Comparison of average rates of soil erosion by reporting region in the Soil Conservation Alternative Compared to the Base Alternative

Region	Soil Loss Per Acre (Tons)	
	Base Alternative	Soil Conservation Alternative
North Atlantic	5.35	2.01
South Atlantic	12.19	3.05
North Central	4.77	2.46
South Central	5.36	2.26
Great Plains	4.36	1.83
Northwest	3.40	1.38
Southwest	1.31	.88
United States	5.51	2.18

Changes in Crop Production Practices

Conservation and tillage practices change as agriculture is limited to those cropping options which restrict acre soil losses to the soil loss tolerance levels (Table 18). As might be expected, straight row farming declines because of the erosion hazard associated with the practice. The number of acres protected by contouring, terracing, and reduced tillage increase in the Soil Conservation Alternative compared to the Base Alternative. Acres farmed under strip cropping decrease in net as some land subject to severe erosion problems is shifted from strip cropping to terracing. Reduced tillage practices are substituted for conventional residue management practices in the Soil Conservation Alternative as compared to the Base Alternative.

Table 18. Acres planted under the various conservation and tillage practices in the Base Alternative and the Soil Conservation Alternative (1,000 acres)

Practice	Base Alternative	Soil Conservation Alternative
Conservation practices		
Straight row	114,473	89,558
Contour	167,037	179,118
Strip cropped	32,296	12,744
Terraced	41,154	77,261
Tillage practices		
Conventional tillage	225,017	176,799
Reduced tillage	129,943	181,882

Grown alone, crops such as corn, sorghum, cotton, and soybeans do not adequately protect the soil from erosion. These crops can, however, be grown in rotation with small grains, grass and hay crops which do protect the soil. Or, they can be raised using soil conservation practices such as contouring and terracing. Regardless of the method employed, the effect is to raise the relative cost of production for a crop like corn silage in the Soil Conservation Alternative compared to the Base Alternative. The rise in relative cost makes it profitable to substitute small grains and hay for silage in the livestock rations.[1] The increased use of legume

[1]The only endogenous changes for beef allowed in the Soil Conservation Alternative are changes in the ration and changes in the location of production. Thus the number of beef cattle and the amount of beef produced in this alternative is the same as in the Base Alternative. In general, we would expect that systems which encourage greater forage production would increase production and lower the supply price of beef. These flexibilities were not built into the model (since a fixed set of point demands were used for all commodities). These limitations of the model will eventually be eliminated as demand functions are incorporated in a more complex quadratic programming model.

hay by livestock reduces the need for soybeans as a protein source in the Soil Conservation Alternative.

Interregional changes in cropping patterns occur when it is profitable to shift crop production to a region less susceptible to erosion in the Soil Conservation Alternative, rather than use a more costly practice like terracing so the crop can continue to be produced in the same region as in the Base Alternative. For example, erosion problems associated with row cropping in the South Atlantic region cause, from a national standpoint, a profitable shift of cotton production to the South Central and Southwest regions of the United States (Table 19) in the Soil Conservation Alternative compared to the Base Alternative. Similarly, soybean production shifts quite dramatically from the South Atlantic region to other regions less susceptible to erosion, primarily to the Great Plains region. Soybeans is an erosive crop in any region when grown on hilly land. It is an especially erosive crop in the South Atlantic region where the winters are open and rainfall is high (3). The smaller erosion problems in the Great Plains greatly favors the production of corn and sorghum as well as soybeans under the Soil Conservation Alternative.

Resource use in agriculture is altered under the requirements of the requirements of the soil conservation policy analyzed in this study. For example in the Base Alternative, corn and sorghum are produced primarily in continuous crop rotations on the most productive land. In the Soil Conservation Alternative the use of these continuous crop rotations declines and corn and sorghum are raised in rotation with small grains

Table 19. Changes in production by commodity group in each reporting region between the Soil Conservation Alternative and the Base Alternative

Region	Production (1,000 units)[a]				
	Corn and Sorghum Grain	Barley, Oats, and Wheat	Soybeans	Cotton	Legume and Non-legume hay
		(bushels)		(bales)	(tons)
North Atlantic	-13,199	-167,184	35,942	0	6,029
South Atlantic	306,837	326,766	-452,958	-7,026	11,461
North Central	-466,668	39,491	9,251	0	12,799
South Central	-452,747	107,876	4,686	4,073	28,260
Great Plains	913,227	-285,096	176,113	0	-4,331
Northwest	-237,874	90,318	0	0	9,806
Southwest	-61,907	-30,106	0	2,953	8,144

[a]Positive values indicate an increase in production of the crop in the Soil Conservation Alternative compared to the Base Alternative. Negative values have the opposite meaning.

and hay. As the concentration of corn and sorghum production on the more productive land declines, average yields fall. The decline in yields is not due to lower productivity of the more productive land as more forage is grown in rotation on it. The average national yield declines as more feed grains are grown over a larger area of less productive lands. Hence, to compensate for reduced yields as domestic and export demands are met, additional acres and more nitrogen fertilizer and pesticides are needed to meet livestock and consumer demands for corn (Table 20).

Table 20. Percentage changes of U.S. production and factor use by commodity group in the Soil Conservation Alternative compared to the Base Alternative

Commodity Group	Percentage Changes			
	Production	Acres	Nitrogen Fertilizer	Pesticide Expenditures
Corn and sorghum grain	0	10	25	23
Barley, oats, and wheat	3	-9	15	128
Soybeans	-7	-5	14	97
Cotton	0	37	84	35
Legume and nonlegume hay	68	83	120	281
Corn and sorghum silage	-74	-68	-67	-34

In the Soil Conservation Alternative small grains (barley, oats and wheat) are grown on a greater proportion of more productive land than in the Base Alternative. The result is higher yields in the Soil Conservation Alternative. Small grains use less land and more nitrogen and pesticides because of regional shifts of production to regions using higher application rates for fertilizer and pesticides (Table 20).

South Central region

Stock cow herds decline in the South Central region in the Soil Conservation Alternative compared to the Base Alternative as cows are shifted to regions such as the North Central and South Atlantic regions (Table 21). The beef feeding industry expands, although corn and sorghum production declines in the South Central region. It is profitable to import both feeders and feed grains from other regions into the South Central region in the Soil Conservation Alternative to complement forage production.

Great Plains region

Although production of corn and sorghum increases, cattle feeding in the Great Plains declines in the Soil Conservation Alternative as compared to the Base Alternative (Table 21). The situation for the Great Plains in the Soil Conservation Alternative is greatly influenced by the feed requirements of 16.9 million hogs shifted from the North Central region to this region. The whole cattle industry is at a comparative disadvantage and stock cow numbers decline by 3.8 million head in the Soil Conservation Alternative compared to the Base Alternative.

Table 21. Changes in the level of various beef cattle industry-related activities between the Soil Conservation Alternative and the Base Alternative (1,000 units)[a]

Region	Feeders From Beef Cows	Feeders From Dairy Cows	Feeders Fed Out	Corn and Sorghum Produced	Corn and Sorghum Consumed by Fed Beef	Corn and Sorghum Consumed by All Livestock
	(head)			(tons)		
North Atlantic	928	-194	-101	-370	-57	-2,849
South Atlantic	1,555	248	-1,754	8,592	-1,970	813
North Central	1,993	-182	-3,624	-13,066	-5,914	-19,007
South Central	-2,867	645	1,051	-12,676	4,396	7,980
Great Plains	-3,881	-95	-629	25,571	2,142	7,010
Northwest	1,359	0	1,359	-6,659	2,054	2,055
Southwest	506	-197	3,520	-1,733	6,146	3,654

[a]Positive values indicate an increase in the level of activity in the Soil Conservation Alternative compared to the Base Alternative. Negative values have the opposite meaning.

cattle will be finished on a high concentrate ration and marketed at an average weight of 1,050 pounds; (2) a 950 Alternative where it is assumed that beef cattle will be finished on a high concentrate ration and marketed at an average weight of 950 pounds; (3) a 1150 Alternative where it is assumed that beef cattle will be finished on a high concentrate ration and marketed at an average weight of 1,150 pounds; (4) the Silage Alternative where it is assumed that beef cattle will be finished on a high silage ration and marketed at an average weight of 1,050 pounds; and (5) the Soil Conservation Alternative where it is assumed that beef cattle will be finished on a high concentrate ration and marketed at an average weight of 1,050 pounds. In the latter alternative, agriculture must use cropping practices that limit soil erosion to levels that allow maintaining land productivity over time.

Alternative Finishing Weights

This study considers three market weights (950, 1,050 and 1,150 pounds) for fed beef to analyze the impact of this changing feed efficiency on the beef industry. Varying the finishing weight of cattle also implies an adjustment in stock cow herds. For example, with reduced finishing weights, more cows are needed to supply the greater number of fat cattle to be slaughtered if given consumer demands are to be met.

950 Alternative compared to the Base Alternative

The beef cattle in the 950 Alternative and the Base Alternative of the model are finished in the feedlot at an average of 950 and 1,050 pounds liveweight, respectively. The improved feed efficiency in the 950 Alternative lowers feed costs for the beef feeding industry by 17 percent compared to the Base Alternative. Feed costs for the entire beef cattle industry, however, increase by 1 percent in the 950 Alternative compared to the Base Alternative. The savings in feed during the feeding phase as cattle are marketed at a lighter weight is more than offset by the higher feed requirements of the larger number of beef cows.

Beef cattle numbers (beef cows and fed beef) increase in most regions of the United States in the 950 Alternative compared to the Base Alternative to compensate for the lighter market weight. The South Central region in particular greatly increases beef production.

1150 Alternative compared to the Base Alternative

In the 1150 Alternative, beef cattle are finished in the feedlot at an average of 1,150 pounds liveweight. Reduced feed efficiency under the 1150 Alternative increases feed costs for the beef feeding industry by 22 percent compared to the Base Alternative. However, feed costs for the entire beef cattle industry increase by only 4 percent in the 1150 Alternative compared to the Base Alternative. The lowered efficiency of feeding cattle to the higher weight is not entirely offset by the savings due to a smaller number of beef cows.

Beef cattle numbers decline in most regions of the United States in the 1150 Alternative compared to the Base Alternative because of the heavier finishing weight of the market cattle. Beef cattle numbers decline most in the Great Plains region.

High Silage Rations for Fed Beef

Using a high silage ration in fed beef cattle feeding frees 9.4 million acres for growing other crops in the Silage Alternative compared to the Base Alternative. Fewer acres of cropland are required to produce the feed required for cattle feeding. Extensive use of silage for beef feeding also lowers the supply prices for the other crops in the Silage Alternative compared to the Base Alternative.

The switch to the high silage rations for beef feeding in the Silage Alternative increases the concentration of the U.S. beef cattle industry in those areas possessing a comparative advantage for beef production because of the higher silage production per acre. In particular, the beef cattle industry in the South Central region expands substantially in the Silage Alternative compared to the Base Alternative.

Soil Conservation

The Base Alternative was formulated so that no restrictions were placed on the selection of cropping practices, regardless of their effect on soil erosion. The Soil Conservation Alternative is formulated

so that soil erosion rates will be reduced to levels allowing maintenance of land productivity over time.

Total soil erosion from agriculture is reduced by 59 percent in the Soil Conservation Alternative compared to the Base Alternative. The reduction in soil loss is achieved by substituting reduced tillage for conventional tillage and replacing straight row farming with contouring and terracing on those lands most susceptible to erosion. Continuous row cropping declines as small grains and forages are grown in rotation with the row crops.

When the grass and legume hay crops are grown in rotation with row crops in regions like the North Central and South Atlantic the supply of roughage for stock cows expands. Consequently, the concentration of beef cow herds in the South Central and Great Plains regions declines as beef cows shift to the North Central and South Atlantic regions in the Soil Conservation Alternative compared to the Base Alternative.

Some corn and sorghum grain production shifts away from the North Central region because of the expense of controlling soil erosion in parts of the region. This interregional shift of feed grains production also causes some beef feeding to shift away from the North Central region to other regions less susceptible to erosion in the Soil Conservation Alternative as compared to the Base Alternative.

The extra expense (e.g., contouring and terracing) incurred by agriculture to control soil erosion and the shifting of corn and sorghum production to regions of higher production costs (e.g., from North Central to Great Plains) raises the cost of growing crops.

General results

At normal export demand levels, the U.S. agricultural plant has great productivity and flexibility. Accordingly, any of the alternatives analyzed in this study could be attained in 1985. Too, the alternatives could be combined in manners other than the discrete scenarios posed for 1985. If policy, market, and price conditions encouraged it, the nation could maintain a higher level of conservation and shift its beef industry so that more cattle are produced but marketed at a lighter weight in 1985. Aside from policies or expanded exports which might force it, however, this outcome is not likely to be brought about by market forces alone by 1985 since the nation's agricultural production capacity is so large relative to normal demand levels.

APPENDIX

The linear programming model used minmizes the total cost of producing the endogenous commodities in the 105 producing areas and of transporting these commodities among the 28 market regions. The model consists of 1,200 equations and 24,000 variables. In mathematical notation the model is as follows:

Find a set of X's such that

$$f(x) = cx \tag{A.1}$$

is minimized subject to

$$Ax \leq b \tag{A.2}$$

$$X \geq 0 \tag{A.3}$$

where:

X is column vector of production and transportation activities;

C is row vector of unit costs for the activities;

A is a matrix of input-output coefficients; and

b is column vector of resource restraints and demand requirements.

Equation A.4 is the objective function to be minimized in the model:

$$f(x) = \sum_i \sum_j \sum_k \sum_m X_{ijkm} XC_{ijkm} + \sum_n \sum_p \sum_q L_{npq} LC_{npq} + W_r WC_r + F_n FC_n + IB_r IC_r + \sum_n \sum_s \sum_t T_{nst} TC_{nst} \tag{A.4}$$

$i = 1, \ldots, 105$ for the producing areas
$j = 1, \ldots, 10$ for the land classes
$k = 1, \ldots, 330$ for the rotations defined
$m = 1, \ldots, 12$ for the conservation and tillage alternatives per rotations
$n = 1, \ldots, 28$ for the market regions
$p = 1, \ldots, 4$ for the endogenous livestock classes
$q = 1, \ldots, 32$ for the livestock rations
$r = 1, \ldots, 58$ for the water supply regions
$s = 1, 2, 4, 5, 7, 8, 10, 11, 13, 14, 15$ for the commodities transported
$t = 1, \ldots, 176$ for the transportation routes defined

where: X_{ijkm} is the number of acres of rotation k with conservation-tillage m in producing area i on land class j; XC_{ijkm} is the cost per acre of rotation k with conservation-tillage practice m in producing area i on land class j; L_{npq} is the number of units of livestock activity p receiving ration q in market region n; LC_{npq} is the cost per unit of livestock activity p receiving ration q in market region n; W_r is the number of acre feet of water purchased in water supply region r; WC_r is the cost per acre foot of water purchased in water supply region r; F_n is the number of pounds of nitrogen fertilizer purchased in market region n; FC_n is the cost per pound of nitrogen fertilizer purchased in market region n; IB_r is the acre feet of water transferred out of region r; IC_r is the cost differential on a per acre foot basis for water in region r; T_{nst} is the number of units of commodity s transported over route t from market region n; and TC_{nst} is the cost per unit of commodity s transported over route t from market region n.

Each producing area has restraints for land availability by the five dry and irrigated land classes. The equations for the ith producing area are as follows:

Dryland restraint by land class

$$\sum_k \sum_m X_{ijkm} AD_{ijkm} \le DA_{ij} \qquad (A.5)$$

$i = 1, \ldots, 105$ for the producing areas
$j = 1, \ldots, 105$ for the land classes
$k = 1, \ldots, 330$ for the rotations defined
$m = 1, \ldots, 12$ for the conservation-tillage alternatives

Irrigated land restraint by land class

$$\sum_k \sum_m X_{ijkm} AI_{ijkm} \le IA_{ij} \qquad (A.6)$$

$i = 48, \ldots, 105$ for the producing areas
$j = 6, \ldots, 10$ for the land classes
$k = 1, \ldots, 330$ for the rotations defined
$m = 1, \ldots, 12$ for the conservation-tillage alternatives

Hay acreage restraint

$$\sum_j \sum_k \sum_m X_{ijkm} W_{ijkm5} \le HR_i \left[\sum_j \sum_k \sum_m X_{ijkm} W_{ijkm6} + \sum_j \sum_k \sum_m X_{ijkm} W_{ijkm5} \right] \qquad (A.7)$$

$i = 1, \ldots, 28$ for the market regions
$j = 1, \ldots, 10$ for the land classes
$k = 1, \ldots, 330$ for the rotation defined
$m = 1, \ldots, 12$ for the conservation-tillage alternatives

where: X_{ijkm} is the level of rotation k using conservation-tillage method m on land class j in producing area i; AD_{ijkm} is the acres of dryland used per unit of rotation k using conservation-tillage method m on land class j in producing area i; AI_{ijkm} is the acres of irrigated land used per unit of rotation k using conservation-tillage method m on land class j in producing area i; DA_{ij} is the acres of dryland available on land class j in producing area i; IA_{ij} is the acres of irrigated land available on land class j in producing area i; HR_i is the proportion of all hay which can be legume hay in market region i; and W_{ijkmu} is the rotation weight for crop u in rotation k using conservation-tillage method m on land class j in producing area i.

In producing areas 48-105, water supplies and irrigation activities are defined. Equation A.8 controls the allocation of water to the endogenously determined agricultural uses.

$$\sum_j \sum_k \sum_m \sum_u X_{ijkm} W_{ijkmu} CWU_{iu} + \sum_n \sum_p \sum_w Y_{npq} LWU_{npq} LW_{npr} - WH_r WA_r \le WS_r \qquad \text{(A.8)}$$

i = 48, ..., 105 for the producing areas
j = 6, ..., 10 for the land classes
k = 1, ..., 330 for the rotations defined
m = 1, ..., 12 for the conservation-tillage alternatives
n = 1, ..., 28 for the market regions
p = 1, ..., 4 for the endogenous livestock types
q = 1, ..., 32 for the livestock rations
r = i-47 to give the water supply region number
u = 1, ..., 15 for the possible irrigated crops

where: X_{ijkm} is the level of crop rotation k using conservation-tillage method m on land class j in producing area i; W_{ijkmu} is the rotation weight for crop u in rotation k using conservation-tillage method m on land class j in producing area i; CWU_{iu} is the acre feet per acre

water use coefficient for crop u in producing area i; Y_{npq} is the level of livestock type p consuming ration q in market region n; LWU_{npq} is the acre feet per unit water use coefficient for livestock type p consuming ration q in market region n; WS_r is the per acre feet of water available for use by the endogenous agricultural sector; LW_{npr} is the proportion of livestock type p from market region n in water supply region r; WH_r is the level of dryland to irrigated pasture conversion in water supply region r; and WA_r is the per acre water use coefficient when converting one acre of dryland pasture to irrigated pasture in water supply region r.

Each commodity market region has a set of equations to balance the supply and demand of the commodities. The equations are:

$$\sum_i \sum_j \sum_k \sum_m X_{ijkmn} W_{ijkmsu} CY_{ijkmsu} + \sum_p \sum_q Y_{npq} LY_{npqs} - \sum_t T_{nst} + \sum_r WH_r DA_{rs} \ge CD_{ns} \qquad \text{(A.9)}$$

i = 1, ..., 105 for the producing areas
j = 1, ..., 10 for the land classes
k = 1, ..., 330 for the rotations
m = 1, ..., 12 for the conservation-tillage practices
n = 1, ..., 28 for the market regions
p = 1, ..., 4 for the endogenous livestock types
q = 1, ..., 32 for the livestock rations
s = 1, 2, 4, ..., 9, 1, ..., 15 for the commodities balanced at the market region
u = 1, ..., 15 for the crops
t = 1, ..., 176 for the transportation activities defined

where: X_{ijkmn} is the level of crop rotation k using conservation-tillage system m on land class j in producing area i which is included in market region n; W_{ijkmu} is the weight of crop u in rotation k using conservation-tillage system m on land class j in producing area i; CY_{ijkmsu} is the per acre production of commodity s from crop u in rotation k using conservation-tillage system m on land class j in producing area i; Y_{npq} is the level of production of livestock type p using ration q in market region n; LY_{npqs} is the per unit interaction coefficient for commodity s with livestock type p consuming ration q in market region n (this will be positive for the livestock products and negative for the ration components); CD_{ns} is the exogenously determined demand for commodity s in market region n; T_{nst} is the net export of commodity s over transportation route t defined in market region n; WH_r is the level of dryland to irrigated pasture conversion in water region r; and DA_{rs} is the increase in hay yield associated with the conversion of an acre of dryland pasture to irrigated pasture in water supply region r. $DA_{rs} = 0$ for all $s \neq 5$.

The equations which are defined at the national level to balance commodity demand are as follows:

$$\sum_i \sum_j \sum_k \sum_m X_{ijkm} W_{ijkmn} CY_{ijkmsu} \geq CD_s \qquad \text{(A.10)}$$

i = 1, ..., 105 for the producing areas
j = 1, ..., 10 for the land classes
k = 1, ..., 330 for the rotations defined
m = 1, ..., 12 for the conservation-tillage alternatives
s = 3, 14 for the commodities cotton and sugar beets
u = 4, 14 for the crops cotton and sugar beets

where: X_{ijkm} is the level of crop rotation k using conservation-tillage practice m on land class j in producing area i; W_{ijkmu} is the rotation weight for crop u in rotation k using conservation-tillage practice m on land class j in producing area i; CY_{ijkmsu} is the per acre production of commodity s from crop u in rotation k using conservation-tillage practice m on land class j in producing area i; and CD_s is the demand for commodity s at the national level.

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