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An Overview of the Structure for the National Agricultural Resource Interregional Modelling System[a]

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Agricultural policies -- Mathematical models

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Introduction

The National Agricultural Resource Interregional Modeling System (ARIMS) includes seven sectors (Figure 1). These seven sectors integrated by a linear programming framework are designed to represent production processes and the driving forces for the U.S. agriculture. The seven sectors are:

1. Crop production,
2. Livestock production,
3. Pasture/Range production,
4. Irrigation requirements and costs,
5. Land availability,
6. Final and intermediate commodity transportation, and
7. Demand.

The first three sectors describe the production process. Sectors four and five define resource availability. The final two sectors identify and move the commodities produced to destinations for final consumption.

This model utilizes three different regional definitions. The first and primary set of regions are the 105 producing areas (PAs) (Figure 2). These areas are the basic regions for crop production, defined according to river basins. The land availability and irrigation sectors are also defined by producing area. The second set of regions serve jointly as the 31 market regions (MRS) and 31 Livestock Producing areas (Figure 3). Fertilizer inputs are purchased by these 31 regions. And, livestock production is defined with these regions as primary units. In addition, these 31 regions serve as transportation hubs. Transportation routes are defined between market regions. The final regions are 34 ecosystems.

Range and pasture production activities are defined at this level (forest output coefficients also exist defined on this regional basis but have not been included in the model). The ecosystems can not be mapped as clearly as can the PA's and MR's, since they are based on natural vegetation characteristics rather than on location (USDA 1988). A given PA may contain acres from any or all 34 ecosystems. And, a given ecosystem may be represented in all the PA's.

In addition to the regions explicitly contained in the model structure, coefficient development involved data sets by county, state, USDA Farm Production Region and Major Land Resource Areas (MLRA) (USDA 1981) regions. Data from these regions were adapted to the model regions based on 1982 Natural Resource Inventory (82 NRI) and (USDA 1984) crop acres. This calibration of of the model using input data minimized overstatement of productive ability and understatement of production costs (Hazel and Norton 1986). The cost bias in ARIMS is within acceptable limits (Robertson, et al. 1987). And these biases are common to all sector programming models (Egbert and Kim 1975).

The equations comprising ARIMS have a coefficient matrix structure which is nearly block diagonal. At the national level, there are cotton demand constraints, national land total and various feed use correction constraints. Only transportation links exist between MR's and PA's. And, only a few constraints (other than demand) link PA's within each MR.

Objective of ARIMS

The primary motivation for ARIMS is as an analytical system useful in agricultural and resource policy evaluation. Since resources and agricultural production practices differ by region, numerous regional attributes and responses to agricultural and resource policies can be evaluated. For example, policy can be evaluated that impact on:

1. Regional resource availability,
2. Farming techniques,
3. Resource prices,
4. Input availability,
5. Levels of domestic and export demand, and
6. Environmental allowances.

The foremost use of the ARIMS, however, has been to appraise future agricultural resource requirements. In achieving this objective, a modeling system capable of examining agriculture production, consumption, and resource use patterns through the year 2030 have been constructed.

Major Methods Employed

The ARIMS modeling system consists of numerous "delineation" models and a large linear programming model. The delineation models project future resource availability, future final demand levels, and the regional distribution of demands, future commodity yields, future changes in the technology for producing barley, beef, corn grain, corn silage, cotton, dairy, legume hay, nonlegume hay, oats, pork, range and pasture, sorghum grain, sorghum silage, soybeans, spring and winter wheat, and available tillage and conservation practices. The projections are then used in the linear programming model, and the composite effects of these individual impacts and the policy provisions introduced are analyzed.

Delineation Models

The delineation models play two roles. The first is to describe that which is occurring in the present. The second role is to project what will occur in the future. These models generally consist of computer programs that are capable of taking information and displaying the present situation, and using the present situation to support best estimates of the future situation. The models are fully described in other documentation. Generally, these models are descriptive in nature, projecting the future values required for solutions of the ARIMS designed for use in policy-related projections.

Linear Programming Model

The linear programming model of the agricultural sector is standard, a set of mathematical relationships incorporating characteristics most relevant to agricultural production, resource use and responses to economic factors (Hazell and Norton 1986). The model minimizes costs of production and transportation for meeting certain levels of final demand and subject to a technology matrix. The basic formulation of a minimizing linear programming model (in matrix form) is:

$$\text{Min OBJ} = C * X \tag{1}$$

subject to:

$$\bar{Y} * X \geq D \tag{2}$$

$$X \leq L \tag{3}$$

$$X \geq S \tag{4}$$

$$X \geq 0 \tag{5}$$

where:

C is a vector representing the cost of production process X;

X is a vector of alternative production processes;

Y is a vector of yields corresponding to production process X;

S is a vector of restrictions on production process X; and

L is a vector of resource constraints, including land.

The first equation (1) describes the agricultural decision processes approximating behavior under long-run competitive equilibrium. The economic rationale is for decision making to provide the lowest costs within prescribed limits. Those limits are defined by the a series of equations, (2) through (5). Equation (2) states that the production process must meet specified levels of demand for the commodities. However, the production process selected to achieve this level of demand must not use more resources than are available (3). Equation (4) prescribes certain quantity restrictions. These are termed shift, restricting or flexibility constraints. Equation (5) simply indicates that the production processes must always operate at a level equal to or greater than 0.

The justification for the national least cost minimization criterion is based on the initial use of ARIMS to examine alternatives for an assumed long-run competitive equilibrium (Robertson, et al. 1987). In a long-run competitive equilibrium producers each minimize long-run average costs (Silberberg 1974) and only the most efficient remain in production (Jayard and Walters 1978). Constraints representing fixed demands are placed in the model and their shadow prices in the final solution become inputed commodity prices, under the assumption of marginal cost equals price in the competitive equilibrium. Various factors not modeled may influence production decisions. The production shift constraints are employed to adapt the model to better simulate real world behavior as influenced by these unspecified conditions (Henderson 1959; McCarl and Apland 1986; Miller 1972).

A general schematic of the ARIMS' linear programming model is provided in Figure 5. This schematic represents two producing areas (x and y), within one market region (z), and one ecosystem (g). In addition, the market region is located on a coast and exports occur. Generally the types of resources required, active constraints and commodity demands are presented vertically with the activity types listed horizontally. The symbols used in this schematic are the same as those used in the detailed mathematical representation provided in the last subsection.

Resource limiting, demand defining, and shift restricting constraints are employed in the 1985 version of the ARIMS. Resource limiting constraints define quantities of resources available for agricultural production. Demand defining constraints specify quantities of commodity production required to satisfy a set of projected final demands. In selected cases the model limits the rate of shift between regions and/or resources.[2]

A Description of the Sectors

As previously stated, there are seven sectors in the ARIMS. A brief description of these seven sectors is provided, concentrating on the model structure, alternatives considered, and the major sources of information for specializing the model.

Crop Sector

The crop sector is the primarily focus of the model. It simulates the production of barley, corn grain and silage, soybeans, sunflowers, and spring and winter wheat through predefined cropping practices; dryland (XD), surface water irrigated (XIS), and groundwater irrigated (XIG).[3] These cropping practices require water (WR) (if irrigated), land, and variable expenses; cost for dry crops (CD) and for irrigated crops (CI), and energy and fertilizer (FD, FI); and in return provide a yield (YD) and erosion (YI)--from water (SWTD and SWII) and from wind (SWDD and SWDI) (see Figure 6).

A cropping practice is defined as a rotation on a given land group using a prespecified conservation and tillage practice in a specific producing area. Eight different land quality groups incorporated in the model for: dry land and irrigated land by surface water; and irrigated land by ground water. There are three conservation practices (strip cropping, contouring, and terracing) and one nonconservation practice (straight row). In addition, there are four tillage methods (conventional without and with winter cover, conservation tillage, and zero-tillage). Finally, summer fallow and double cropping are incorporated where applicable.

Crop rotations were selected from a USDA survey and updated and approved by Soil Conservation Service (SCS) National Technical Centers. Note that many different types and levels of tillage are actually represented in the model; selected for economic reasons, primary tillage and/or amounts of residue remaining on surface. Each tillage practice can be combined with one conservation practice. In designated PA's, strip cropping is introduced for wind rather than water erosion.

ARIMS base yield levels are calibrated to 1985-86 with technology adjustment factors employed to develop yields for future scenarios. Costs and production technology represent 1980-82 average costs of production according to USDA cost of production surveys. Yields, costs and erosion factors are discussed in more detail in subsequent subsections.

Land and water resource requirements for exogenous crops were not mentioned above but not are accounted for by reducing resources available for endogenous crop production in ARIMS. Base acreages of the exogenous crops are from 1982 National Resources Inventory (82 NRI) and (USDA 1984), with adjustments in future scenarios designed to reflect changes in predicted commodity levels of these crops.

Crop Yields

Several sources were used for estimating the yields of individual crops within each cropping practice in ARIMS. Base level yields for each PA were the 1985-86 average of yields reported at the county level by the Statistical Reporting Service (1987). These base yields were for nonirrigation, unless the crop was only grown irrigated. Adjustments to the base yields for land groups, tillage methods, crop after crop sequences and the impact of erosion over time are from the Erosion Productivity Impact Calculator (EPIC) (Putman et al. 1987, Putman and Dyke 1987). Irrigated yields are derived from dry yields by proportional indices which are specified by crop, land group, and PA. These indices were determined by a national panel of irrigated cropping experts.

For analysis of future scenarios, all yields were adjusted for technological growth. Different scenarios involved different assumptions about rate of growth. The rates were an outcome of an RCA symposium (English et al. 1984). Fertilizer requirements per unit of output were held constant as yields increased.

Crop Costs

The starting point in developing the crop costs for ARIMS was the enterprise budgets developed from USDA Cost of Production Surveys and organized to be used with the Firm Enterprise Data System (FEDS) (Kletke 1975). These budgets represented acreage costs for 1980 and were supplemented with budgets from SCS and CARD data files. The technical matrix of each budget in the final set was reviewed in 1984 by the appropriate SCS National Technical Center. Finally, several adjustments were made for the selected cost items as described below.

ARIMS contains MR level fertilizer buying activities and endogenous fertilizer supply from livestock activities. All N, P, and K budget entries were deleted. Final yields for each crop in each activity were used with Spillman yield functions (English et al. 1982) to determine fertilizer requirements per unit output for the 1980 base levels. When new yields were developed for future scenarios and an adjusted fertilizer requirement multiplied by the new yield gave fertilizer use. The requirement adjustments were based on the EPIC impacts due to soil erosion over time. Rotational fertilizer requirements also account for carryover from legume crops.

Pesticide costs were included in some budgets for some crops in some regions while not in others. Pesticide expenditures per acre were taken from all budgets and statistical regressions used to determine pesticide per acre costs for all crops and regions, with differentiation for dry and irrigated production. Then, all pesticide costs were removed from all budgets and the regression results used instead.

Drying costs were also removed from budgets and handled separately. For each crop in each region, engineering coefficients were used to construct a data set consisting of beginning and ending moisture content percentages and the LP gas energy equivalents required to reduce moisture content by one percent. Total drying costs were calculated and included in the cropping activity costs.

Crop production costs were also adjusted for terracing, contouring, and strip-cropping, since these items were not included in the base budgets. The annual maintenance costs of terracing were directly included in the crop activity costs. Increased labor requirements (and machine time) due to these conservation practices were accounted for with proportional timing factors multiplied by original budget entries.

Separate activities deliver and apply irrigation water. These costs vary according to whether source of water is ground or surface. Only the variable costs of irrigation are included. The crop activities include water use coefficients. The water application activities account for water transportation, application, and incidental loss efficiencies. Development of the water application activities is documented in Smith et al. (1986).

Transportation costs in the budgets were adjusted to reflect only moving the crops to the farm gate. Prices for inputs assume delivery to the farm gate by suppliers. Commodity transportation activities account for nonfarm transportation costs.

Crop Erosion

Each cropping activity ARIMS includes an estimate of sheet and rill erosion by the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) and wind erosion (Smith and English 1982). The water erosion was calculated by EPIC using the R.K. and L.S. factors for a representative soil from each PA and land group. EPIC also produced wind erosion estimates; however, wind erosion data from 82 NRI were used to calibrate the EPIC results. Combination of ARIMS solution with input data sets also allows calculation of the AOF erosion estimates.

Erosion impacts on crop yields, nitrogen use, phosphorous use, and potassium use were estimated by EPIC for each crop, land group, and region. For each activity in the future scenario variations of ARIMS, the number of elapsed years and, the annual erosion and the EPIC impacts were used to adjust model coefficients.

All land resource rows in ARIMS are equalities, and land is forced to be cropped, enrolled in the Conservation Reserve Program (CRP) or idled with a green cover crop. The green cover establishment costs were determined by SCS staff and varied between $40 to $100 per acre. These costs are amortized over a ten-year period with a six percent discount rate. It is also assumed that an annual clipping to control weeds must occur. The erosion coefficients are roughly equivalent to those of nonlegume hay for the same area and land group.

Conservation Reserve Program and Idle Land

ARIMS contains individual activities by PA, land group, dry and ground and surface irrigated for enrolling land in the Conservation Reserve Program (CRP). These CRP activities incur the cost of establishment and maintenance for ground cover as described above for the idle land except for a 50 percent government subsidy for establishment. No CRP rent is accounted for. CRP land may be on land groups two through eight but level of enrollment is subject to eligibility requirements based on erodibility and allocated based on the 25 percent maximum per county rule.

Currently, pre-modeling work determines by land groups and PA the acreage which must be enrolled in CRP. These enrollments are determined based on previous sign-up data and likely distributions of future sign-ups. First state level allocations of a desired national total are determined. These state levels are introduced into a quadratic programming (WP) model which includes county and land group level restrictions on eligibility, county totals, and acreage requirements needed for other exogenous items in ARIMS. The QP objective function considers in part, the deviation from past sign-ups which it seeks to minimize. The QP output for the PA and land group CRP enrollments is used in ARIMS. Erosion on CRP enrollments is calculated just as for the idle cropping activities.

Livestock Production Sector

The livestock sector produces dairy, pork, and beef. The production process is modeled using nutrient requirements (JA), demand for replacement animals (-NA), and capital (CA) as inputs. These inputs, when used, produce dairy, pork, or beef to meet the final demands. The production activities can be broken into two types--final demand producing and offspring producing. The offspring producing activities produce some red meat, however, from inventory adjustment. The nutritional and water requirements for producing an exogenously specified mix of other livestock are fixed in the model constraints and met by endogenous feed transfer activities. All livestock activities are defined by MR.

The specific types of activities are as follows: for dairy there is "dairy"; for pork there are "farrow to finish", "feeder pig to finish", and "feeder pig"; for beef there are "cow calf", "cow, calf, yearling", "cow, yearling", "heifer calf", "steer calf", "heifer and steer yearling", "roughage fed, heifer calves", "roughage fed, heifer calves", "roughage fed, steer calves", and "roughage fed, heifer, and steer calves". All of these activities are based on Firm Enterprise Data Systems (FEDS) budgets and represent average technology and costs for 1980.

There are alternative activities for different size operations in each MR. The activities use, however, many primary or intermediate inputs that are required for one unit of output. The "feeder pigs", "heifer calves", "heifer yearlings", "steer calves", and "steer yearlings" are intermediate input producing activities.

The dairy subsector produces milk as a primary product. However, steer calves are available for use by the beef subsector and culling yields roughage fed beef that can be used to meet final beef demands.

Pork production is represented through three production processes. These include: farrow-finish, finish, finish, and feeder pig. The feeder pig operation supplies pigs to the other two production processes. In addition, it supplies some pork (from culling) to meet the pork final demands.

The final livestock commodity produced in the model is beef. Beef final demands are divided into grain-fed and roughage-fed. Cow/calf and cow/calf/yearling operations produce heifers and steers for use in the finishing activities. In addition, these activities supply beef to the roughage fed beef final demand requirements through the culling of the breeding herd. Both the grain and roughage fed activities produce beef and require offspring.

The nutrients accounted for are protein, net energy, metabolizable energy, phosphorous, calcium and lysine. The nutrients may be supplied from the cropping sector, from private and/public pasture/range and by the purchase of calcium and phosphorous. The pasture/range activities are described in the next section.

ARIMS contains additional constraints setting upper and lower bounds on roughage consumption (implicitly the opposite for grain use), a wheat feeding maximum and upper bounds on roughage fed beef and/or pasture production. Wheat prices often indicate a higher than biologically feasible feeding level if unconstrained in the model solution. The public prefers grain fed over roughage fed beef to a large extent and the model inadequately captures the seasonality aspects of grazing since specified on an annual basis.

Livestock activities also produce fertilizer nutrients which are transferred to the crop activities, reducing the required purchases. Technology over time is also captured in the livestock sector by means of increases in feed conversion and decreases in mortality rate ratios (English et al. 1984).

Pasture/Range Production Sector

The pasture/range production sector used the Forest Service's data base developed for the last Resource Planning Act appraisal. It contains information on the privately owned lands that are classified as grazed lands. These production activities (XG) are defined for 34 ecosystems (U.S. Dept of Ag. 1988)[4]. Under each ecosystem, the resources available to grazed land production are defined through resource units. There are 12 resource units[5] based on productivity and condition class (Figure 7). Five different management strategies are defined ranging from no livestock to intensive livestock production.

Ecosystems are based on vegetation characteristics (USDA 1988) rather than on regional location. Since the ecosystems overlap PA's, each ecosystem activity requires land from a number of PA's and land groups in fixed proportions--based on 1982 NRI acreages.

The costs for achieving a given management level (CG) and the land requirements are the specified inputs into the production process. Yield of grass (YG) and the timber (net wood growth) in addition to the sediment (SSED) from water erosion, are the outputs from particular production process.

For public land the published U.S. Department of Interior grazing rates per Animal Unit Month (AUM) are used as model costs. For private land direct management costs are included in ARIMS. It is assumed that an AUM converts to 800 pounds of nonlegume hay equivalent.

The nutrient content of the pasture by region is documented in Disney and English (1984). State extension personnel were surveyed to determine separately for beef and dairy the proportions of diet made up of various grasses and legumes. Standard nutrient data for these species were combined with the diet percentages to yield nutrient output per pasture unit.

Irrigation and Other Inputs Sectors

Inputs--water and nitrogen fertilizers are purchased within the programming model. Activities for water application are by PA (Smith et al. 1986) and by MR for nitrogen. Livestock production produces nitrogen which is available to the crop sector at zero cost.

The irrigation sector differentiates between the two basic sources of water--ground and surface. Surface water availability (RWS) is fixed to its present allocation. Pumping costs for groundwater are an increasing function of aquifer depletion in the model.

The irrigation model allows an acre-foot of water to be purchased for crop use. As it is pumped, applied, and/or delivered, losses occur. These efficiency losses (WEI) are incorporated. The variable costs that occur when using water are reflected in the objective function value for activities in this sector. The sunk costs (i.e., cost of drilling the well or building a dam or canal) and the fixed cost of various equipment and facilities not included.

The fertilizer purchase activity (XF) reflects pounds of nitrogen purchased. The objective function value (CF) represents the 1980 cost of nitrogen in dollars per pound.

Land Availability Sector

The land resource available to agricultural production is defined at all three modeling levels. There are nine different types of constraints. Eight of these constraints impact on the amount of cropland available for production and one is for grazing. The basic purposes of these constraints are twofold: 1) to define the available resource, and 2) to reflect appropriate adoption (abandonment) rates. In addition, there are four types of land transfer activities. These include:

1. Conversion of dry to irrigated land with surface water as the source (XMDIC) (PA's 11 - 44) and dry to ground irrigated land with ground water as the source (XMDIC) (PA's 45 - 105),
2. Conversion of irrigated to dry (XMIDC),
3. Conversion of range and forest land to cropland (XLP), and
4. Conversion of presently cropped w/ soils to prime farmland (XMWET).

The nine land constraint types serve the following roles:

1. Define the amount of land available for dryland production (producing area and land group) (RLDY),
2. Define the amount of land available for surface and groundwater irrigation production (producing area and land group) (RLIR),
3. Require a predetermined amount of irrigated land to be used (producing area and source and national) (RLIT and RLIN),
4. Define the amount of land available for grazing production (ecosystem, productivity, and condition class) (RLG),
5. Limit the amount of acres of conservation tillage in crop production (producing area) (RLCTL),
6. Limit the amount of acres of zero-tillage in crop production (producing area) (RLZTL),
7. Require at least 1982 levels of terraced acres (producing area) (RLTER), and
8. Require a predetermined level of cropland to be in a specific crop (market region) (RLCRP).
9. Control availability for grazing.

Conservation, Zero Tillage, and Terracing Constraints

ARIMS includes maximum allowable acreage constraints for conservation and zero tillage and minimum required terracing. As explained below for each case these are needed to represent neglected producer decision factors which if included, would increase model size to an unworkable level. These constraints are generally activated in base runs, particularly if the time frame of the analysis is current, and are relaxed somewhat for different policy considerations.

ARIMS does not include all the factors which influence farmers adaptation of conservation and zero tillage practices. However, the cost and yield coefficients developed for ARIMS give conservation and zero tillage a competitive advantage over conventional methods. ARIMS would adapt these practices entirely if not constrained. To overcome this problem, upper bound acreage constraints reflecting the most likely adoption rates for conservation and zero tillage are placed in ARIMS by PA. Currently these constraints are set at 120 percent of the tillage levels reported in the Conservation Tillage Information Center's (CTIC) 1987 County level survey (CTIC 1987).

CTIC reported zero tillage directly, while conservation tillage was the sum of ridge-till, strip-till, mulch-till, and reduced-til. Model activities must leave 85 and 30 to 85 percent residue cover after planting to qualify as zero and conservation tillage, respectively. The 120 percent level was thought to be optimistic for 1990 given the conservation provisions of the 1985 Farm Bill, rates of depreciation on existing equipment, etc.

When these tillage constraints are binding in the model solution, a pre-acre shadow price is inputed which implies a lower rent for the land resource. However, if one thinks of the shadow prices as rent to the specialized factors controlled by farmers who have adopted, then the rent (sum of shadow prices times constraint levels) can be added to producer surplus calculations. This interpretation is followed in current analysis. Alternatively, the shadow price could be interpreted as a cost due to asset fixity, reluctance to adopt, etc. and be deducted from producer surplus.

Terracing is a conservation practice with many benefits, the chief being flow control for heavy run-off on a field. However, terraces are expensive to build, the government has heavily subsidized construction in the past and ARIMS captures only the yield and input use impacts due to decreased sheet and rill erosion. The result in the terraces do not competitively come-in to the model solution at historic or current levels even when erosion restrictions are in place. Since it seems unlikely that farmers will abandon terraces immediately, ARIMS contains restrictions forcing in the terrace levels reported in the 82NRI by PA. In addition, it is assumed that as cropland use has declined from 1982 to 1990 the terraced acres have continued in production.

The shadow prices inputed to binding terrace constraints in the model solution indicate the reduction in production cost if the constraints were relaxed. If the constraints were relaxed the rent attributed to the land resource would generally increase. Therefore, these constraints have a negative impact on producer surplus.

Crop acreage constraints in ARIMS were originally set such that each MR had to have at least 60 percent of the acreage of each crop reported in 1982NRI. However, for major crops reported by the Statistical Reporting Service these constraints have been updated to reflect 80 percent of the reported average of 1985-86. In some policy runs, these constraints are relaxed in some areas due to erosion, etc. Also in runs simulating the distant future, such as year 2030, the constraints are generally relaxed completely.

Final and Intermediate Commodity Transportation

This sector transports endogenous crop commodities (XTC) of barley, corn, oats, sorghum, soybeans, and wheat (cotton, peanuts, and sunflowers have only national and not regional demand; hay and silage are bulky and assumed used in MR where produced.) National demand levels are the FAPRI (1988) projections for 1990. In addition, some national feed disappearance correction requirements have been incorporated. Regional demands are updated from the original ARIMS by assuming regional proportions of national are unchanged. Originally, population, and related trends are used to determine regional demands. In addition, the livestock commodities of calves, yearlings, beef, pork, and dairy are transported from market region to market region (XTA). The crops are transported primarily by rail although barge routes do exist along the Missouri-Mississippi Rivers and for the Great Lakes. Most of the routes are between adjacent market regions. Longer haul routes do exist, however, if mileage is reduced by ten percent.

Demand

This sector drives the model. Regional demands based on per capita consumption levels are specified (RDC, RDL, RDCN). Exports are predetermined with port location estimated, from the East, Gulf, or West (Figure 9) (REX). Exogenous livestock demands for feed are specified as feedgrains, other concentrate, and roughages (RB).

Mathematical Description of ARIMS

The presentation of the equations is divided into two sections, the objective function and the constraints. The equations use the same nomenclature as the schematic. Table 2 describes the variables used in the equations. Generally, activities are identified as starting with an X and levels of constraints begin with an R. Coefficients in the objective function begin with the letter C.

Objective Function

The objective function minimizes the total cost of crop, range, and livestock production along with commodity transportation. The costs (represented by variables beginning with a C in the normaclature adopted) associated with each activity are the total cost per unit of activity of the resources and inputs not explicitly modeled with purchase activities. In the model solution process these C values, which taken as a whole determine the value of the resources and inputs not explicitly modeled. The objective function has the form:

$$OBJ = \sum_{i=1}^{105} \sum_{j=1}^{8} \sum_{k=1}^{K} \sum_{m=1}^{16} (CD_{i,j,k,m} * XD_{i,j,k,m})$$

Crop Sector

$$+ \sum_{i=1}^{105} \sum_{j=1}^{8} \sum_{k=1}^{K} \sum_{m=1}^{16} \sum_{w=1}^{2} (CI_{i,j,k,m,w} * XI_{i,j,k,m,w})$$

$$+ \sum_{i=1}^{105} \sum_{w=1}^{2} (CWA_{i,w} * XWA_{i,w} * (WEO_{i,w}/WEI_{i,w}))$$

Water Sector

$$+ \sum_{e=10}^{44} \sum_{f=1}^{4} \sum_{g=1}^{3} \sum_{h=1}^{90} (CG_{e,f,g,h} * XG_{e,f,g,h})$$

Range/ Forest Sector

$$+ \sum_{p=1}^{31} \sum_{q=1}^{14} (CA_{p,q} * XA_{p,q})$$

Livestock Sector

$$+ \sum_{p=1}^{31} \sum_{n=1}^{16} \sum_{u=1}^{7} (CJ_{p,n,u} * XJ_{p,n,u})$$

$$+ \sum_{i=1}^{105} \sum_{r=1}^{4} (CLP_{i,r} * XLP_{i,r})$$

$$+ \sum_{i=1}^{105} \sum_{j}^{8} \sum_{w=1}^{2} (0.01 * XMIDC_{i,w,s})$$

Land Conversion Sector

$$+ \sum_{i=1}^{105} \sum_{j}^{8} \sum_{w=1}^{2} (CMDIC_{i,j} * XMDIC_{i,w,j})$$

$$+ \sum_{i=1}^{105} (CMWET_{i} * XMWET_{i})$$

$$+ \sum_{p=1}^{31} (CF_p * XF_p)$$ Fertilizer Sector

$$+ \sum_{t=1}^{967} \sum_{n=1}^{16} (CTC_{t,n} * XTC_{t,n})$$

$$+ \sum_{t=1}^{967} \sum_{u=1}^{6} (CTA_{t,u} * XTA_{t,u})$$ Transportation Sector

Constraints

Fertilizer Constraints (MR)

The fertilizer constraint balances the amount of nitrogen required for dry (FD) and irrigated (FI) production practices with the amount purchased (XF). The amount produced by endogenous livestock (FA) and the amount required/supplied by exogenous commodities (RF). This equation, defined at the market region level takes the form:

$$\sum_{i \epsilon p} \sum_{j=1}^{8} \sum_{k=1}^{k} \sum_{m=1}^{16} (FD_{i,j,k,m} * XD_{i,j,k,m}$$

$$+ \sum_{w=1}^{2} (FI_{i,j,k,m,w} * XI_{i,j,k,m,w})) - \sum_{q=1}^{14} (FA_{p,q} * XA_{p,q})$$

$$- XF_p \le RF_p$$

Water Sector Constraints (PA)

The water sector contains information on two water sources: ground water and surface water. When ground water is required to meet a rotations need (WR), an acre foot of ground water is pumped and applied (less efficiency loss (WEI)). The amount of water to be pumped in a year from ground water sources is not restricted.[6] The amount of water available to surface source irrigation activities is limited by that which is available less the net amount exported from the region. The water sector constraints take the form:

$$\sum_{j=1}^{8} \sum_{k=1}^{K} \sum_{m=1}^{12} ((XI_{i,j,k,m,w} * WR_{i,k,w}) - (WEI_{i,w} * XWA_{i,w})) \geq 0.0$$

when w=1, XWA_i is unconstrained (i.e. groundwater)

when w=2 (i.e. surface water):

$$XWA_{i,2} + \sum_{d=1}^{D} XWE_{i,d} \leq RWS_{i,2}$$

Erosion Accounting Rows (PA)

Two types of erosion estimates are included in ARIMS: 1) sheet and rill and 2) wind. These equations account for the erosion that occurs under both dry and irrigated crop production activities that come into solution.

Sheet and rill erosion:

$$\sum_{j=1}^{8} \sum_{k=1}^{K} \sum_{m=1}^{16} (SWTD_{i,j,k,m} * XD_{i,j,k,m}$$

$$+ \sum_{w=1}^{2} (SWTI_{i,j,k,m,w} * XI_{i,j,k,m,w}))$$

$$\geq 0.0$$

Wind erosion:

$$\sum_{j=1}^{8} \sum_{k=1}^{K} \sum_{m=1}^{16} (SWDD_{i,j,k,m} * XD_{i,j,k,m}$$

$$+ \sum_{w=1}^{2} (SWDI_{i,j,k,m,w} * XI_{i,j,k,m,w}))$$

$$\geq 0.0$$

Land Constraints

There are ten types of land constraints in the ARIMS. They are active at various regional levels. Six of these define resource land availability or restrict shifts at the producing area level. The two constraints at the market region level restrict land area patterns for crop acreages and terrace land. The ecosystem constraint defines the amount of resource available for grazing. Finally, an irrigation constraint that requires total irrigated acreage to at least equal a prespecified quantity is defined at a national level. These constraints are of the following form:

Total land constraint (PA):

$$\sum_{j=1}^{8} \sum_{k=1}^{K} \sum_{m=1}^{16} (XD_{i,j,k,m} + \sum_{w=1}^{2} (XI_{i,j,k,m,w})) \geq RLTOT_i$$

Dryland constraint (PA):

$$\sum_{k=1}^{K} \sum_{m=1}^{16} XD_{i,j,k,m} - (PDRY_{i,j} * XMDIC_i)$$

$$+ \sum_{w=1}^{2} (PIRR_{i,j,w} * XMIDC_{i,w}) + \sum_{r} PLR^{e}_{i,j,r} \leq RLDY_{i,j}$$

Irrigated land constraint (PA):

$$\sum_{k=1}^{K} \sum_{m=1}^{16} XI_{i,j,k,m,w} + (PDRY_{i,j} * XMDIC_{i})$$

$$- (PIRR_{i,j,w} * XMIDC_{i,w}) \leq RLIR_{i,j,w}$$

Conservation tillage land constraint (PA):

$$\sum_{j=1}^{8} \sum_{k=1}^{K} \sum_{m=9}^{12} \sum_{w=1}^{2} (XD_{i,j,k,m} + XI_{i,j,k,m,w}) \geq RLCTL_{i}$$

Zero tillage land constraint (PA):

$$\sum_{j=1}^{8} \sum_{k=1}^{K} \sum_{m=13}^{16} \sum_{w=1}^{2} (XD_{i,j,k,m} + XI_{i,j,k,m,w}) \geq RLZTL_{i}$$

Required irrigation land constraint (PA):

$$\sum_{j=1}^{8} \sum_{k=1}^{K} \sum_{m=1}^{16} XD_{i,j,k,m,w} \geq RLIT_{i,w}$$

Terraced land constraint (MR):

$$\sum_{i \epsilon p} \sum_{j=bb} \sum_{k=1}^{K} \sum_{m=aa} \sum_{w=1}^{2} (XD_{i,j,k,m} * XI_{i,j,k,m,w}) \geq RLTER_{p}$$

where:

aa = 4,8,12,16

bb = 2,3,4,8

Crop acreage constraint (MR):

$$\sum_{i\epsilon p} \sum_{j=1}^{8} \sum_{k=1}^{k} \sum_{m=1}^{16} (WTC_{n,i,j,k,m} * XD_{i,j,k,m}$$

$$+ \sum_{w=1}^{2} (WTC_{n,i,j,k,m} * XI_{i,j,k,m,w}))$$

$$\geq RLCRP_{n,p}$$

Grazing land constraint (ecosystem):

$$\sum_{h} XG_{e,f,g,h} + \sum_{i\epsilon e} PLR^{e}_{i,j,r} * XLP_{i,r} \leq RLG_{e,f,g}$$

Total irrigation land constraint (national):

$$\sum_{i=1}^{105} \sum_{j=1}^{8} \sum_{k=1}^{K} \sum_{m=1}^{16} \sum_{w=1}^{2} XI_{i,j,k,m,w} \geq RLIN$$

Final Demands

There are different types of demand defining constraints within ARIMS. Basically, that which is produced within a market region less that transported out plus the quantity transported in less the quantity required of a feedstuff must be greater than or equal to domestic consumption. There are three commodities, cotton, peanuts, and sunflowers, which do not have a transportation network, and hence a national demand is defined. The commodity final demand constraints are:

Crop (MR):

$$\sum_{i\epsilon p}^{105} \sum_{j=1}^{8} \sum_{k=1}^{K} \sum_{m=1}^{16} (YD_{n,i,j,k,m} * XD_{i,j,k,m}$$

$$+ \sum_{w=1}^{2} (YI_{n,i,j,k,m,w} * XI_{i,j,k,m,w}))$$

$$- XE_{p,c} - XB_{p,n} + \sum_{t\epsilon p} (XTC^{I}_{t,n} - XTC^{E}_{t,n})$$

$$- \sum_{u=1}^{7} XJ_{n,p,u} \geq RDC_{p,n}$$

Crop (national):

$$\sum_{p=1}^{31} XCT_{p,n} \geq RDCN_{n}$$

n = 4, 9, and 14

Dairy (MR):

$$(YA_{p,1,1} * XA_{p,1}) + \sum_{t\epsilon p} \quad XTA^{I}_{t,1} - XTA^{E}_{t,1} \quad - XE_{p,7} \geq RDL_{p,1}$$

Pork (MR):

$$\sum_{q=2}^{3} (YA_{p,q,2} * XA_{p,q}) + (YA_{p,4,2} * XA_{p,4}) + \sum_{t\epsilon p} \quad XTA^{I}_{t,2}$$

$$+ XTA^{E}_{t,2} \quad - XE_{p,8} \geq \ RDL_{p,2}$$

Grain fed beef (MR):

$$\sum_{q=8}^{12} (YA_{p,q,3} * XA_{p,q}) + \sum_{t\epsilon p} (XTA^{I}_{t,3} - XTA^{E}_{t,3})$$

$$- XE_{t,3} \geq RDL_{p,3}$$

Roughage fed beef (MR):

$$\sum_{q=13}^{14} (YA_{p,q,4} * XA_{p,q}) + (YA^{I}_{p,1,4} * XA_{p,1})$$

$$+ \sum_{q=5}^{7} (YA_{p,q,4} * XA_{p,q})$$

$$+ \sum_{t\epsilon p} (XTA^{I}_{t,4} - XTA^{E}_{t,4}) - XE_{t,4}$$

$$\geq RDL_{p,4}$$

Intermediate Demands

Finishing livestock activities require offspring as inputs. Thus, two equation types are required to balance feeder pigs and calves and yearlings availability. There is no transportation activity for feeder pigs. Thus, feeder pigs produced must be consumed within the same market region. These two equations have the form:

Feeder pigs (MR):

$$\sum_{q=2,4} (YA_{p,q,7} * XA_{p,q}) - \sum_{q=2}^{3} (NA_{p,q,7} * XA_{p,q}) \geq 0.0$$

Calves and yearlings (MR):

$$\sum_{q=5}^{7} (YA_{p,q,u} * XA_{p,q}) + (YA_{p,1,1} * XA_{p,1})$$

$$- \sum_{q=8}^{14} (NA_{p,q} * XA_{p,q}) + \sum_{t\epsilon p} XTA^{I}_{t,u} - XTA^{E}_{t,u} \geq 0.0$$

Other Demands

There are several other demand defining constraints required for the ARIMS. Export demands are identified for three coasts, the Atlantic, the Gulf, and Pacific. Exogenous livestock require feedstuffs. These are represented in the defining of feed grains, other concentrates, and roughages. Finally, livestock do not get all feed from endogenous sources. Some of the feed is produced on federal land and harvested through grazing at exogenously specified levels. In addition, the private sources of grazing land can be represented either exogenously or endogenously. These equations take the form:

Export demands (export region):

$$\sum_{p\epsilon s} XE_{p,c} \geq REX_{s,c}$$

where:

when: s=1, p=1,2,3,4,5,7,10,11
s=2, p=9,14,19
s=3, p=29,30,31

Exogenous feed demands (MR):

$$\sum_{n\epsilon b} XB_{p,b} \geq RB_{p,b}$$

where:

when: b=1, n=1,2,3,7,10,11
b=2, n=12
b=3, n=3,5,6,11

Pasture demands:

Private (grazing sector exogenous):

$$\Sigma XJ^{a}_{p,8,u} \leq RPR^{a}p$$

Private (grazing sector endogenous):

$$\Sigma XJ^{a}_{p,8,u} - \sum_{e=10}^{44} \sum_{f=1}^{3} \sum_{g=1}^{4} \sum_{h=1}^{90} (YG_{p,e,f,g,h} * XG_{e,f,g,h}) \leq RPR^{a}_{p}$$

Nutrient Needs (market region)

The nutrient requirements equation serves as the link between the livestock and crop sectors. These equations ensure a balanced ration for the various livestock types. The nutrient requirements equation is:

$$\sum_{n=1}^{16} (JJ_{p,n,v,z} * XJ_{p,n,v}) - (JA_{p,q,z} * XA_{p,q}) \geq 0.0$$

Roughage Limiting Constraints

There are two types of roughage limiting constraints. The first set provides a range of roughage that livestock can consume, and that is adequate to maintain the yield level specified in the model. The second roughage constraint type defines the maximum amount of roughage from range and pasture that can be utilized by beef and dairy. These take the form:

Roughage constraints (MR):

$$\sum_{n=1,2,7,10,12,15,16} XJ_{n,p,q} * (1-MINR_u)$$

$$- \sum_{n=3,5,6,8,9,11,14} XJ_{n,p,q} * (1-MINR_q)$$

$$\geq 0.0$$

$$\sum_{n=1,2,7,10,12,15,16} XJ_{n,p,q} * (1-MAXR_u)$$

$$- \sum_{n=3,5,6,8,9,11,14} XJ_{n,p,q} * (1-MAXR_q) \geq 0.0$$

Maximum range allowable constraint (national):

$$\sum_e \sum_f \sum_g \sum_h (XG_{e,f,g,h} * \sum_p YG_{p,e,f,g,h}) \leq RPRT$$

a = 1,2 for the two pasture/range ownership categories (1 = private and 2 = public)

b = 1,...,3 for the three exogenous crop categories

c = 1,...,6 crop and 7,...,10 livestock exporting activities

d = 1,...destinations of water outflows and exports

e = 10,....,44 ecosystems

f = 1,...,4 Range/Forest productivity classes

g = 1,....,3 Range/Forest condition classes

h = 1,....,90 Range/Forest strategies management

i = 1,....,105 crop production areas

j = 1,....,8 land groups

k = 1,....,500 single crop and 509,....,516 double crop rotation sequences

m = 1,....,12 conservation tillage possibilities

n = 1,....,16 endogenous crops

p = 1,....,31 market regions

q = 1,....,14 livestock types

r = 1,....,4 potential land conversion activities

s = 1,...,3 for the three exporting regions

t = 1,....,967 transporttion routes

u = 1,...,7 for the seven major livestock production categories: dairy, pork, grain-fed beef, roughage-fed beef, calves, yearlings, and feeder pigs

v = 1,....,5 for five livestock production categories: dairy, pork, cow/calf/yearling, grain-fed beef, and roughage-fed beef

w = 1,2 water source

z = 1,..,6 for the six nutrient types

Endnotes

[1] This has since been revised in the 1985 Food Security Act. The time between appraisals has been subsequently set at 10 years.

[2] These constraints provide inexpensive modeling means to deal with the rate of shifts in capital use, transfer of technology, and changes of institutions over time.

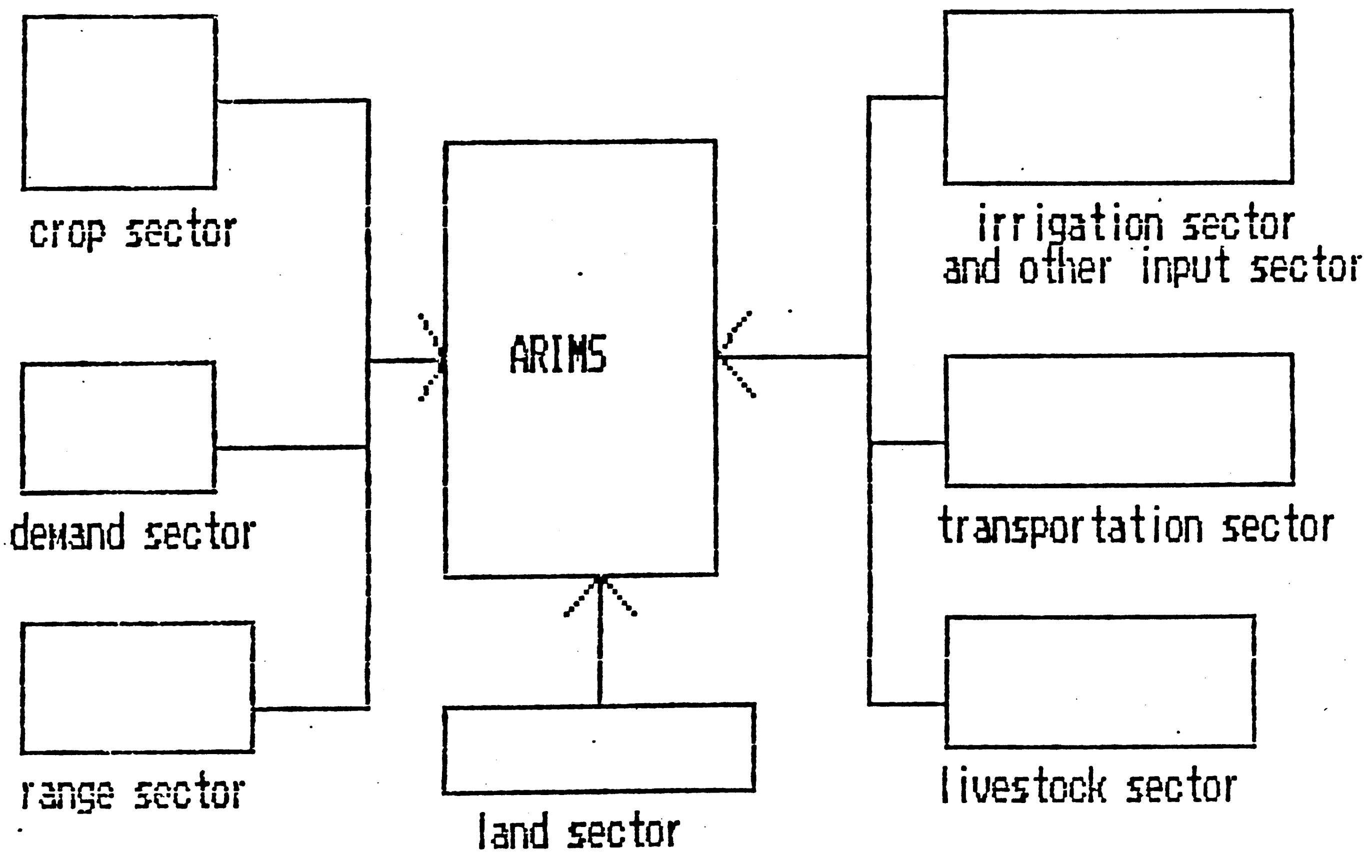
[3] When describing variables represented in Figure 5, the variable name is enclosed in parentheses, ().

[4] An ecosystem is defined as an ecological community considered together with the nonliving factors of its environment.

[5] A resource unit identifies the acres of privately owned land by productivity and condition class for an ecosystem.

[6] However, in moving from one time period to the next, the costs of acquiring groundwater are adjusted to reflect increases in depth to water.

Figure 1. The National Agricultural Resource Interregional Modelling System used in the appraisal required by the Resource Conservation Act



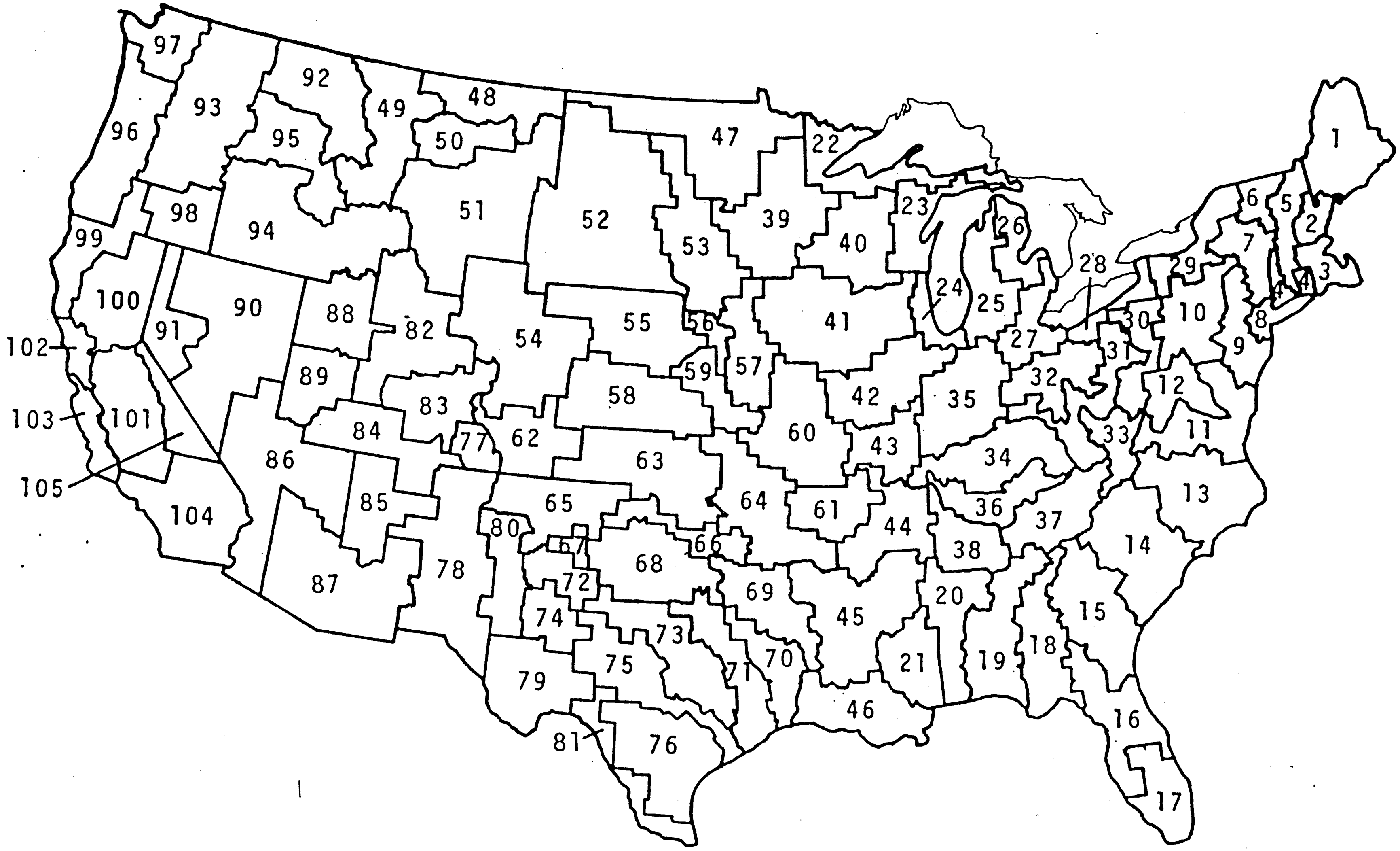


Figure 2. The 105 producing areas

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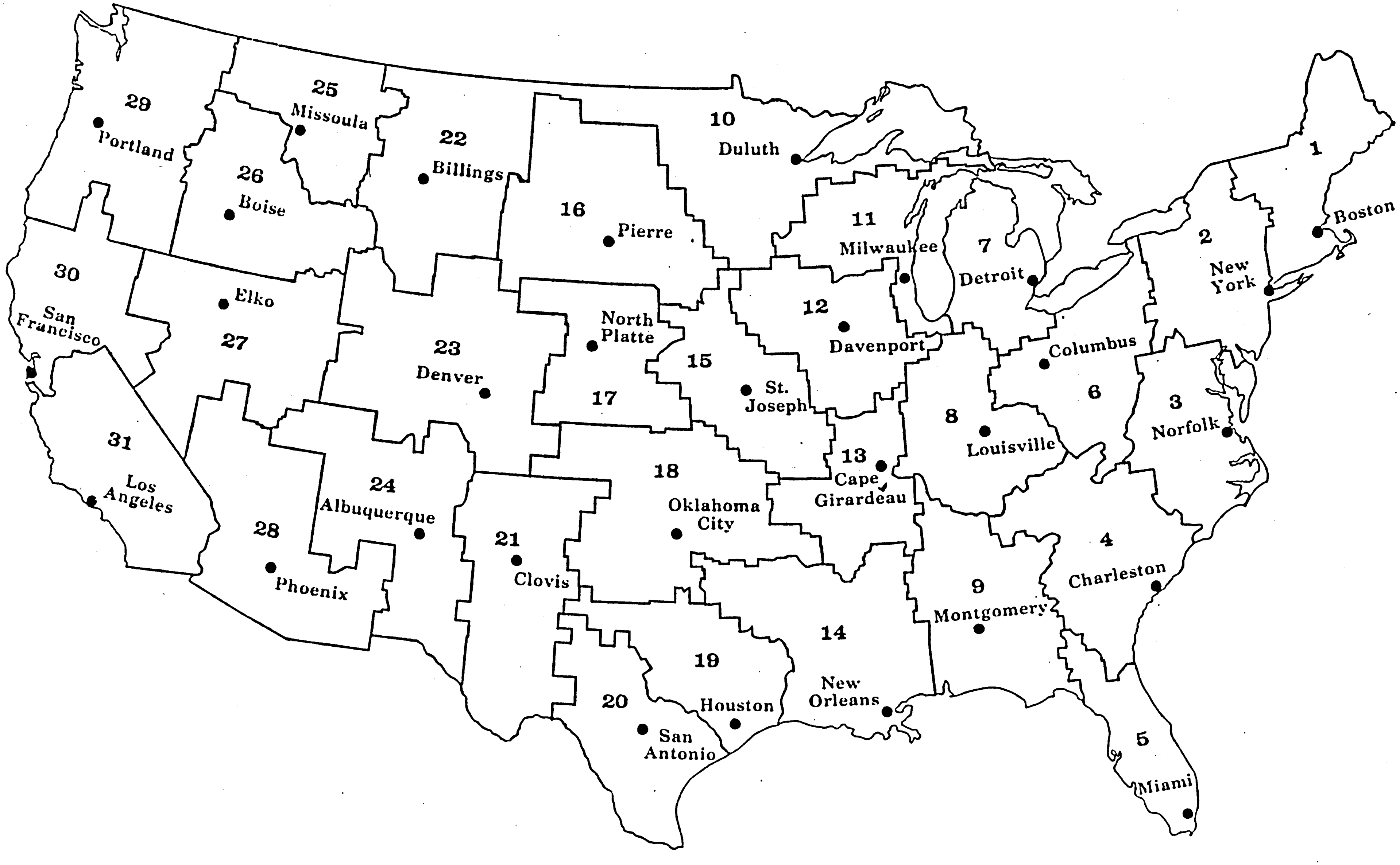
Figure 3. **THIRTY-ONE CARD-RCA MODEL MARKET REGIONS**



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Constraint Type	Row Type	RHS	XD PAx	XIS PAx	XIG PAx	XLP PAx	XMDIC PAx	XMIDC PAx	XMWET PAx	XWAS PAx	XWAG PAx	XWB PAx	XWO PAx	XD PAy	XIS PAy	XIG PAy	XLP PAy	XMDIC PAy	XMIDC PAy	XMWET PAy	XWAS PAy	XWAG PAy	XWB PAy	XWO PAy	XA MRz	XB MRz	XE MRz	XF MRz	XJ MRz	XTA MRz TO MRv	XTC MRz TO MRv	XG ECq
Objective Fn.			CD	CI	CI	CLP	CMDIC	0.01	CMWET	CWA	CWA			CD	CI	CI	CLP	CMDIC	0.01	CMWET	CWA	CWA			CA		CE	CF	CJ	CTA	CTC	CG
Total Irr. Land	G	RLIN		1	1										1	1																
Nat. Crop Demand	G	RDCN	YD	YI	YI									YD	YI	YI																
Total Range	L	RPRT																														YG
Export Demands	G	REX																									1					
Graze Land	L	RLG				-PLR											-PLR															1
Erosion (SSED)	N	0																														SSED
Total Land (x)	G	0	1	1	1																											
Dry Land (x)	L	RLDY(x)	1			PLR	-PDRY	PIRR	(+-1)																							
Irr. Land (Surf) (x)	L	RLIR(x)		1			PDRY	-PIRR																								
Irr. Land (Grnd) (x)	L	RLIR(x)			1		PDRY	-PIRR																								
Cons. Till Max (x)	L	RLCTL(x)	0,1	0,1	0,1																											
Zero Till Max (x)	L	RLZTL(x)	0,1	0,1	0,1																											
Irr. Land Req. (x)	G	RLIT(x)		1	1																											
Irr. Needs (Surf) (x)	L	0		WR						-WEI																						
Irr. Needs (Grnd) (x)	L	0			WR						-WEI																					
Surf. Water Supply (x)	L	RWS(x)								1		(+-1)	(+-1)																			
Erosion (S&R) (x)	N	0	SWTD	SWTI	SWTI																											
Erosion (Wind) (x)	N	0	SWDD	SWDI	SWDI																											
Total Land (y)	G	0												1	1	1																
Dry Land (y)	L	RLDY(y)												1			PLR	-PDRY	PIRR	(+-1)												
Irr. Land (Surf) (y)	L	RLIR(y)													1			PDRY	-PIRR													
Irr. Land (Grnd) (y)	L	RLIR(y)														1		PDRY	-PIRR													
Cons. Till Max (y)	L	RLCTL(y)												0,1	0,1	0,1																
Zero Till Max (y)	L	RLZTL(y)												0,1	0,1	0,1																
Irr. Land Req. (y)	G	RLIT(y)													1	1																
Irr. Needs (Surf) (y)	L	0													WR						-WEI											
Irr. Needs (Grnd) (y)	L	0														WR						-WEI										
Surf. Water Supply (y)	L	RWS(y)																			1		(+-1)	(+-1)								
Erosion (S&R) (y)	N	0												SWTD	SWTI	SWTI																
Erosion (Wind) (y)	N	0												SWDD	SWDI	SWDI																
Fertilizer (z)	L	RF	FD	FI	FI									FD	FI	FI									-FA			-1				
Terrace Min. (z)	G	RLTER(z)	0,1	0,1	0,1									0,1	0,1	0,1																
Crop Acreage (z)	G	RLCRP(z)	WTC	WTC	WTC									WTC	WTC	WTC																
Final Demands (Crop) (z)	G	RDC(z)	YD	YI	YI									YD	YI	YI										-1	-1		-1		(+-1)	
Final Demands (Live) (z)	G	RDL(z)																							YA		-1			(+-1)		
Inter. Demands (Live) (z)	G	0																							YA,NA					(+-1)		
Exog. Feed Demands (z)	G	RD(z)																								1						
Pasture Demands (z)	L	RPR(z)																											1			-YG
Nutrient Needs (z)	G	0																							JA				JS			
Roughage Cons. (z)	G	0																							MINR,MAIR							
Bounds						BND	BND										BND	BND														

Note: 0,1 indicates that either value can occur depending on the activity type
(+-1) indicates that either a +1 or a -1 can be placed in these cells depending on the activity flow

Figure 5. A schematic of the Agricultural Resource Interregional Modelling System's Programming Models

Figure 6. Attributes of the crop sector

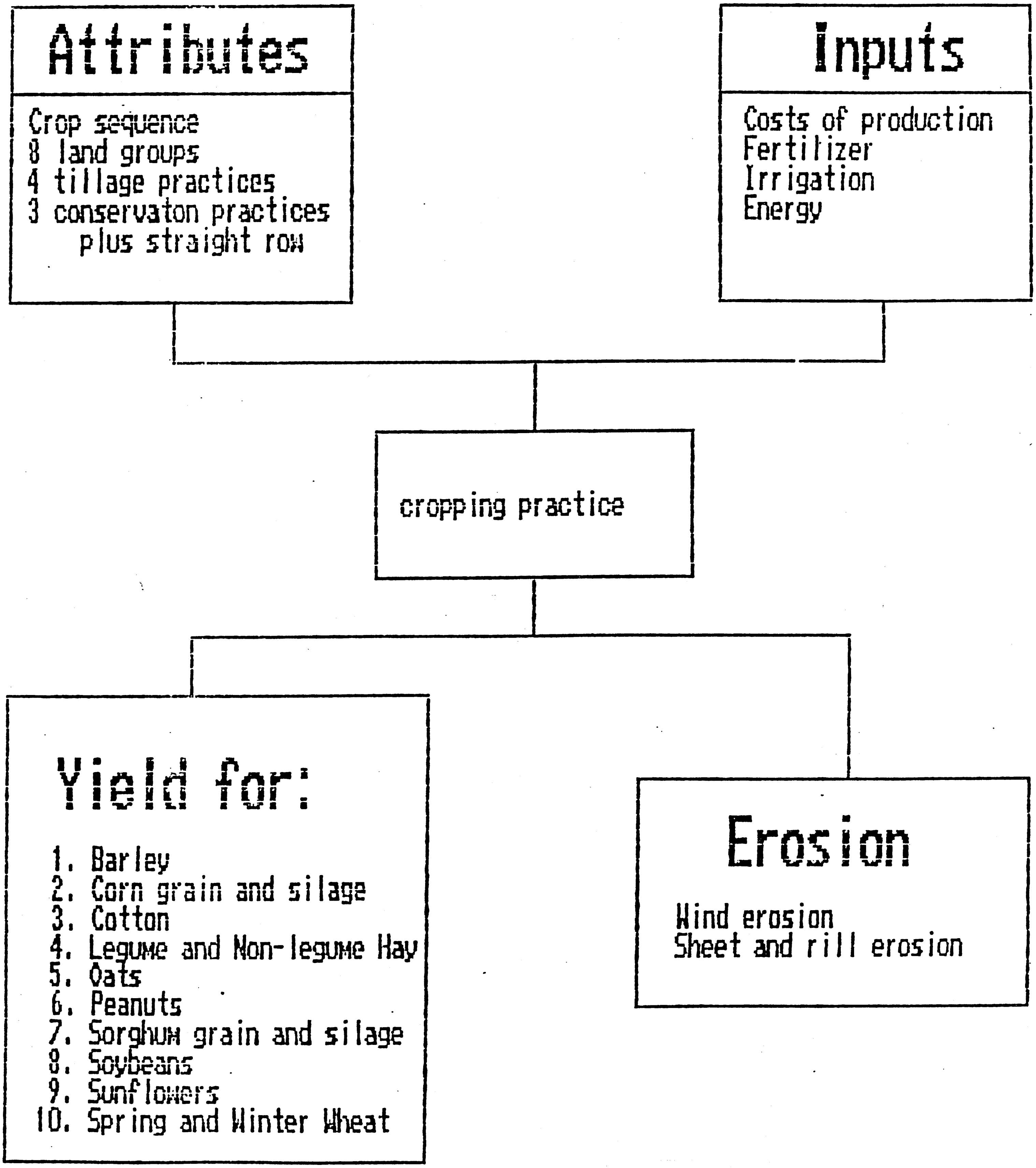
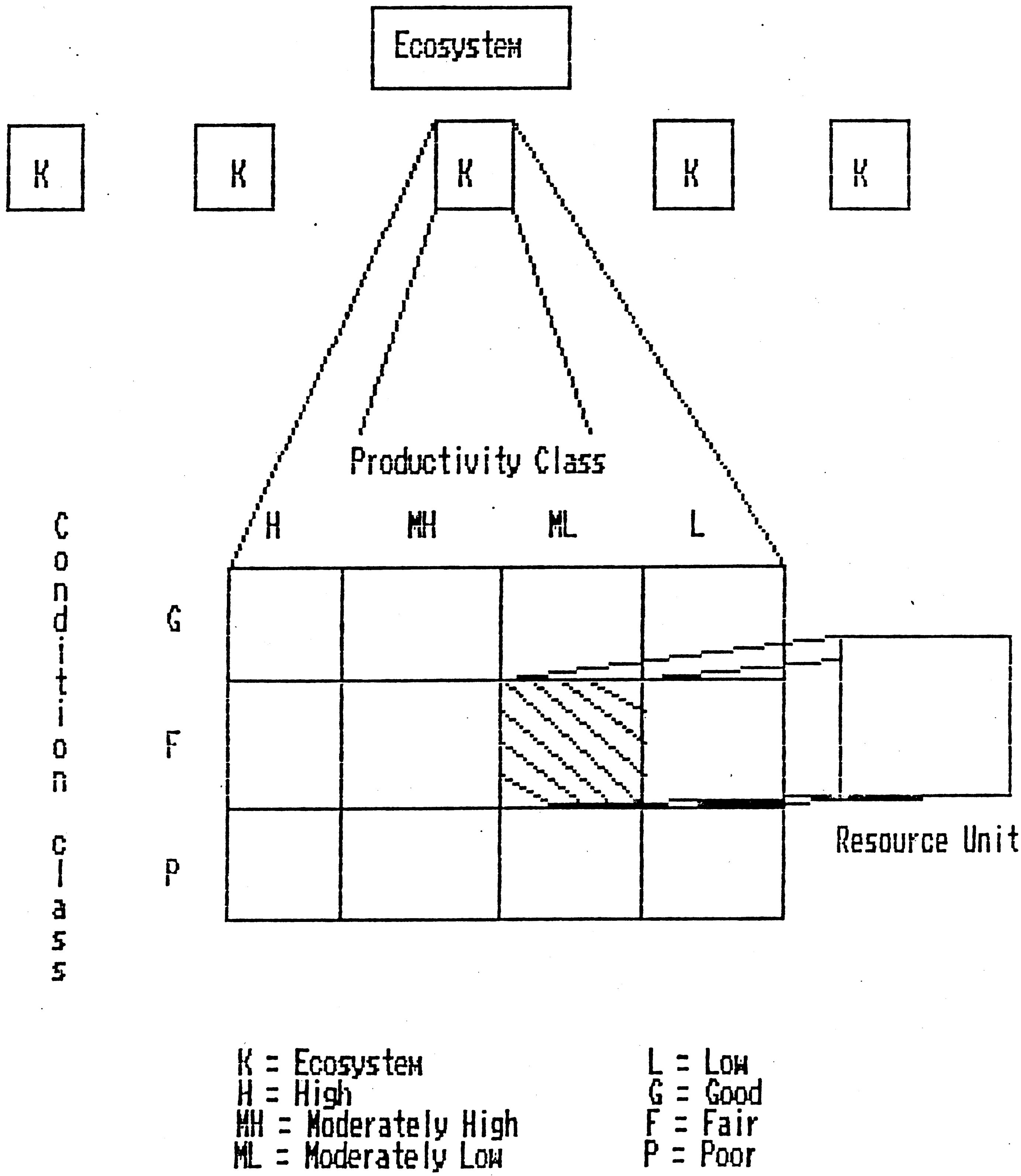


Figure 7. Schematic of a resource unit



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THIRTY-ONE CARD-RCA MODEL MARKET REGIONS

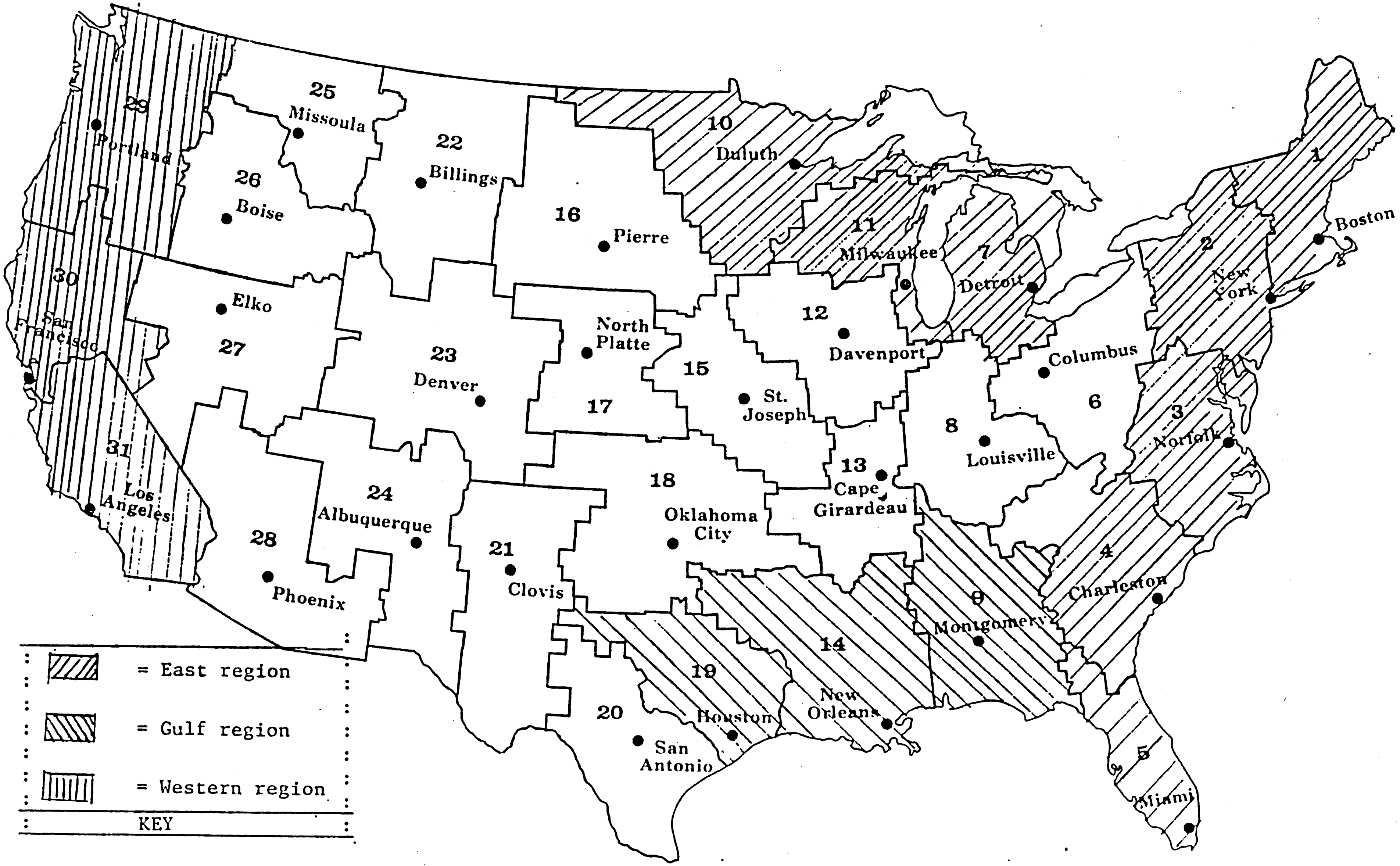

Figure 8: Definitions of exporting regions

Table 1. Listing of documentation publications

Title	Authors
A Documentation of the Transportation and Demand Sectors of the National Agricultural Resource Interregional Modeling System Used in the Resource Conservation Act Analysis	English and Campos
A Documentation of the Range-Forest Sector of the National Agricultural Resource Interregional Modeling System Used in the Resource Conservation Act Analysis	Campos and English
Costs of Irrigation and the Availability of Water: A Documentation of the Irrigation Sector of the National Agricultural Resource Interregional Modeling System Used in the Resource Conservation Act Analysis	Smith, English, and Hansen
A Documentation of the Endogenous and Exogenous Livestock Sectors of the National Agricultural Resource Interregional Modeling System Used in the Resource Conservation Act Analysis	English, Disney, and Schraufnagel
A Documentation of the Endogenous and Exogenous Crop Sectors of the National Agricultural Resource Interregional Modeling System Used in the Resource Conservation Act Analysis	English, Atwood, and Smith
A Documentation of the Land Sector in the National Agricultural Resource Interregional Modeling System Used in the Resource Conservation Act Analysis	English and Post
An Overview and Mathematical Representation of the National Agricultural Resource Interregional Modeling System	English, Smith, and Oamek
The National Agricultural Resource Interregional Modeling System: A Documentation	English and Johnson
The National Agricultural Resource Interregional Modeling System: An Executive Summary	English and Johnson
Costs of Producing Crops by Tillage Practice and Major Land Resource Area: A Discussion of the Budget Developed During the 1985 Resource Conservation Act Analysis	English, Smith, Eveland, and Atwood

Table 1. Definition of land quality groupings and allowable conservation practices in the Southeast Model[a]

Land Group[b]	USDA Land Capability Class/Subclass[c]	Conservation Practices: Straight Row	Contour	Strip Cropping	Terracing
I	I, II_{wa}, III_{wa}	X			
II	II_e	X	X	X	X
III	III_e	X	X	X	X
IV	IV_e	X		X	X
V	II_e, III_c, IV_c	X		X	
VI	II_s, III_s, IV_s	X	X[d]	X	
VII	II_w, III_w, IV_w	X			
VIII	V, VI, VII, VII	X	X	X	X

[a]Each X incorporates fall and spring conventional, conservation and zero tillage practice in combination with the conservation practice.

No till = more than 70 percent residue cover after planting
Conservation tillage = between 30 and 70 percent residue covering after planting
Conventional tillage = less than 30 percent residue cover after planting (without winter cover = fall primary tillage, with winter cover = spring primary tillage)

[b]These are the land groupings defined for the 1985 Resource Conservation Appraisal.

[c]The subclass subscripts are standard except that wa indicates land classified as having a wetness problem but that the problem has been adequately treated.

[d]This practice is not allowed on sand.

[e]In specified PAs, strip cropping is designated as being for wind erosion control rather than for water.

Table 2. Description of variables used in the mathematical expression of the model

Variable Name	Variable Description
$CA_{p,q}$	is the per unit cost of livestock production in market region (p) for livestock type (q) (dollars per cwt. of primary product)
$CD_{i,j,k,m}$	is the cost of dryland cropping practices in producing area (i), on land group (j), rotation (k), employing tillage practice (m) (dollars per acre)
$CE_{p,e}$	is the cost of exporting commodity (c) from Great Lakes Region to the east cost market regions (p) (7,10, and 11) (dollars per unit)
CF_{p}	is the per unit cost of fertilizer in market region (p) (dollars per pound)
$CG_{e,f,g,h}$	is the per unit cost of forage production in ecosystem (e), productivity class (f), condition class (g), with management strategy (h) (dollars per acre)
$CI_{i,j,k,m,w}$	is the cost of dryland cropping practices in producing area (i), on land group (j), rotation (k), employing tillage practice (m) (dollars per acre)
$CJ_{p,n,v}$	is the per unit cost of feeding crop (n) for livestock type (v) in market region (p) (dollars per unit)
$CLP_{i,r}$	is the cost of converting potential crop land in producing area (i) and conversion type (r) (dollars per acre)
$CMDIC_{i,j}$	is the cost of converting an acre of non-irrigated land to irrigated land in producing area (i) on land group (j)
$CMWET_{i}$	is the cost of converting an acre of wetlands to non-irrigated cropland in producing area (i)
$CTA_{t,u}$	is the per unit cost of transporting endogenous commodity (u) over transportation route (t) (dollars per hundred weight)
$CTC_{t,n}$	is the per unit cost of transporting endogenous commodity (n) over transportation route (t) (dollars per unit)
$CWA_{i,w}$	is the cost per acre foot of applying water source (w) in producing area (i) (dollars per acre-foot)
$FA_{p,q}$	is the amount of manure (expressed in nitrogen equivalents) produced in market region (p) by livestock type (q)

Table 2. continued

Variable Name	Variable Description
$FD_{i,j,k,m}$	is the amount of nitrogen required by a dryland cropping practice in producing area (i), land group (j), rotation (k), and conservation tillage practice (m) (pounds)
$FI_{i,j,k,m,w}$	is the amount of nitrogen required by a dryland cropping practice in producing area (i), land group (j), rotation (k), using irrigation type (w) and conservation tillage practice (m) (pounds)
$JA_{p,q,z}$	is the amount of nutrient (z) required by the livestock production activity type (q) in market region (p)
$JJ_{p,n,u,z}$	is the amount of nutrient (z) supplied by one unit of commodity (n) to major livestock type (u) in market region (p)
$MAXR_u$	is the maximum percent roughage that can occur in the ration and maintain the level of yield for livestock type (u)
$MINR_u$	is the minimum percent roughage that can occur in the ration and maintain the level of yield for livestock type (u)
$NA_{p,q,u}$	is the amount of replacement stock required of major livestock type (u) for livestock production activity (q) in market region (p)
$PDRY_{i,j}$	is the percent of dryland in land group (j) and producing area (i) that is converted when one dryland acre is converted to irrigated land.
$PIRR_{i,j,w}$	is the percent of irrigated land using source (w) in land group (j) and producing area (i) that is converted when one dryland acre is converted to dry land
$PLR^e_{i,j,r}$	is the percent of land in ecosystem (e) having potential of (r) in producing area (i) and land group (j)
$RB_{p,b}$	is the amount of feed required by the exogenous livestock in market region (p) for feed type (b)
$RDC_{p,n}$	is the amount of commodity (n) demanded in market region (p)
$RDCN_n$	is the amount of crop commodity (n) demanded at a national level [This RHS value exists only for those crops with no transportation network]
$RDL_{p,u}$	is the amount of livestock commodity (u) demanded in market region (p)

Table 2. continued

Variable Name	Variable Description
$REX_{s,c}$	is the level of exports for commodity (c) in exporting region (s)
RF_{p}	is the level of fertilizer available (required) by exogenous agriculture in market region (p)
$RLCRP_{n,p}$	is the amount of land that is planted in crop (n) in market region (p)
$RLCTL_{i}$	is the maximum quantity of land available for conservation tillage cropping practices in producing area (i)
$RLDY_{i,j}$	is the amount of land available for endogenous dryland cropland production in land group (j) and producing area (i)
$RLG_{e,f,g}$	is the quantity of grazing land in ecosystem (e), productivity class (f), and condition class (g)
RLIN	is the minimum number of acres irrigated
$RLIR_{i,j,w}$	is the amount of land available for endogenous irrigated cropland production in land group (j) and producing area (i)
$RLIT_{i,w}$	is the minimum level of irrigated acres in producing area (i) using water source (w)
$RLTER_{i}$	is the amount of land required to be in terraces in producing area (i)
$RLTOT_{i}$	is the total amount of land required to come into solution in producing area (i)
$RLZTL_{i}$	is the amount of zero or no tillage that can come into the solution in producing area (i)
$RWS_{i,w}$	is the quantity of water available in producing area (i), and source of water (w)
RPR_{p}^{a}	is the quantity of pasture available in market region (p) and ownership category (a) [when the grazing sector is endogenous and a = 1, this value is 0]
RPRT	is the maximum amount of tons from the range sector
$SWDD_{i,j,k,m}$	is the per acre wind erosion coefficient for dryland farming in producing area (i), land group (j), rotation (k), and conservation tillage practice (m)

Table 2. continued

Variable Name	Variable Description
$SWDI_{i,j,k,m,w}$	is the per acre wind erosion coefficient for irrigated land farming in producing area (i), land group (j), rotation (k), and conservation tillage practice (m)
$SWTD_{i,j,k,m}$	is the per acre sheet and rill erosion coefficient for dryland farming in producing area (i), land group (j), rotation (k), and conservation tillage practice (m)
$SWTI_{i,j,k,m,w}$	is the per acre sheet and rill erosion coefficient for irrigated land farming in producing area (i), land group (j), rotation (k), conservation tillage practice (m), and water source (w)
$WEI_{i,w}$	is the incidental efficiency of water for producing area (i) and source of water (w)
$WEO_{i,w}$	is the on-farm water efficiency for producing area (i) and source of water (w)
$WR_{i,k,w}$	is the water requirement for producing area (i), rotation (k), and source of water (w)
$WTC_{n,i,j,k,m}$	is the percentage of crop (n) in producing area (i), land group (j), rotation (k), and conservation tillage practice (m)
$XA_{p,q}$	is the activity level of livestock production type (q) in market region (p)
$XB_{p,n}$	is the activity level to transfer crop (n) so that exogenous livestock needs can be met in market region (p)
$XD_{i,j,k,m}$	is the activity level of dryland crop production in producing area (i), land group (j), rotation (k), and conservation/tillage practice (m)
$XE_{p,c}$	is the amount of commodity (c) transferred from the market region (p) final demand constraints to the exporting regions
XF_{p}	is the level of the nitrogen purchasing activity in market region (p)
$XG_{e,f,g,h}$	is the level of the range activity in ecosystem (e), productivity class (f), condition class (g), under management level (h)
$XI_{i,j,k,m,w}$	is the activity level of irrigated land crop production in producing area (i), land group (j), rotation (k), conservation/tillage practice (m), and water source (w)

Table 2. continued

Variable Name	Variable Description
$XJ_{p,n,q}$	is the level of crop (n) used for major endogenous livestock type (q) in market region (p)
$XLP_{i,r}$	is the quantity of potential land type (r) in producing area (i) that is converted to cropland
$XMDIC_{i,w,j}$	is the quantity of land converted from dry to irrigation source (w) in producing area (i) of land group (j)
$XMIDC_{i,w,j}$	is the quantity of land converted from land with irrigation source (w) in producing area (i) of land group (j)
$XMWET_{i}$	is the quantity of cropland classified as a W soil (Land Group 7) and converted to RCA Land Group 1 soil through drainage
$XTA_{t,u}$	is the amount of major livestock type (u) transported on route (t) with a superscript I indicates an Import into a region, with an E it is an Export
$XTC_{t,n}$	is the amount of crop (n) transported on route (t) with a superscript I indicates an Import into a region, with an E it is an Export
$XWA_{i,w}$	is the amount of water applied in producing area (i) from source (w)
$XWE_{i,d}$	is the amount of water exported in producing area (i) to destination (d)
$XWO_{i,d}$	is the amount of water outflow in producing area (i) to destination (d)
$YA_{p,q,u}$	is the yield for major livestock type (u) in livestock category (q) in market region (p)
$YD_{n,i,j,k,m}$	is the dryland yield for crop (n) in producing area (i), land group (j), rotation (k), and tillage practice (m)
$YG_{p,e,f,g,h}$	is the proportion of pasture/range yield in market region (p) that is in—ecosystem (e), productivity class (f), condition class (g), under range management practice (h)
$YI_{n,i,j,k,m,w}$	is the irrigated yield for crop (n) in producing area (i), land group (j), rotation (k), tillage practice (m), and water source (w)

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DOCUMENT INFORMATION SHEET

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Title or Topic: An Overview of the Structure for the National Agricultural Resource Interregional Modelling System

Date Received: 7/20/88

Date Needed: ASAP

Date Completed: 7/22/88

tjc--revision 7/27/88

- _X_ New Paper
- ____ New Paper Created from Existing Paper
- ____ Preliminary Draft
- _X_ Rough Draft # 2
- ____ Final Draft
- ____ Proposal

Authors: Stan

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Comments: This paper presented at pre-conference symposium at AAEA in Knoxville, TN, July 29-30, 1988.

Solution Summary Tables for Policy Scenarios

The CARD LP contains 125,000 activities and 7,000 rows/constraints. In solution to to 7,000 of the activity will have nonzero values. In addition, these activities often produce several commodities and are by region other than those for which results must be reported. Therefore, a set of solution summary programs were developed which arrange the model results in tabular form. The tables currently available are listed in Table 1. These tables are available at the national, USDA Farm Production Region, CARD LP Product Area (PA) and States, though selected tables are only appropriate at the national level. Weighting methods are required in moving from the PA to the state and USDA regional levels. Programs are also available for computing the percentage difference between one solution and another and putting the results out in the same tables.

Example tables, reporting results more directly relevant to these policy exercises are provided for the national level and also for the Corn-Belt Region. The tables carry numbers that are consistent with the summary table system outlined in Table 1.

Table 1. Titles of solution summary tables available for the CARD LP

Table 1.	Available private land by land group and major land use
Table 2.	Total available acres of endogenous and exogenous cropland, and of wetlands and other potential cropland by land group
Table 3.	Cropland use--dry, irrigated and total--by land group
Table 4.	Cropland use--dry, irrigated, and total--by major crop and land group
Table 5.	Cropland used for double crops--dry, irrigated, and total--by major crop and land group
Table 6.	Crop yield per planted acre--dry, irrigated, and total--by major crop and land group
Table 7.	Double crop yield per planted acre--dry, irrigated, and total--by major crop and land group
Table 8.	Crop production--dry, irrigated, and total--by major crop and land group
Table 9.	Cropland use by land group, tillage system, and supporting practice.
Table 10.	(AOF) Soil loss per acre from sheet and rill and wind erosion--dry, irrigated, and total--by land group
Table 10.	(USLE) Soil loss per acre from sheet and rill and wind erosion--dry, irrigated, and total--by land group
Table 11.	Total (AOF) soil loss from sheet and rill and wind erosion--dry, irrigated, and total--by land group
Table 11.	Total (USLE) soil loss from sheet and rill and wind erosion--dry, irrigated, and total--by land group
Table 12.	Total (AOF) soil loss from sheet and rill erosion by land group, supporting practice, and tillage system
Table 12.	Total (USLE) soil loss from sheet and rill erosion by land group, supporting practice, and tillage system
Table 13.	Total soil loss from wind erosion by land group, supporting practice, and tillage system.
Table 14A.	Endogenous cropland acres and soil loss from wind erosion by land group and soil loss interval
Table 14B.	Endogenous cropland acres and (AOF) soil loss from sheet and rill erosion by land group and (AOF) soil loss interval

Table 1. Titles of solution summary tables available for the CARD LP (continued)

Table 14C.	Endogenous cropland acres and (AOF) soil loss from sheet and rill and wind erosion by land group and (AOF) soil loss interval
Table 14D.	Endogenous cropland acres and (USLE) soil loss from sheet and rill erosion by land group and (USLE) soil loss interval
Table 14E.	Endogenous cropland acres and (USLE) soil loss from sheet and rill and wind erosion by land group and (USLE) soil loss interval
Table 15.	Total acres converted to cropland and the cost of conversion by land use and land group
Table 16.	Total acres served by terracing and the annual cost by land group
Table 17.	Total acres of cropland and wet soils drained and the annual cost of drainage (Land Group 7)
Table 18.	Water Gross divisions and consumption by source, surface, or groundwater, and by use
Table 19.	Water used on endogenous cropland by source
Table 20.	Net water depletion in irrigating endogenous cropland by major crop and land group
Table 21.	Nitrogen, phosphorous, and potassium used by crop
Table 22.	Total energy used, on-farm and off-farm, by major crop and operation
Table 23.	Diesel fuel used, on-farm and off-farm, by major crop and operation (gasoline used in diesel equivalent)
Table 24.	Natural gas used, on-farm and off-farm, by major crop and operation
Table 25.	L.P.G. used, on-farm and off-farm, by major crop and operation
Table 26.	Electricity used, on-farm and off-farm, by major crop and operation
Table 27.	Total cost of production and the marginal land value for the major crops
Table 28.	Production, distribution, value of production, and marginal value by major commodity

Table 1. Titles of solution summary tables available for the CARD LP (continued)

Table 29.	Total production, value of production, and marginal value by major commodity
Table 30.	Manure production and water used by major livestock enterprise
Table 31.	Total cost of livestock production by major livestock enterprise
Table 32.	Total livestock feed consumption by major livestock enterprise and crop
Table 33.	Energy used in livestock production by major livestock enterprise and energy type
Table 34.	Consumer cost of commodities endogenously and exogenously produced
Table 35.	Net flow of commodities between market regions and transportation costs accrued at point of destination
Table 36.	Exogenous livestock sector
Table 37.	Input requirements for the exogenous crop sector by crop type
Table 38.	Private land used for grazing under selected management levels by productivity and condition class
Table 39.	Wood production (net wood growth) on private land grazed under selected management levels by productivity and condition class
Table 40.	Dry weight production of grazed material and cost of production under selected management levels by productivity class on private land
Table 41.	Dry weight herbage and browse yields under selected management levels by productivity class on private land
Table 42.	Sediment delivered from grazed lands to streams under selected management levels by productivity class
Table 43.	Per acre sediment delivered to streams under selected management levels by productivity class
Table 44.	Acres of CRP and Buffer Strip Land
Table 45.	Soil Loss per Acre on CRP, Buffer Strip, and Other Idle Land

Table 1. Titles of P
(continued)

Transparencies for Symposium Presentation

ion and

Choice Variables:

- Production location
- Commodities transported for consumptio
- Crop rotations
- Tillage method and conservation practice
- Irrigation
- Purchase or production of Nitrogen
- Transportation method
- Livestock enterprises, sizes and types
- Idle land with a green cover
- Enrollment in CRP

attern

MINIMIZE: National Production and Transportation Cost

Subject To:

- Fixed commodity demands
- Available land resources
- Available water resources
- Available technology
- Allowable changes from historical pattern
- Policy constraints

Choice Variables:

- Production location
- Commodities transported for consumption
- Crop rotations
- Tillage method and conservation practice
- Irrigation
- Purchase or production of Nitrogen
- Transportation method
- Livestock enterprises, sizes and types
- Idle land with a green cover
- Enrollment in CRP

CARD LP DIMENSIONS -- ACTIVITIES

125,000 activities

7000 rows/constraints

105 CROP PRODUCTION AREAS (PA's)

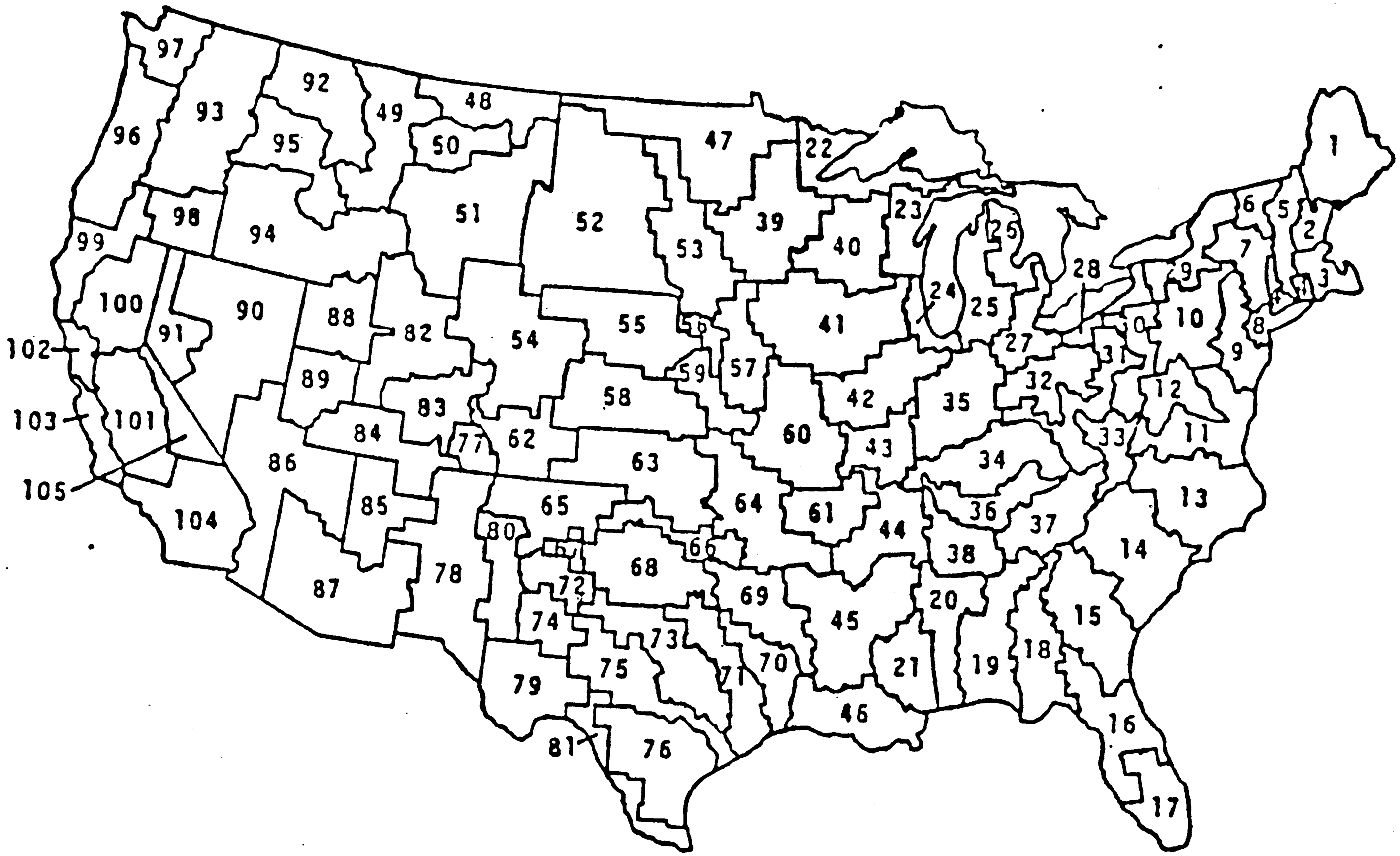
(River basins/water sheds)

3 LAND TYPES (dry and irrigated with surface or ground water)

8 SOIL GROUPS (productivity and erodability)

16 TILLAGE AND CONSERVATION PRACTICE OPTIONS

- Fall and Spring Conventional, Conservation and Zero Till
- Straight Row, Contouring, Strip Cropping and Terracing



Crop Producing Areas (PAs)

- 105 in number
- based on water basins and watersheds
- define homogeneous land and water resource areas

590 CROP ROTATION OPTIONS

(1 to 6 years and about 20 per area)

- Some Double Crops

2 IRRIGATION OPTIONS (surface and ground water)

36 LAND CONVERSIONS:

- Dry to Irrigated by Water Source and Soil Type
- Irrigated to Dry by Water Source and Soil Type
- From Potential Cropland, High and Medium Potential and Forest and Range

1 LAND DRAINAGE

8 LAND IDLING

7 CRP SIGNUPS (soil types 2 to 8)

CARD LP DIMENSIONS -- ACTIVITIES

31 MARKET REGIONS (OVERLAP PA's)

14 LIVESTOCK ENTERPRISES (diary, pork, beef, vertical integration and size choices)

112 RATION CHOICES (16 feeds and 7 major types of livestock consumption)

967*22 COMMODITY TRANSPORTATION (967 routes for barge, rail or truck, and 22 commodities)

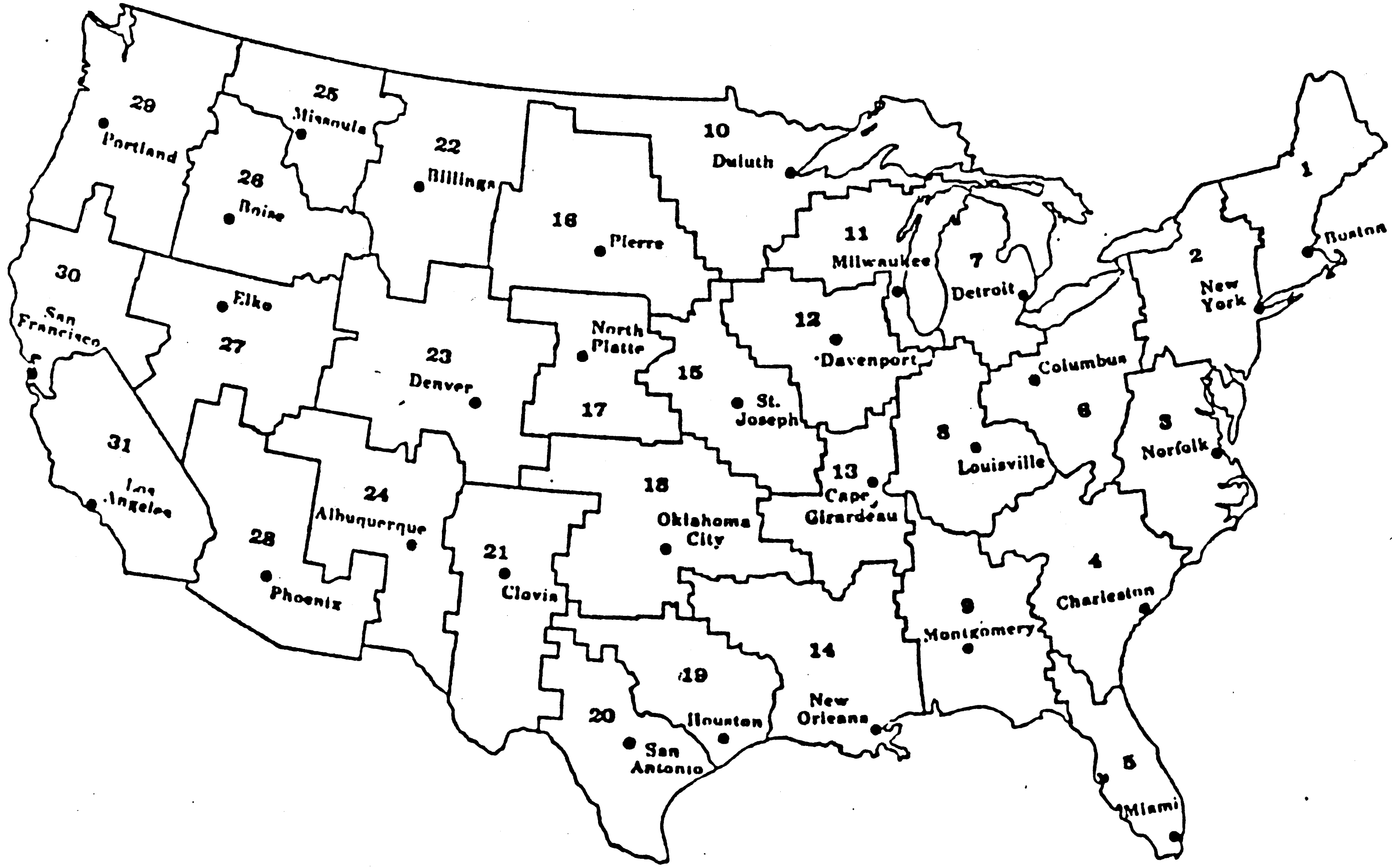
1 NITROGEN PURCHASE

34 ECOSYSTEMS

4 PRODUCTIVITY CLASSES

3 CONDITION CLASSES

90 MANAGEMENT STRATEGIES



Market Regions (MRs)

- 31 in number
- commodity demand centers
- commodity transportation centers
- input supply
- livestock production
- 3 MR have export roles

CARD LP DIMENSIONS -- ROWS/CONSTRAINTS

105 CROP PRODUCTION AREAS (PA's)

- 2 IRRIGATION WATER BALANCE (ground and surface)
- 2 EROSION ACCOUNTING (sheet and rill; wind)
- 24 LAND AVAILABILITY (dry, surface and ground and 8 soils)
- 2 TILLAGE UPPER BOUNDS (conservation and zero)
- 1 MINIMUM IRRIGATED ACREAGE
- 1 EROSION RESTRICTION
- 1 CRP ENROLLMENT ACCOUNTING
- 1 MINIMUM TERRACED ACRES

31 MARKET REGION (MR's)

1 NITROGEN FERTILIZER BALANCE

16 MINIMUM CROP ACREAGE CONSTRAINTS

16 CROP COMMODITY DEMAND/BALANCES

14 LIVESTOCK COMMODITY DEMAND/BALANCES

n EXOGENOUS FEED DEMAND

n ROUGHAGE CONSUMPTION CONSTRAINTS

3*X EXPORT DEMAND/BALANCES (3 MR's and X commodities)

34 ECOSYSTEMS

1 PRIVATE GRAZING

1 PUBLIC GRAZING

7 RESOURCE AVAILABILITY (productivity and condition classes)

NATIONAL

3 COMMODITY BALANCE (cotton, peanuts and sunflower)

1 TOTAL LAND CONSTRAINT

1 UPPER BOUND ON ROUGHAGE FED BEEF

n FEED DISAPPEARANCE CORRECTION

CARD LP MAJOR DATA SOURCES

1982 NATURAL RESOURCES INVENTORY

- Land and Soil Resources
- HIstorical Crop Acreage
- Historical Tillage, Conservation Practices and Irrigation Type

STATISTICAL REPORTING SERVICE COUNTY ESTIMATES
(1985-86 average)

- Base Yield and Production Levels

EROSION PRODUCTIVITY IMPACT CALCULATOR (EPIC)

- Erosion Estimates
- Fertilizer Adjustments for Accumulated Erosion
- Yield Adjustments for:
  Soil type, tillages, crop sequence, and
  accumulated erosion

FIRM ENTERPRISE DATA SYSTEM (supplemented by CARD and USDA)

- Crop and Livestock Enterprise Budgets

FAPRI

- National Commodity and Export Level Projections for 1990

CONSERVATION TILLAGE INFORMATION CENTER

- Acres by County of Crops and Tillage Methods

SCS CROP AND CONSERVATION SURVEY

- Crop Rotations

BASIC ASSUMPTIONS WORK GROUP (USDA RCA task force)

- Projections of Land Change due to Urbanization, etc.
- Regional Distribution of Demand
- Other

NUMEROUS SCS AND OTHER USDA

- Surveys
- Special Studies
- Other

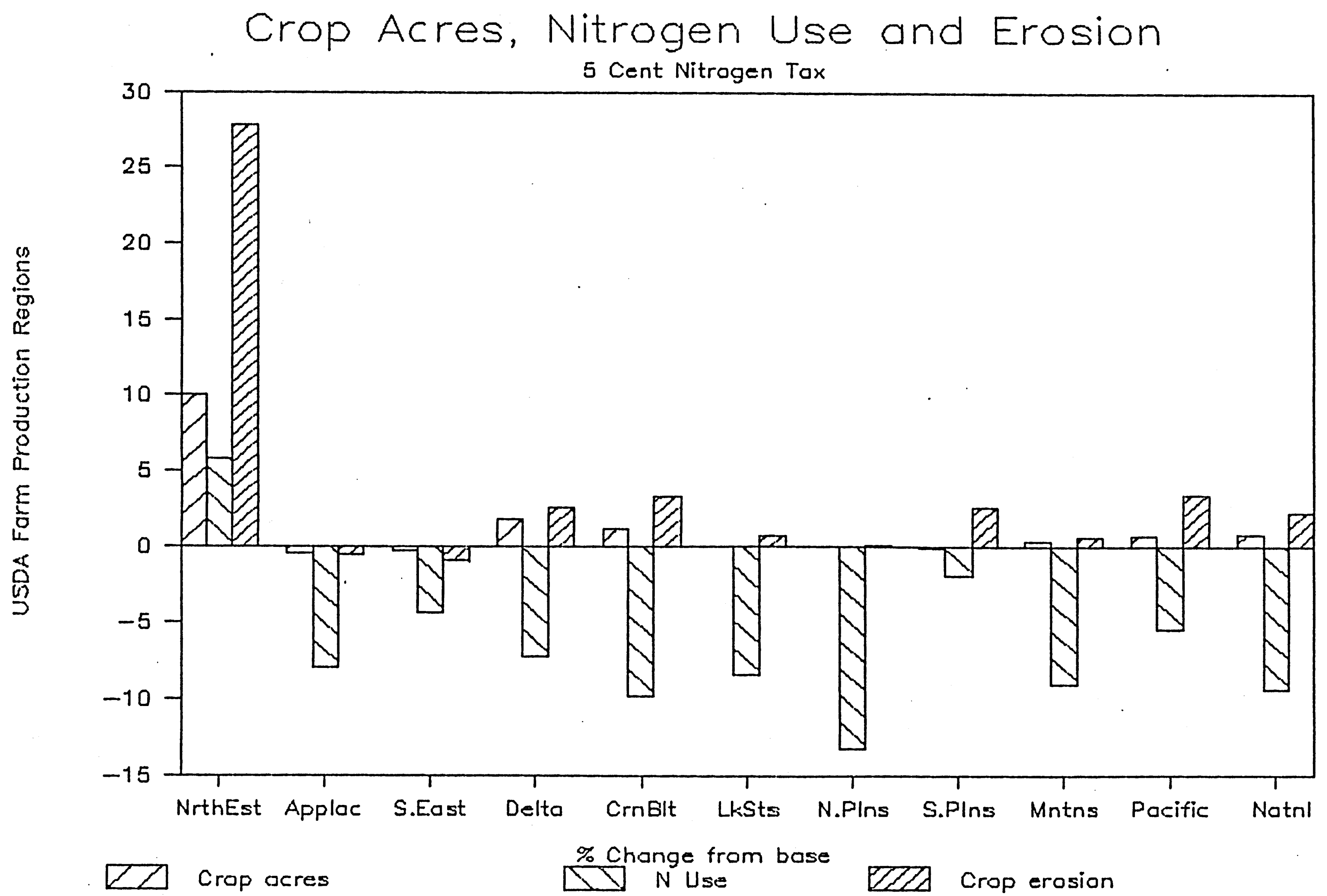
CARD LP -- Impacts of 5 cent Nitrogen Tax[a]

Item	Base	Change	Percent Change
Cash Receipts:			
Crops	NR	1,297,153.0	5.1
Livestock	NR	-206,877.0	-0.8
Production Cost	56,228,000.0	434,741.0	0.8
Government Payments	NR		
Net Farm Income	NR		
Consumer Surplus:			
Domestic Crop	NR	-340,983.0	NR
Domestic Livestock	NR	-347,824.0	NR
Foreign Consumers	NR	-356,537.0	NR
Asset Value Index	NR		

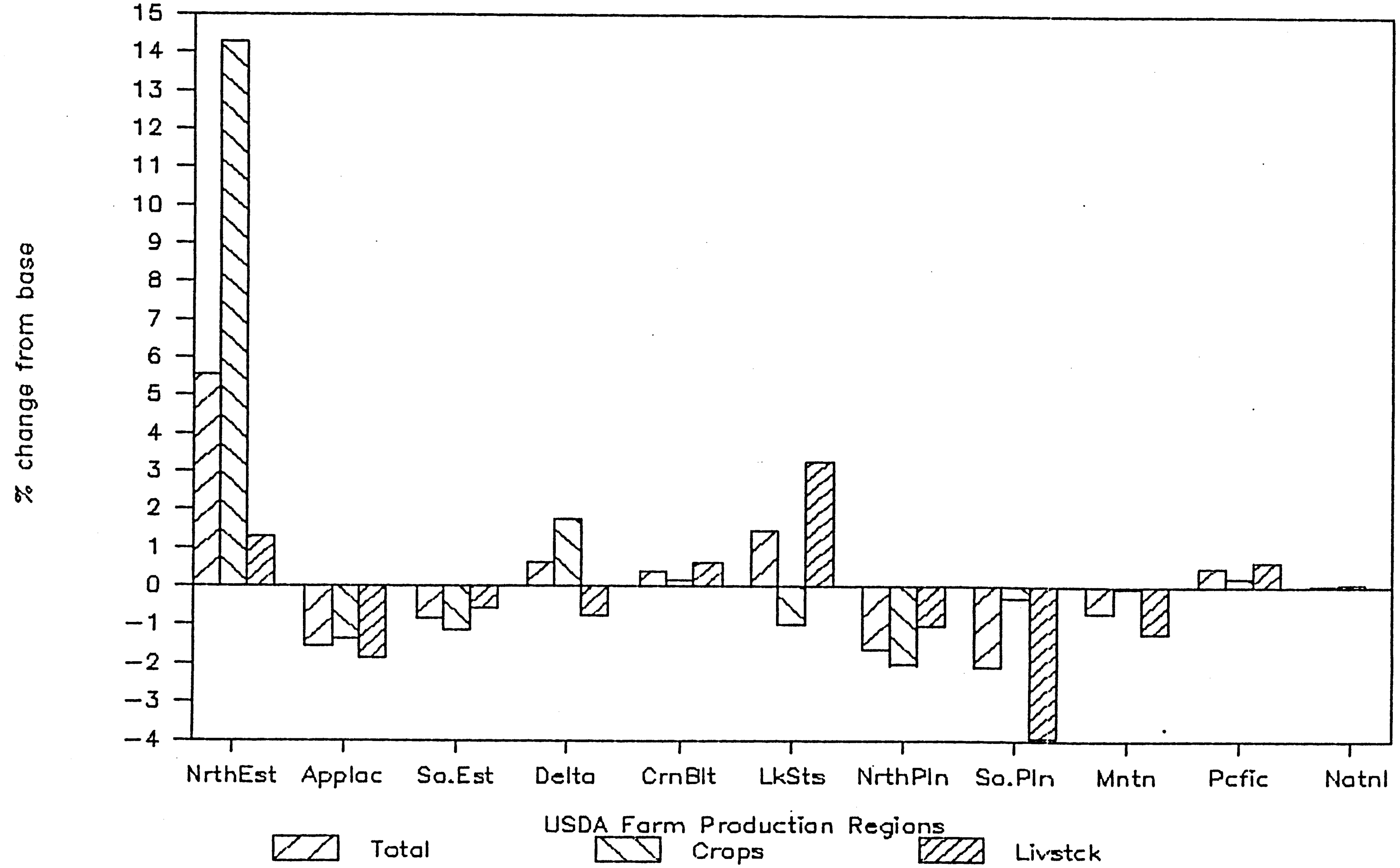
Value of Exports	NR	348,264.0	4.5
Output Price Index:			
Crops	NR	101.3	0.3
Livestock	NR	100.0	0.0
Acreage Planted	318,109	2,469.0	0.8
Acres Idled (Without the CRP)	51,309	-2,342.0	-4.6
Acreage Equivalent of Stocks	NR		
Crop Yield Index	100.0	99.2	-0.8
Dairy Stock Utilization Ratio	NR		

NR = Not Reportable

[a] Physical quantities are in 1000's while values are in $1000's units


Crop Acres, Nitrogen Use and Erosion
5 Cent Nitrogen Tax
USDA Farm Production Regions
30
25
20
15
10
5
0
−5
−10
−15
NrthEst
Applac
S.East
Delta
CrnBlt
LkSts
N.Plns
S.Plns
Mntns
Pacific
Natnl
% Change from base
Crop acres
N Use
Crop erosion

Cash Receipts Impact of 5 Cent N tax



CARD LP -- Impacts of 65 Million Acre CRP[a]

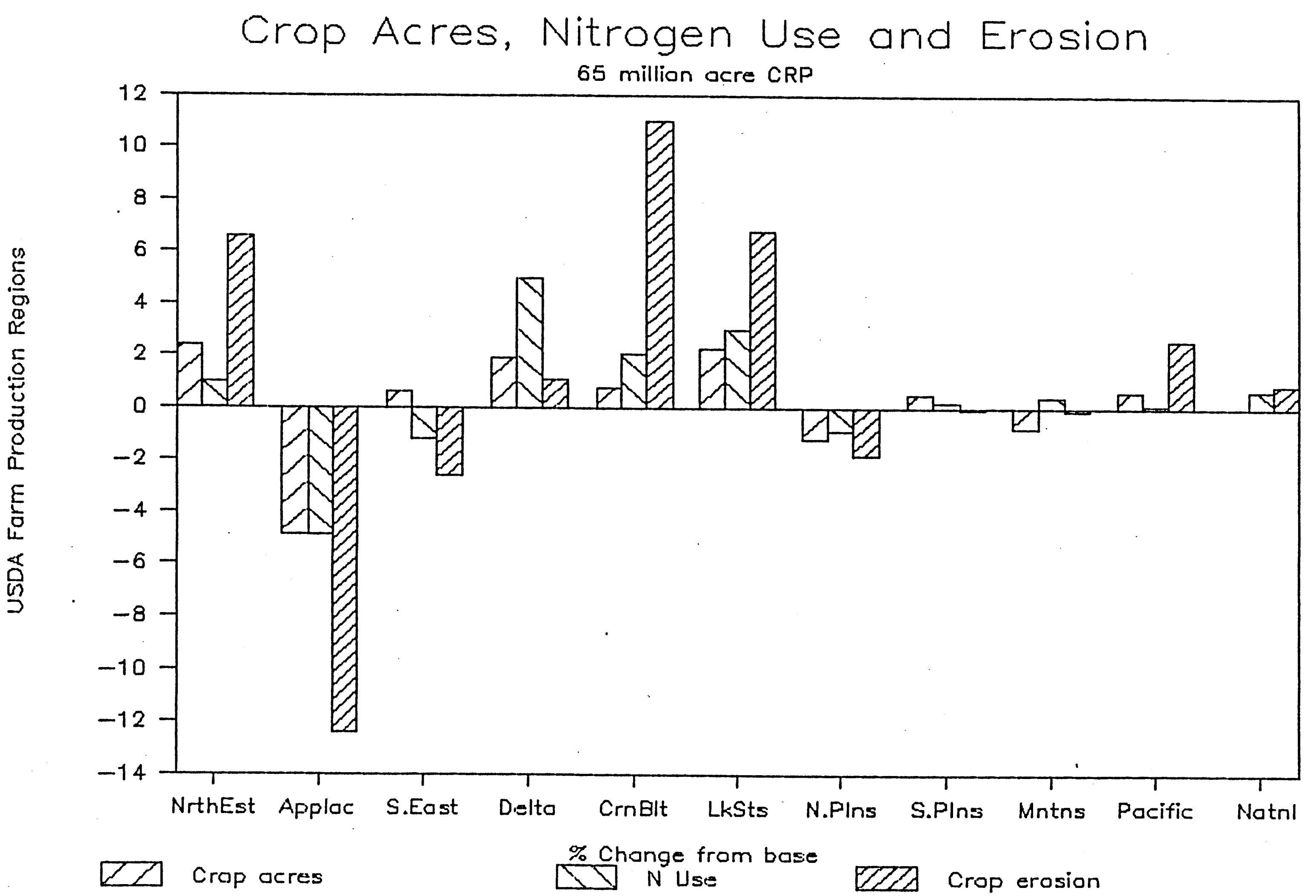
Item	Base	Change	Percent Change
Cash Receipts:			
Crops	NR	383,198.0	1.5
Livestock	NR	24,072.0	0.1
Production Cost	56,228,000	110,366.0	0.2
Government Payments	NR		
Net Farm Income	NR		
Consumer Surplus:			
Domestic Crop	NR	-87,479.0	NR
Domestic Livestock	NR	-207,152.0	NR
Foreign Consumers	NR	-58,927.0	NR

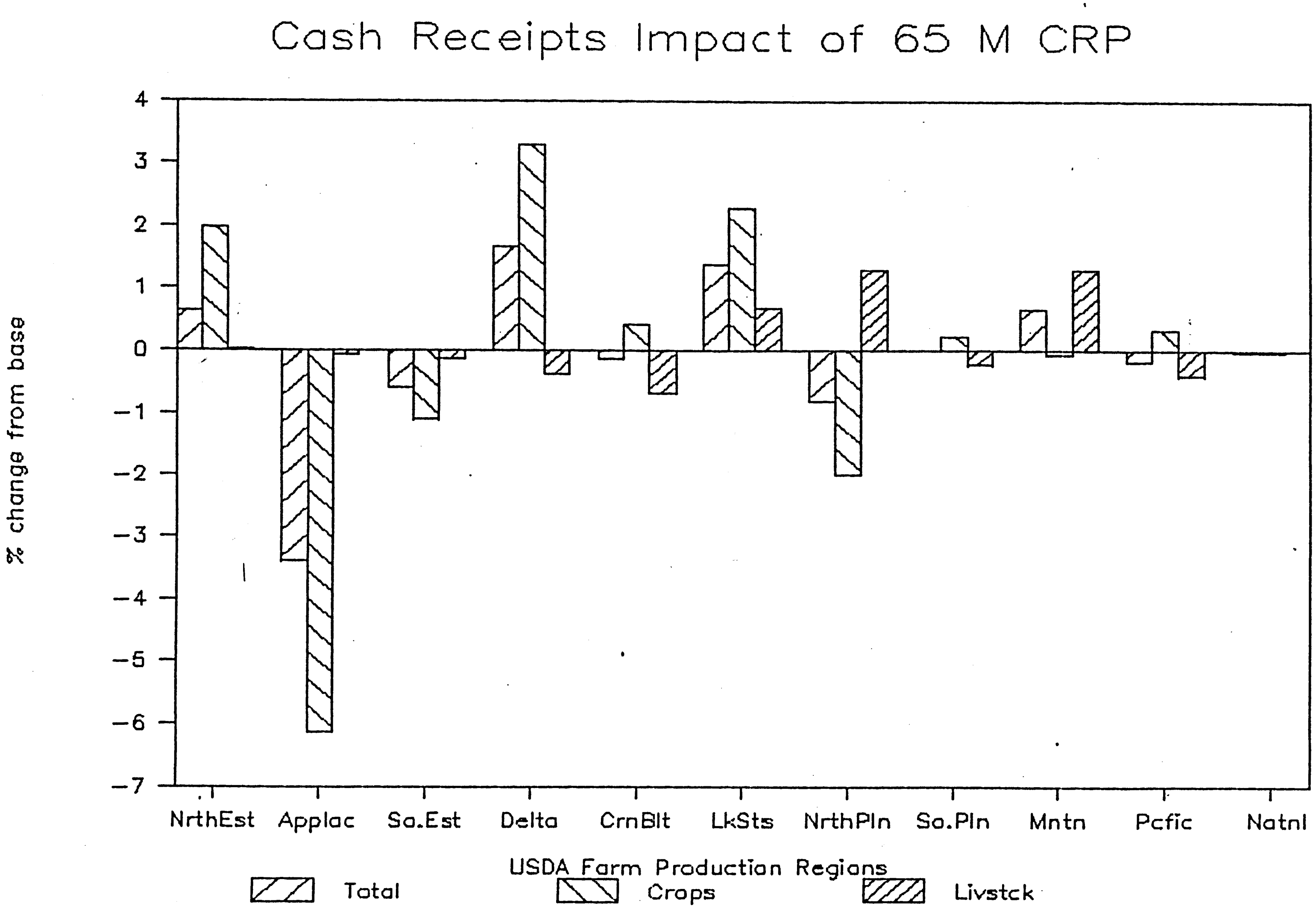
2a

Asset Value Index	NR		
Value of Exports	NR	59,245.0	0.7
Output Price Index:			
Crops	NR		
Livestock	NR		
Acreage Planted	318,109.0	-47.0	-0.0
Acres Idled (Without CRP)	51,309.0	-18,950.0	-36.9
Acreage Equivalent of Stocks	NR		
Crop Yield Index	100.0	100.0	0.0
Dairy Stock Utilization Ratio	NR		

NR = Not Reportable

[a]Physical quantities are in 1000's while values are in $1000's units.


Crop Acres, Nitrogen Use and Erosion
65 million acre CRP
USDA Farm Production Regions
12
10
8
6
4
2
0
−2
−4
−6
−8
−10
−12
−14
NrthEst
Applac
S.East
Delta
CrnBlt
LkSts
N.Plns
S.Plns
Mntns
Pacific
Natnl
% Change from base
Crop acres
N Use
Crop erosion



Cash Receipts Impact of 65 M CRP
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
% change from base
NrthEst
Applac
So.Est
Delta
CrnBlt
LkSts
NrthPln
So.Pln
Mntn
Pcfic
Natnl
USDA Farm Production Regions
Total
Crops
Livstck