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# REGIONAL PROGRAMMING OF EFFICIENT AGRICULTURAL PRODUCTION PATTERNS[1]

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This is a study in interregional competition and the optimum spatial allocation of crop production in the United States. Efficient production patterns are specified by a linear programming model restrained by regional land resources and national demands. The models used are based on 122 producing regions and include as many as 500 restraints, including upper bounds on each crop category within regions. Production patterns are indicated to allow minimum national food costs and alternatives in livestock feed substitution. Three models are used and a set of national supply prices for crops is derived for each. The results have policy implications, in indicating the location and amount of land which should be withdrawn from production if the nation is to arrive at a long-run solution to its mammoth surplus problem and to lessen the treasury costs of farm subsidies.

OUR PURPOSE here is to employ linear programming in an analysis of interregional competition in agriculture and in the efficient location of crop production. We are concerned with regional adjustments needed to bring agricultural production into greater balance with "food requirements," and to cause the interregional allocation of crops to be more consistent with differential changes in technology and factor prices by regions. As an analysis of agricultural production, this study also has importance for other sectors of the 122 regions delineated. The quantitative analysis suggests the amount of land to be withdrawn from crop production and shifted to less intensive uses, such as recreation, forestry, and grazing in the various regions. This shift would necessarily require larger farms and a smaller farm population. Finally, the study allows examination of national supply prices for the commodities studied and within the particular model formulation.

## 1. THE BASIC STUDY

This study is the result of an application of linear programming to determine efficient regional production patterns for specified farm commodities. While the approach is somewhat conventional, we believe that for no previous study of this large a problem has there been a parallel effort in data assembly and construction. Several man-years were invested in assembling basic data and in converting them to the restraint and resources requirement vectors which serve as the quantitative foundation. The assembling and refining of data will continue for years; models and results will continue to be extended and improved, as time and resources allow. We look upon the results which follow as progress toward a useful

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and detailed analysis of interregional relationships in production, resource use, and structure of agriculture. We have models under way which incorporate nonlinear objective functions and regional demand functions.

We made an earlier analysis of grain allocation over the United States, an elementary one which included fewer regions and only feed grains and wheat [**1**, **2**]; the data referred to the year 1954, as a benchmark from which to launch our larger studies. The study reported here was extended to include 122 producing regions and considers wheat to be used for either livestock feed or human food, several feed grains (corn, oats, barley, and grain sorghum), cotton, and soybeans. Also, the current study is devised to allow substitution among feed categories, in order that national requirements can be met in terms of both (a) locations with greatest comparative advantage, and (b) the technical substitutability among feed categories in livestock production. Too, whereas the earlier and more elementary models pointed to a time in the past, since it was necessary to establish a benchmark in time, the present study is projected to 1965 as a basis (a) for better specifying the magnitude of surplus capacity in agriculture, and (b) for suggesting policies for alleviating surplus problems.

## 2. BASIC PROCEDURE AND COEFFICIENTS

Our objectives are to determine (a) which field crops should be produced in 122 agricultural regions, (b) the total acreage required to produce the nation's food and fiber requirements, (c) the amount of land which should be shifted from crop production if the nation were to cease accumulation of surplus stocks, and (d) the location of this land. Production of major field crops (corn, wheat, oats, barley, grain, sorghums, tobacco, and cotton) has been under acreage or output control most of the time since 1933. This study includes the field crops mentioned above, with soybeans added and tobacco excepted. Soybeans serve in either competitive or complementary relationship to the other crops, and their acreage and location are affected by control programs which cause land to be shifted from these other crops.

Linear programming models are used to specify which of the 122 regions might provide the nation's requirements for wheat, feed grains, cotton, and soybeans most efficiently in 1965, the efficiency criterion being the lowest total supply cost when national requirements are met. Unit production costs were estimated for each cropping possibility within each region. Cost estimates for 1965 are based on projections of trends in technology and inputs. Consumption restraints for 1965 are based on population and per capita income projections and on existing knowledge of price and income elasticities of demand. Since demand elasticities are low for food (e.g., the income elasticity of expenditures on food is about .15, with most of this for services with food, while the elasticity approaches zero for food in physical form), it is not highly unrealistic to consider domestic food demand in terms of a discrete requirement resting largely on population. The projected bill of goods to be produced for 1965 is approximately: food wheat, 1,113 million bushels; feed grain, 5,338 million bushels; oilmeal, 316 million hundredweight; and cotton, 16.4 million bales (500-pound gross weight). These restraints limit production nationally.

Production is limited in each region by the maximum total acreage available for growing wheat, feed grains, soybeans, and cotton. The first model requires that feed grain and protein from soybean meal be used in fixed proportions for livestock rations, and that soybeans be grown in rotation. The second model allows the least-cost mix to be used, depending on regional variation in production costs for feed grains and soybeans. The third model allows continuous cropping of soybeans in each region, rather than requiring this crop to be combined in rotations or specified mixes with other feed grains. (One purpose of the analysis is to determine how a simultaneous shift in soybeans and cotton acreages might affect an efficient regional distribution of wheat and feed grain production.)

Crop yields were estimated by regions. The yield trend for the period 1940–59 was used to project to 1965. This method of projection assumes that technological advancement in crop production will be at about the same rate for 1960–65 as for 1940–59. Input coefficients or production costs included those for labor, machinery, seed, chemicals, and all miscellaneous items. Estimated production costs were weighted averages of several production methods used within each region, which ranged from fully mechanized to the use of horse-drawn equipment and much hand labor; production costs for cotton also included costs of hauling cotton to the gin and ginning. Only mechanized techniques were considered for soybean production, since full mechanization of this crop is nearly universal over the nation. Estimates of 1965 levels of fertilizer use were made by fitting linear regressions to the use of nitrogen, phosphorus, and potassium individually, by states. Projected changes in fertilizer use were used to estimate yield increases.

The model used to estimate national requirements considered demand for each commodity to be a function of its own price, the price of substitutes, per capita income, and population. Because per capita income and population are exogenous variables with respect to the production or programming problem, their values could be derived independently and were obtained from other independent projections. On the other hand, commodity prices are "somewhat" endogenous with respect to the programming problem. Hence, in order to estimate requirements for programming, it was necessary to estimate approximate supply prices. While this procedure is more or less circular, our previous experience with national programming models has provided insight as to the supply price levels which might prevail. Given the prices and demand so estimated, total requirements of each commodity were estimated on the basis of a national demand model, which is not presented here but is synthesized from the many estimates of food demand made over the last decade.

Acreage constraints or maximum acreage that could be planted to the seven crops considered were the actual acreages of the seven crops planted in 1953, as production or acreage controls were not in effect in that year and, following high postwar prices, crop acreages tended to be near their physical maximum. Hence, these acreages perhaps best represent maximums that could be planted under free market conditions or efficient allocation of crop acreages. Two objectives were kept in mind in making adjustments of acreage restraints to 1965 conditions: (1) to establish a realistic upper bound on plantings of either wheat, feed grains, soybeans, or cotton, and (2) to establish new weights for feed grain rotations that reflect trends evident in a number of sections in the country.

### 3. THE PROGRAMMING MODELS

Three programming models, summarized in Table I, were formulated. Each

TABLE I

SUMMARY OF UNIQUE CHARACTERISTICS OF SIX PROGRAMMING MODELS USED IN REGIONAL ANALYSIS OF MAJOR FIELD CROPS

| Model | Regional Activities | Net Demand Constraint Levels: Food Wheat Mil.bu. | Feed Grain Mil.bu. | Oilmeal Mil.cwt. of SBOM eq. | Cotton Million 500-lb. G.W. bales | Programming Objective |
|---|---|---|---|---|---|---|
| A | Food wheat<br>Feed wheat<br>Feed grain rotation<br>Feed grain-soybean rotation<br>Cotton-cottonseed | 949.2 | 4,895.9 | 299.4 | 16.1 | Minimum of total costs and price differentials |
| B | Food wheat<br>Feed wheat<br>Feed grain rotation<br>Feed grain-soybean rotation<br>Cotton-cottonseed | 949.2 | 4,807.5 to 4,943.0 | 283.4 to 329.4 | 16.1 | Minimum of total costs and price differentials |
| C | Food wheat<br>Feed wheat<br>Feed grain rotation<br>Feed grain-soybean rotation<br>Cotton-cottonseed<br>Soybeans | 949.2 | 4,807.5 to 4,943.0 | 283.4 to 329.4 | 16.1 | Minimum of total costs and price differentials |

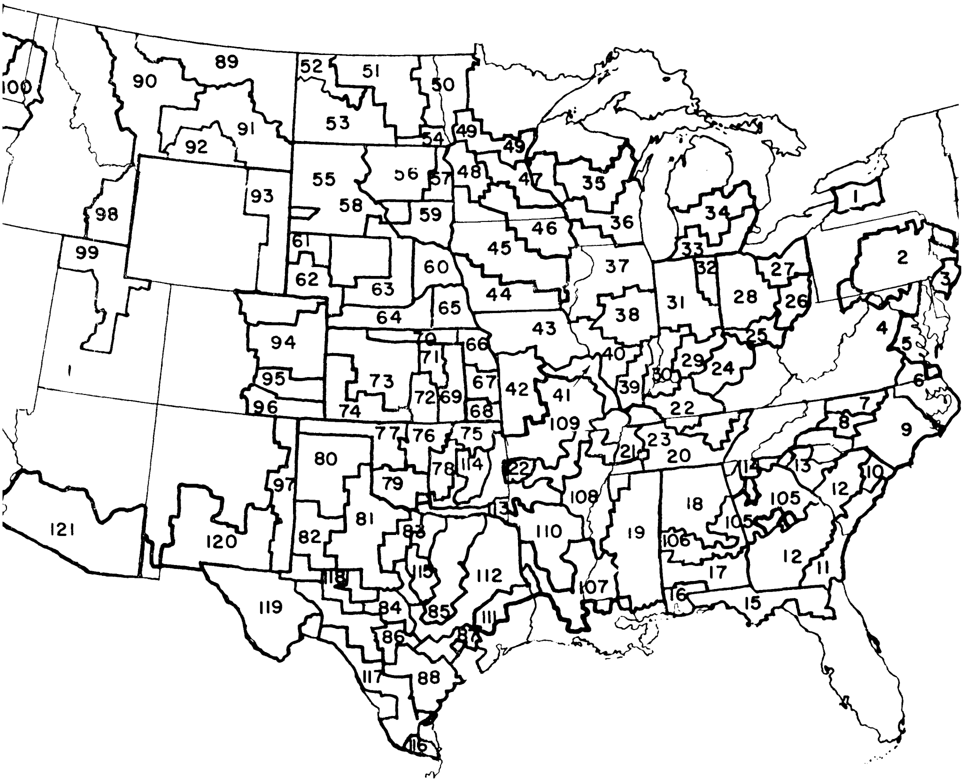


FIGURE 1.—The 122 programming regions.

region has five activities or production alternatives: (a) food wheat, (b) feed wheat, (c) feed grain rotation, (d) feed grain-soybean rotation, and (e) cotton (plus soybeans grown out of rotation for model C). The upper acreage bound for each region is that described above. The discrete demand restraints in Table I allow a small fraction of national production (not included in the amounts) to be produced in the regions without numbers in Figure 1. (This small production from scattered regions is not for purposes of major crop competition and is somewhat fixed and, plus seed requirements, accounts for differences between Table I and the total bill of goods.)

Table I shows that two of the models allow for ranges in feed grain and oilmeal production and demand restraints. The matrix and restraint system for these models was constructed so that if feed grain were at its maximum level, oilmeal had to be at its minimum level, or vice versa. Substitutions of feed grains and oilmeal between this limit was possible. These model details permit selection of a program to produce the nation's total feed requirements most efficiently, within the bounds specified, in the sense that farmers are allowed the least-cost ration for livestock. The objective for the models is to minimize cost, given regional price differences for the national aggregate of requirements. The use of regional price differentials, if certain conditions hold true, permits the estimation of a general price equilibrium solution. While, as explained later, we do not present a general price solution in this report, we will be able to do so after further computation, as the models were designed to allow methods of analysis, extending beyond those reported in this study.

## 4. FORMAL MODELS

The models now can be summarized as follows:
Let
$x_{ij}$ be the level of the $j$th activity in the $i$th region,
$c_{ij}$ be the cost per unit of the $j$th activity in the $i$th region,
$P_k^0$ be the price of the $k$th product in the base region,[2]
$P_{ik}$ be the price of the $k$th product in the $i$th region,
$d_{ik}$ be the price differential of the $k$th product with respect to the base region,
$b_{ij}$ be the primary output of the $j$th activity in the $i$th region,
$b'_{ij}$ be the secondary output of the $j$th activity in the $i$th region,
$C_{ij}=c_{ij}+b_{ij}d_{ik}+b'_{ij}d_{ik}$, where $d_{ik}=P_{ik}-P_k^0$,
$s_i$ be the land constraint in the $i$th region,
$a_{ij}$ be the per-unit land requirement of the $j$th activity in the $i$th region,
$D_k$ be the national requirement of the $k$th product,
where

($i=1, 2, 3, \ldots, 122$), ($j=1, 2, 3, 4, 5$—and 6 for model C), and ($k=1, 2, 3, 4$).

The objective is

$$\text{(1)} \qquad \min. f(c)=\sum_{i=1}^{122}\sum_{j=1}^{5} x_{ij}C_{ij},$$

which is subject to regional land constraints of the form

$$\text{(2)} \qquad \sum_{j=1}^{5} x_{ij}a_{ij} \leqslant s_i,$$

and also subject to national requirement constraints of the form

$$\text{(3)} \qquad \sum_i x_{i1}b_{i1}=D_1,$$

$$\text{(4)} \qquad \sum_i\sum_j x_{ij}b_{ij}=D_2,$$

[2] Prices in base regions were used in estimating prices for other regions. (See discussion in the text.)

$$(5) \qquad \sum_i \sum_j x_{ij} b_{ij} = D_3$$

and

$$(6) \qquad \sum_i x_{i4} b_{i4} = D_4 \,,$$

where $k=j=1$ is food wheat, $j=2$ is feed wheat, $j=3$ is feed grain, $k=j=4$ i cotton, $j=5$ is feed grain-soybean rotation, $j=6$ is soybeans grown alone, $k=2$ i feed grain, and $k=3$ is oilmeal.

Model B is similar to model A in all respects except for the demand constraints which are

$$(7) \qquad \sum_i b_{i1} x_{i1} = D_1 \,,$$

$$(8) \qquad \sum_i \sum_j b_{ij} x_{ij} \leqslant D_2' \,,$$

$$(9) \qquad \sum_i \sum_j b_{ij}' x_{ij} \geqslant D_3 \,,$$

$$(10) \qquad \sum_i b_{i4} x_{i4} = D_4$$

and

$$(11) \qquad D_2' - \sum_i \sum_{j=2}^{4} b_{ij} x_{ij} = \pi \left[ D_3' + \sum_i \sum_{j=4}^{5} b_{ij} x_{ij} \right] ,$$

in which $D_2'$ is the upper bound on feed grain requirements, $D_3'$ is the lower bound on oilmeal requirements, and $\pi$ is a constant equal to the marginal rate of substitution of oilmeal for feed grains. Model C is similar to B in all respects except for the number of activities or production possibilities: One more activity, $j=6$, is included.

## 5. QUANTITATIVE RESULTS

The above models were used in specifying the regions which would be devoted in majority to particular crops if most efficient production patterns were used in meeting national requirements for food wheat, feed grains, oilmeal, and cotton. Since requirements are defined as discrete quantities, rather than in terms of continuous demand functions, the results must be considered accordingly. The following results show the amounts of crops which would be produced, given the objective function as stated. Hence, the results also suggest the location and extent of surplus acreage devoted to the specified field crops.

Figure 2 shows the regional pattern of production arising from model A. As compared to the present, wheat production would be lessened in the marginal areas of the Great Plains and the West. Feed grain acreage could shrink into a

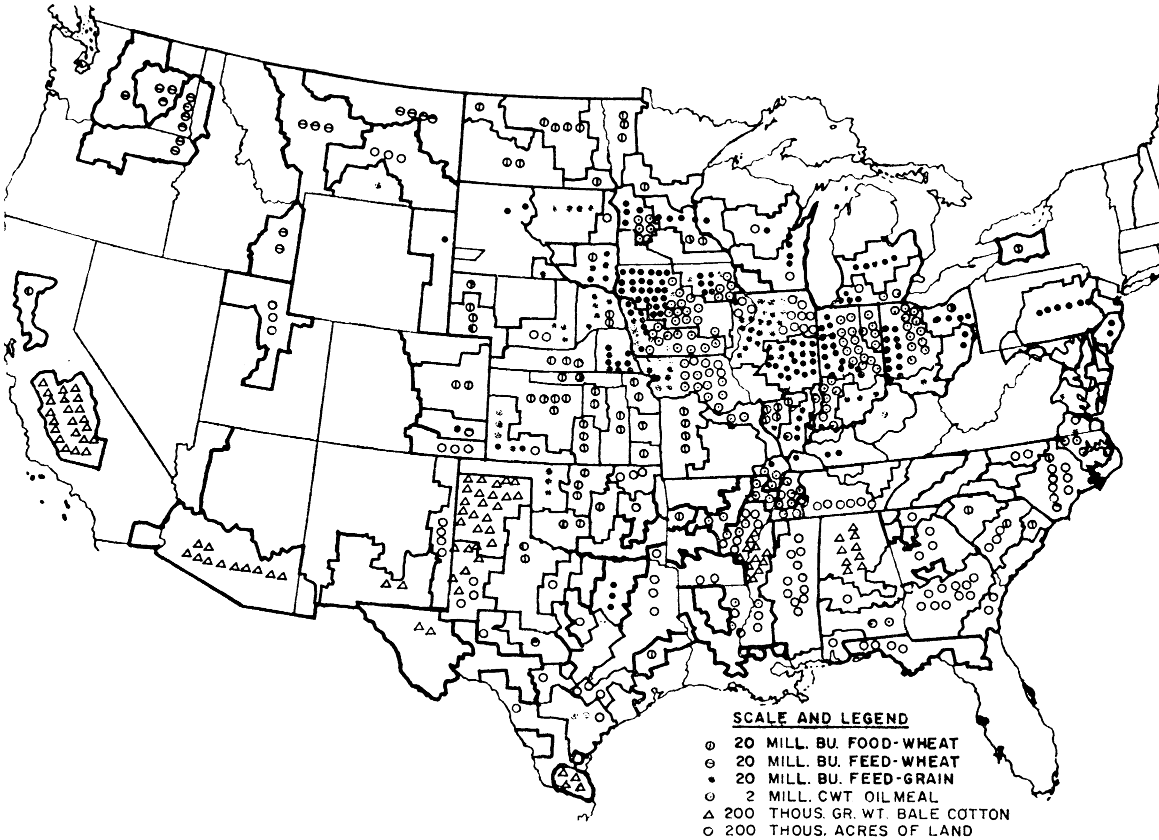


FIGURE 2.—Optimum production of field crops, Model A. Demands—1965 projection.

more concentrated area of the Corn Belt, and into other advantageous but smaller regions. Soybean production would be held more or less to the current spatial distribution by models A and B (but not by C). Cotton acreage and production would shift greatly from the Southeast to the Southwest. Some wheat production would move into the Southeast[3] and some feed grains into the eastern seaboard of the Appalachian area.

[3] The specification of wheat production in the Southeast may be due somewhat to inappropriateness of production coefficients and prices. First, production coefficients were based on a few observations from the limited area where wheat is presently grown in the region. They may not represent an entire region which might move into wheat production. Second, regional price differentials may be "in the wrong direction" for this area. This area has a history for garlicky wheat, which is heavily discounted at the mills. In the analysis, however, United States prices for average grade wheat were used to construct price differentials, so that even though these prices were too high in terms of quality of the crop produced in the area, wheat would be included for the Southeast in the programming results, when actually it would be produced more efficiently elsewhere.

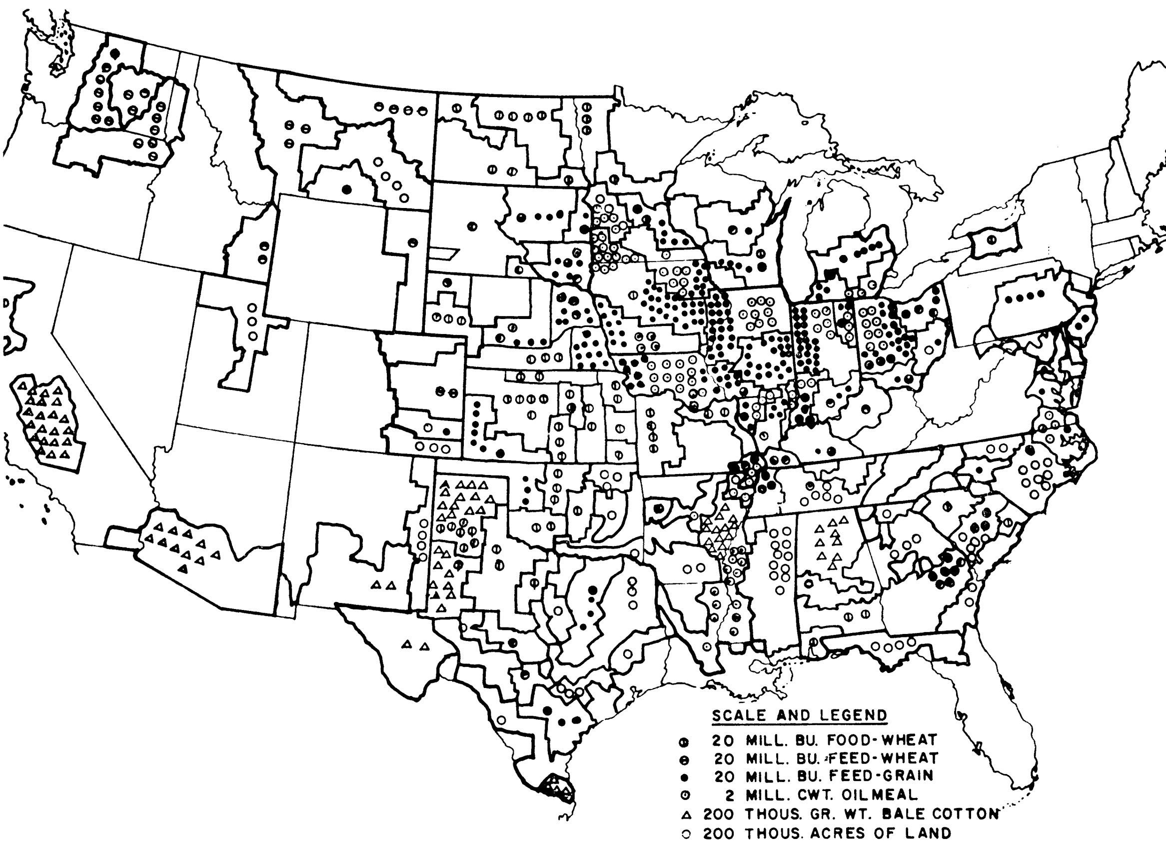


FIGURE 3.—Optimum production location of field crops with oilseed and feed grain substitutions in consumption, Model B.

The results presented in Figure 2 suggest a potential surplus acreage of land which might be withdrawn from grain and cotton production. This surplus acreage is concentrated in Montana, New Mexico, Texas, southeastern Colorado, Oklahoma, and selected regions of the Southeast, Appalachian, and Eastern Seaboard areas. Given the production coefficients as measured and the regional price structure assumed, the production pattern shown is the economically efficient one for producing the specified output mix. (It is not implied, however, that this output mix would be produced, in the short run, as a result of farmer behavior.)

Model B permitted either feed grain or oilmeal production to expand beyond the levels of model A. Minimum-cost feed production is achieved by substituting feed grains for soybeans, as compared to model A (see Figure 3). Some other minor changes also occur in the regional pattern from model B as compared to A. Feed grain production is increased in region 31 (Indiana) to replace soybean production in this region. Feed grain production decreases in region 55 (South Dakota)

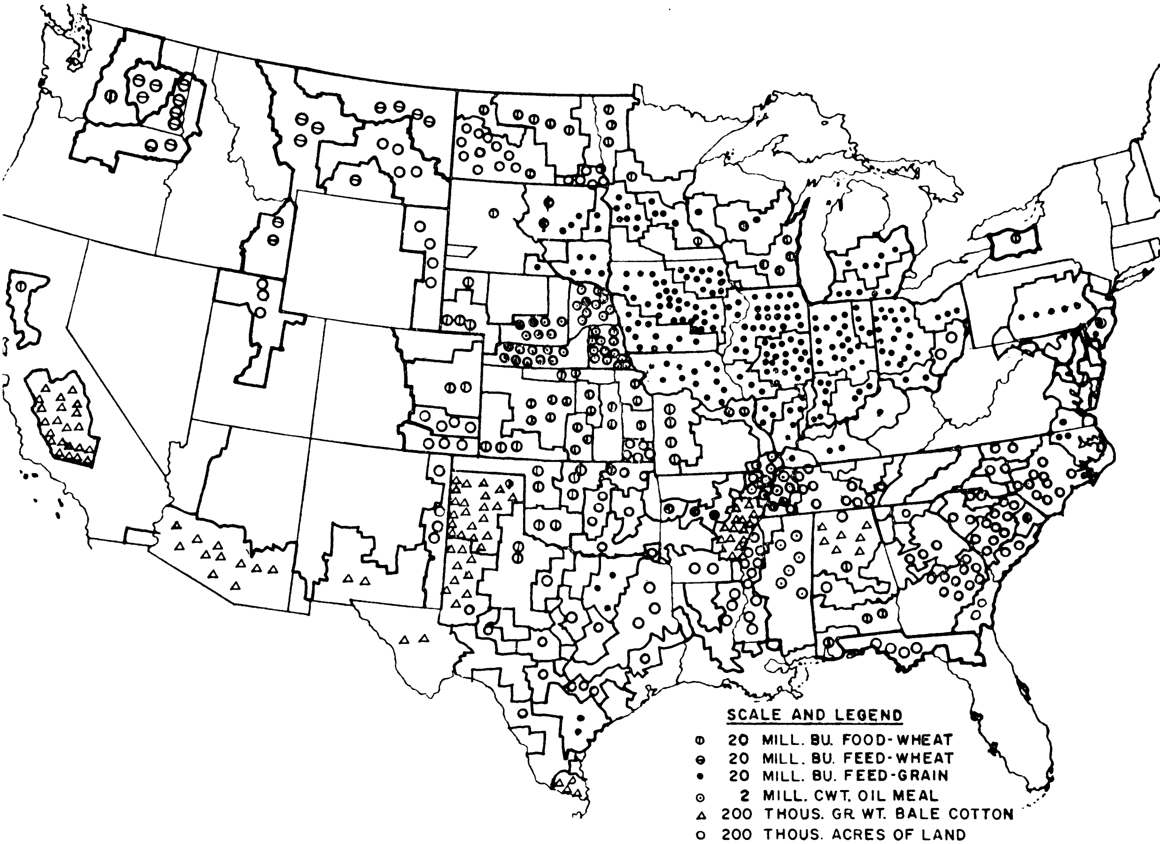


FIGURE 4.—Optimum production location of field crops with regional soybean specialization and oilseed and feed grain substitution in consumption, Model C.

and region 36 (Wisconsin). Wheat output increases in these two regions because the programmed price of feed grains declines slightly as compared to model A.[4]

The price of feed is lower under B than under A because the marginal units of feed are produced at lower costs. Model A forces a specific proportion of oilmeal into the production requirements, the resulting oilmeal component of total feed production thus being greater. Both models allow the production of soybeans only as a part of a feed grain rotation, so that although some regions may be able to produce soybeans at a relatively low cost, the cost of feed grain production included in the "fixed" rotation may be relatively high. Therefore, if the total requirement of oilmeal is so high in a particular region that it must be selected to produce

[4] The term "programmed price" refers to the marginal supply price obtained by the dual programming solution. These prices determine whether a region will be selected to produce, and which activity within the region will be selected.

soybeans, the marginal quantities of feed grains (which are tied to the soybean production by rotation) will have relatively high unit cost.

Model C allows soybeans to be produced independently of feed grains. In other words, soybeans can be produced under a system of continuous cropping. As indicated for the results of C in Figure 4, soybean production is not specified for the Corn Belt by this model. The soybean production specified for the Corn Belt under the B solution is replaced, under C, by soybean production in region 19 (Mississippi) and region 64 (Nebraska) and additional production in region 21 and regions 60 and 65.

Since complete regional specialization in soybeans is allowed under model C, soybeans and feed grains for national requirements can be produced on fewer acres. Feed grains recede, in comparison with models A and B, from the less efficient producing area, and other crops are allowed to take their place. Therefore, wheat production replaces feed grain production in region 36, which in turn substitutes for wheat production in region 53 and regions 12 and 13. Additional feed grain production in the Corn Belt in this solution replaces feed wheat production in region 93.

The primary purpose in application of model C was to show the possible impact of a greater degree of crop specialization on the optimum regional production and land use pattern. A trend towards greater specialization in field crops has been taking place over recent years. In the Corn Belt, for example, the relative acreages of corn and soybeans have been increasing, while the relative acreages of oats, forages, and other minor crops have been decreasing. This trend may become accelerated as more farmers learn that oats are a low return crop and as they find satisfactory ways to handle erosion problems under continuous row cropping (i.e., exclusion of meadow or hay rotations).

## 6. AVERAGE NATIONAL SUPPLY PRICES

Each model solution gives rise to national average supply prices for each crop.

TABLE II

UNITED STATES AVERAGE SUPPLY PRICES FOR CROPS UNDER THE THREE MODELS WHERE LAND COSTS ARE NOT INCLUDED IN COEFFICIENTS

| Crop | A | B | C |
|---|---|---|---|
| Wheat ($/bu.) | 1.33 | 1.33 | 1.21 |
| Corn ($/bu.) | 1.09 | 1.09 | .95 |
| Soybeans ($/bu.) | 2.10 | 2.10 | 1.35 |
| Cottonseed ($/ton) | 39.15 | 39.15 | 28.26 |
| Cotton ($/bale) | 95.31 | 95.31 | 98.10 |

These are presented in Table II to illustrate the structures arising from the regional production patterns depicted in Figures 2–4 and the particular characteristics of the data and the individual models. In general, these prices represent average marginal cost supply prices derived under the conditions and assumptions of the programming models and solutions. They cover all estimated costs except those for the land resource. Because regional differences are inherent in the models, imputed prices in individual regions are higher or lower than the averages given in the table. (If space had permitted, the implied regional prices also could have been presented.)

Basically, the individual commodity prices (Table II) represent averages of regional prices as they might arise in a perfectly competitive situation and under the conditions assumed in the models. These average supply prices are lower than prevailing government price supports over recent years. However, they do not represent general equilibrium price quantities since, for the programming models, it was assumed that certain quantities (see Table I) would be consumed if they were produced. (We did estimate disappearance with a general equilibrium price solution in mind: specifically with wheat at $1.39, corn at $1, soybeans at $1.80, and cotton at $120 per bale.)

The average supply prices (costs) derived for model A in which demands are discrete (see Table II) are slightly higher, except for cotton, than those assumed for the consumption requirements used in the national restraints. Hence, both of two conditions would prevail: Actual demand would be slightly lower at the programmed supply prices than the demand requirements used in establishing national restraints. Production would be slightly higher than allowed by our restraints under an actual equilibrium solution.

Supply costs under model B, where feed grain can be substituted for oilmeal and expanded to meet total feed requirements, change so slightly from those of A that differences are not apparent in the rounded prices of Table II. However, use of model C for soybean activities which can be grown outside of rotation allows a large change in cropping patterns and supply prices. All supply costs (prices) except cotton decline markedly for C as compared to B. These prices decline because soybeans and feed grains are produced singly in areas where they have the greatest absolute or comparative advantage. Or, in other words, feed grains and soybeans are produced separately in the regions where they have the lowest cost for the collective over-all model. With the added degree of specialization permitted in model C, the land base used for soybeans and feed grains shrinks. Consequently, land is released for other uses. This released land is more productive for wheat than are other areas used for wheat in the solution for model B. When this land is used for wheat production under C, the supply price of wheat also declines. The supply cost of cotton increases under model C as compared with B because of the decline in price of soybeans; the lowered soybean price forces a reduction in the price of cottonseed (and oilmeal from it), creating a cost-income deficit that must be made up by higher prices for cotton lint as a joint product with cotton seed.

## 7. LIMITATIONS OF THE ANALYSIS

The results presented above are conditioned by resource and data deficiencies. Had research funds and time not been limited, more realistic models could have been constructed. These models would have included more crop activities and also livestock activities (studying feeder stock and slaughter animals, as well as market livestock).

Because we were not able to incorporate more detail and nonlinear and non-discrete objective functions at the present, the results presented have some obvious limitations in exact specification of equilibrium quantities. However, as broad indicators of the competitive positions of particular areas in field crop production, the results are considered to be adequate and helpful in suggesting (a) adaptations in spatial patterns of crop production and (b) the general level of surplus cropland or producing capacity for particular crops. Additional time and refinements can allow estimates of even greater use in public policy and planning. The current study represents a necessary step in attaining these more refined estimates. The next step will include livestock activities and regional demand functions.

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