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THE SIMPLIFIED U.S. MODEL
(PRELIMINARY VERSION)
FOR THE IIASA/FAP GLOBAL SYSTEM
OF FOOD AND AGRICULTURE MODELS:
DOMESTIC UTILIZATION AND PRICES

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PREFACE

The Food and Agriculture Program of the International Institute for Applied Systems Analysis has been developing, as its major task, a global system of national food and agriculture models linked in a general equilibrium framework. The main objective is to analyze, over a 15- to 20-year horizon, the impact of national domestic and trade policies and of international agreements on the distribution of food and hunger in the world and on the pace of development in the LDCs. The United States, as a major exporter of food and feed grains, is a key link in the system. It can, through its aid, trade and domestic food policies, have a major influence, both intentional and unintentional, on the world food situation. Michigan State University (MSU) is collaborating with IIASA/FAP and the USDA in the development of simplified and detailed models of U.S. food and agriculture for linkage in the FAP global system.

This working paper presents some rough notes describing the demand side of the preliminary version of the simplified U.S. model. The supply side is based on the domestic supply component of the MSU Ag Model, which has been under development at MSU for several years on a grant from the John Deere Corporation and other contract research support. Detailed documentation of that model is in preparation at MSU; this paper limits its scope to the demand and price components developed for linkage to IIASA's system. The model presented here is preliminary in the sense that a great deal more testing and refinement are necessary in the context of the global system to enhance its usefulness.

The major contributors to the simplified U.S. model are Michael Abkin, Donald Mitchell, Eric Wailes and Chris Wolf of MSU, and David Watt of USDA. Dan Kauffman, Tracy Miller and Dave Zeitler have contributed at various stages of data collection and parameter estimation, and others contributing to the MSU Ag Model over the years are too numerous to mention here.

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Total utilization of each commodity includes exports, if any, and several components of domestic disappearance. Exports (actually net imports) are determined as a residual of domestic supply over demand in the simultaneous national-international exchange model of IIASA's linkage system consistent with world prices, domestic price, quota and stock policies; and assumed international agreements. Domestic utilization includes seed, losses, feed, nonfood industrial uses, government consumption, stocks and human consumption. Feed demand is discussed elsewhere with the supply side of the model, which is based on the MSU Agriculture model; prices and the other components of demand will be described here.

Commodities and Units

The thirty commodities of supply are aggregated to twenty commodities for utilization purposes, and these are further aggregated to IIASA's ten commodities for the international linkage. Table 1 shows the commodity correspondences and units used in the model.

There remain a few relatively minor inconsistencies between the commodity definitions of this preliminary version of the U.S. simplified model and those of the international system. These will be resolved in the "final"¹ version as the international commodity list for the simplified system is expanded to

¹The word "final" is in quotes because no model, if it is to remain useful, can ever have a final version.

the 19 commodities of the detailed model system in order to conduct analyses using both simplified and detailed models. The current inconsistencies are:

1. alcoholic beverage consumption should be included in the "other foods" category, whereas the model currently includes it in aggregate consumption of the primary ingredients (e.g., wheat, coarse grains, fruit, etc.);
2. use of sweeteners derived from corn should be included with sugar in "other foods" instead of its current accounting in "coarse grains;"
3. "coffee, tea, cocoa" currently includes only coffee; and
4. a few miscellaneous items, such as flowers and hides and skins, are not yet accounted for in "nonfood agriculture;" likewise for miscellaneous crops, such as rye.

Seed and Losses, and Industrial and Government Consumption

Seed rates per acre are assumed for wheat, rice, the four coarse grains, potatoes, dry beans, soybeans (accounted to fats and oils, and protein feeds) and cotton (accounted to protein feeds). Losses due to waste, spoilage, insects, etc., in farm and market storage, processing and distribution activities are modeled as proportions of annual production. In addition, milk fed to calves, as a proportion of milk production, is considered a feed use of milk, and eggs used for hatching is considered a seed use of eggs. The seed and loss rates used are shown in Table 2.

A general Cobb-Douglas functional form is postulated for the nonfood industrial consumption of each food commodity.

$$(1) \text{ DEMIND}_i(t) = \alpha_i \left(\frac{\text{CPRICE}_i(t)}{\text{CPRICE}_{20}(t)} \right)^{\beta_i} \left(\frac{\text{DOMSUP}_{20}(t)}{1000} \right)^{\sigma_i}$$

where

- DEMIND_i = industrial demand for commodity i (th MT)
- CPRICE_i = consumer price of commodity i (\$/lb)
- CPRICE₂₀ = nonagricultural consumer price index (1967=1.00)
- DUMSUP₂₀ = nonagricultural production (mi. 1967 dollars)
- α_i, β_i, σ_i = parameters of the function

A preliminary data search for this version of the model yielded data on non-food use of only two food commodities: fats and oils, and fish. Zero industrial consumption is assumed for the other food commodities; further research will be necessary to determine if this is a reasonable assumption (e.g., grains, potatoes and sugar for starch, nondrinking alcohol, etc.).

Industrial demand for the nonagricultural commodity, in million 1967 dollars, is interpreted as demand for intermediate inputs and is computed using the same two-sector input-output model used to determine gross non-agricultural production.

$$(2) \text{ DEMIND}_{20}(t) = \text{AIO}_{21} \cdot \text{VA67}(t) + \text{AIO}_{22} \cdot \text{VN67}(t)$$

where

- AIO₂₁ = dollars of nonagricultural input per dollar of sector 1 output
- VA67 = value of agricultural production at 1967 prices
- VN67 = value of nonagricultural production at 1967 prices

Total government consumption expenditures (e.g., for the military, institutions, etc.) is assumed to be a fixed proportion (namely, 21 percent) of GNP. This total is modified in order to achieve the exogenously specified national trade balance (necessary for consistency within the global system), if that balance cannot otherwise be achieved at equilibrium prices given quota constraints and tax rate constraints.

This total public expenditure is then allocated to the individual commodities by first assuming a proportion goes to the nonagricultural commodity, and then distributing the rest to the food commodities in the same proportion as lagged private consumption expenditures. The data for food consumption used to calibrate the human food consumption functions described below appears to have been derived as a residual in food balance sheet calculation, with no distinction between public and private consumers. Therefore, until this question can be resolved or other data can be found which explicitly identifies government consumption of food commodities, all government consumption is assumed to be of the nonagricultural commodity.

Carry-Out Stock Demand

Stocks are considered in the model for wheat, coarse grains, milk, soybeans and peanuts. The oil and cake equivalents of soybean and peanut stocks are allocated to fats and oils and protein feeds, respectively. Milk stocks include the fresh milk equivalents of milk products stocks. Coarse grain stocks are modeled as an aggregate of corn, sorghum, barley and oat stocks.

The modeling of wheat and coarse grains stocks is more complicated than that of the other commodities because stocks of these commodities are closely related to price control policies. Specifically, the government will act as a buyer (or stockpiler) of last resort, if necessary, in order to maintain

a minimum farm price (or "loan rate"). At the other end, if farm price is rising above an upper target (the "call price"), the government will call in loans, essentially requiring farmers to sell the stocks they hold as part of government programs. It should be mentioned here that this version of the model does not distinguish different types of stocks, such as on-farm stocks, government buffer stocks, market stocks, etc. Rather, total national carry-out stocks are modeled in the aggregate.

Since wheat and coarse grains stocks are modeled identically, the following discussion applies to both commodities. The basic hypothesis is that stocks build up as prices fall and are depleted as prices rise. A negative exponential function is assumed to represent this behavior over most of the relevant price range (curve III in Figure 1). For the function to be homogenous of degree zero, the independent variable is the price P of the commodity relative to nonagricultural prices P_n . At the call price PC , stocks are assumed to have fallen to a minimum, pipeline level XL below which they will not go even if the relative price is higher than PC (curve IV in Figure 1).

Since the government is assumed to be the stockpiler of last resort, the price will not fall below the loan rate PL . (Given the U.S. role in the world market for wheat and coarse grains, this implies supporting the world price as well.) This would imply a vertical, perfectly elastic segment of the stock demand curve at PL . In order for stocks to be a function of price, however, as required by the overall model, a steep negative exponential segment (curve II in Figure 1) is modeled within a narrow band between $PL-$ and $PL+$ around PL .

At PL+, stocks are assumed to be at their "normal" maximum XU and at PL- their "logical" maximum XU. The logical maximum XU, assuming there will be no imports of these commodities, is defined as total supply Y (production plus carry-in stocks) less a specified minimum level of domestic utilization. Since stocks cannot logically increase above this level, the demand curve (I in Figure 1) is perfectly inelastic at prices below PL-. However, this represents an unrealistically high level of stocks, so that the loan rate should be successfully supported before reaching this level. At PL+, the normal maximum XU is defined to be

$$(3) \quad XU(t) = \frac{\lambda}{1+\lambda} Y(t)$$

where

Y = total supply (th MT)

λ = maximum stock as a proportion of non-stock disappearance

The parameter λ is currently assumed to be 70 percent for wheat and 60 percent for coarse grains. Similarly, at and above the call price PC, pipeline stocks XL are defined to be

$$(4) \quad XL(t) = \frac{\mu}{1+\mu} Y(t)$$

where μ is again a proportion of non-stock disappearance (currently assumed to be 15 percent for wheat and 10 percent for coarse grains).

The negative exponential curves II and III both have the form, for stock level X,

$$(5) \quad X(t) = \alpha e^{-\beta(P(t)/P_n(t))}$$

Two points on each of these curves are assumed to be known: (PL-, XU) and (PL+, XU) for curve II, and (PL+, XU) and (PC, XL) for curve III. Therefore, the parameters α and β can be determined as

$$(6) \quad \alpha = \overline{XU}(t)e^{\beta PL^-} \quad \text{and} \quad \beta = \frac{\ln(\overline{XU}(t)/XU(t))}{(PL^+) - (PL^-)}$$

for curve II, and

$$(7) \quad \alpha = XU(t)e^{\beta PL^+} \quad \text{and} \quad \beta = \frac{\ln(XU(t)/XL(t))}{PC(t) - (PL^+)}$$

for curve III. Thus, the curves are completely specified by the parameters λ and μ , and by the price policies PC and PL. It is interesting to note that, with α and β defined as in (6) and (7), the stock demand functions reduce to the Cobb-Douglas form, for example for curve III,

$$(8) \quad X = (XU)^\gamma (XL)^\delta$$

whose exponents, which add to unity, are

$$\gamma = \frac{PC - (P/P_m)}{PC - (PL^+)} \quad \text{and} \quad \delta = \frac{(P/P_n) - (PL^+)}{PC - (PL^+)}$$

For this version of the model, peanut stocks are projected exogenously, while milk and soybean stocks are modeled with the following econometrically estimated equations. The soybean stock equation will be replaced when the model is updated to incorporate the new soybean component of the MSU Agriculture Model (part of which serves as the supply side of the present model).

$$(9) \quad \text{MLKSTK}(t) = A_0 + A_1 \cdot \text{MKSUPP}(t) + A_2 \cdot \text{DOMSUP}_{17}(t) + A_3 \text{GNPPC}(t)$$

$$(10) \quad \text{SBSTK}(t) = B_0 (\text{QSUPSB}(t))^{B_1}$$

where

MLKSTK	= milk stocks (th MT)
SBSTK	= soybean stocks (th MT)
MKSUPP	= milk support price (\$/kg)
DOMSUP ₁₇	= milk supply (production plus carry-in stocks) (th MT)
GNPPC	= per capita GNP (th \$/person)
QSUPSB	= soybean supply (production plus carry-in stocks) (mi MT).

Human Consumption

A rather complicated, nonlinear function is used to model the per capita consumption of each food commodity (in pounds per person per year) in order to exhibit a hypothesized mode of consumption behavior with respect to income, prices and time. Specifically, per capita consumption PCC is the product of three functions representing an income factor, a price factor and a time factor, respectively. For each food commodity i ,

$$(11) \quad PCC_i(t) = f_i(M(t), P(t)) \cdot g_i(P(t)) \cdot h_i(t)$$

where M is current nominal per capita disposable income (\$/person-year), P is a vector of nominal consumer prices (\$/pound), and t is time, and where

$$(12) \quad f_i(M,P) = a_i + (b_i - a_i) e^{-c_i} (M/CPI)^2$$

$$(13) \quad g_i(P) = \prod_j [1 - x_{ij} d_j (1 - e^{-\sigma_j} (P_j/CPI))]]$$

$$(14) \quad h_i(t) = \alpha_i + (\beta_i - \alpha_i) e^{-\delta_i} (t - t_{0i})^2$$

and where the consumer price index CPI is

$$(15) \quad CPI(t) = \sum_i \omega_i \frac{P_i(t)}{P_i(1967)}$$

As shown in Figures 2 and 3,² the income factor f and its parameters a and b have units of per capita consumption and are the major determinants of PCC, while g and h serve as multipliers. The price factor g is nominally unity when all prices are zero, and the time factor h is unity (with $\alpha = \beta = 1$) for commodities with no time trend assumed.

²A figure is not given for the time factor h ; it would look exactly the same as Figure 2, with α and β in place of a and b , and $(t - t_0)$ in place of (M/CPI) .

Indeed, there are only four commodities (wheat, coarse grains, tobacco and milk) for which time trends are assumed to reflect changes in per capita consumption not reasonably attributable to price, income or other endogenous model variables. For example, a sharp decline in tobacco consumption per capita has been observed, beginning in about 1964 when the first Surgeon-General's report was issued on the health hazards of cigarette smoking. Zero food consumption of "protein feeds" is assumed ($a_{1g} = b_{1g} = 0$), although this restriction may have to be relaxed if food use of soybeans can be projected to become significant in the U.S.

The asymptotic behavior of f_i has advantages over a constant income elasticity model, particularly in long-run analysis as real income increases, in that consumption will remain within reasonable physical and nutritional ranges. Indeed, the set of values for the a_i s may be specified according to what could be considered to be a realistic or plausible dietary and nutritional mix in the limit "as real income goes to infinity." Note in Figure 2 that setting $b_i > a_i$ implies an inferior good, while $b_i < a_i$ indicates a normal good.

Cross-price effects in the price factor g_i , i.e., the impacts of the price of commodity j on consumption of commodity i , are reflected in the matrix $[x_{ij}]$. For the own-price effect, $i=j$, $x_{ij}=1.0$, for complementary goods $x_{ij} > 0$, and for substitute commodities $x_{ij} < 0$. $x_{ij} = 0$ implies no cross-price effect. From this point of view, a commodity is a perfect complement to itself, i.e., one always eats rice with rice.

Note in equation (13) and Figure 3 that x_{ij} is a proportion of d_j . That is, the effect of commodity j 's price on consumption of commodity i is proportional to its effect on own consumption, i.e., the consumption of

commodity j . The d_j represents the maximum proportional deviation of commodity j consumption as the real price of j increases without limit. Thus, $d_j = 1$ implies consumption goes to zero "as real price goes to infinity," while $d_j = 0$ indicates no price response.

In order to maintain a consumption expenditure budget constraint, per capita consumption of the nonagricultural commodity PCC_{20} (in 1967 \$/person) is computed as a residual, where the total budget is taken to be disposable income M , implying savings as a component of PCC_{20} .

Econometric estimation of the parameters-- $a_i, b_i, c_i, d_i, x_{ij}, \alpha_i, \beta_i, \sigma_i, \delta_i$ for i and $j = 1, 2, \dots, 18$ --has not yet been attempted. Preliminary judgemental estimates were made and then further refined in "manually tuning" the model to track PCC for the 1970-1976 period using actual historical values for M and P over that period. Although elasticities as such are not used in the model, as a check on model performance with these parameter values, Table 3 shows elasticities computed from the partial derivatives of PCC in equation (11) with respect to prices and income. In addition, the Appendix includes plots comparing historical observations $PCCACT$ with simulation results PCC using the parameter values estimated in this way. The following measure of overall goodness of fit for these results

$$(16) \quad \sum_{t=1955}^{1976} \sum_{\substack{i=1 \\ i \neq 19}}^{20} \left| \frac{PCC_i(t) - PCCACT_i(t)}{PCCACT_i(t)} \right|$$

has a value of 22.3. For 22 years (1955-1976) of data on each of 19 commodities, i.e., 418 observations, this implies an average error of about 5.3 percent per observation. With emphasis given on turning to track the 1970 - 1976 period, earlier tracking for some commodities is not too good. This is particularly evident for those with time trend factor (wheat, tobacco and milk).

Prices

Prices are the major feedback from the simultaneous national-international exchange system to the national model. Domestic consumer prices are determined based on world prices and national price policies. A "target" (or "desired" or "normal") price for each commodity PD_i is defined to be proportional to the retail-level world price PWD_i .

$$(17) \quad PD_i = DPD_i \cdot PWD_i$$

where DPD can be interpreted to embody not only tariff policies, for instance, but also quality and other differences between the domestic commodity and the world commodity, transportation costs, etc. The retail-level world price PWD_i is defined as the world price PW_i plus a domestic marketing/processing margin PRM_i representing a quantity of the nonagricultural good (commodity n) times the price of that good. PRM_i is also used as the margin between domestic farm and consumer prices.

$$(18) \quad PWD_i = PW_i + PRM_i \cdot PW_n$$

The price PD_i will be the equilibrium price P_i unless a specified minimum QEX_i or maximum QIM_i demand constraint is effective, where these can be interpreted as export and import quotas, respectively. If one of these constraints is effective, the equilibrium price P_i will be below or above PD_i , respectively--unless buffer stock behavior is modeled. In that case (as for wheat, coarse grains, milk and protein feeds discussed above), equilibrium carry-out stocks will deviate above or below a target level, respectively, where the target stocks are those determined in equations (5), (9) and (10) above. Maximum and minimum stocks are also specified, and if the stock adjustment is such as to make a stock constraint effective, then P_i will deviate from PD_i .

These prices are at the 10-commodity international aggregation and must be disaggregated to the U.S. model's 20-commodity utilization level for consumer prices and the 30-commodity supply level for farm prices (see Table 1). The 10-commodity aggregate prices P_i are related to the 20-commodity consumer prices CP_k by

$$(19) \quad P_i = \left[\sum_k \omega_k \frac{CP_k}{\sigma_k} \right] / \sum_k \omega_k$$

for $i = 1, 2, \dots, 10$ and where the summation is over commodities k belonging to aggregate i . In (19), ω_k is the consumer price index weight of equation (15), and σ_k is a unit conversion factor, e.g., th.MT of carcass weight to the th.MT of protein equivalent (see Table 1).

For commodities with a one-to-one correspondence, i.e., wheat, rice, coarse grains, milk and nonagriculture, the consumer prices are simply

$$(20) \quad CP_k = \sigma_k P_i$$

For the other commodities, the CP_k are determined from econometrically estimated equations, generally as functions of per capita income, per capita supply, and other prices. Each CP_k in a group i is then ratioed, given P_i , so (19) holds.

Producer prices PP_k at the 20-commodity level are determined from consumer prices and an assumed farmer share α_k

$$(21) \quad PP_k = \delta_k \alpha_k CP_k$$

where δ_k is a unit conversion, e.g., from \$/pound for consumer prices to \$/bushel for farm prices. The marketing/processing margins PRM_i used in (18) are computed from the farmer shares α_k by

$$(22) \quad PRM_i = \left\{ \left[\sum_k \omega_k (1-\alpha_k) \frac{CP_k}{\sigma_k} \right] / \sum_k \omega_k \right\} / P_i$$

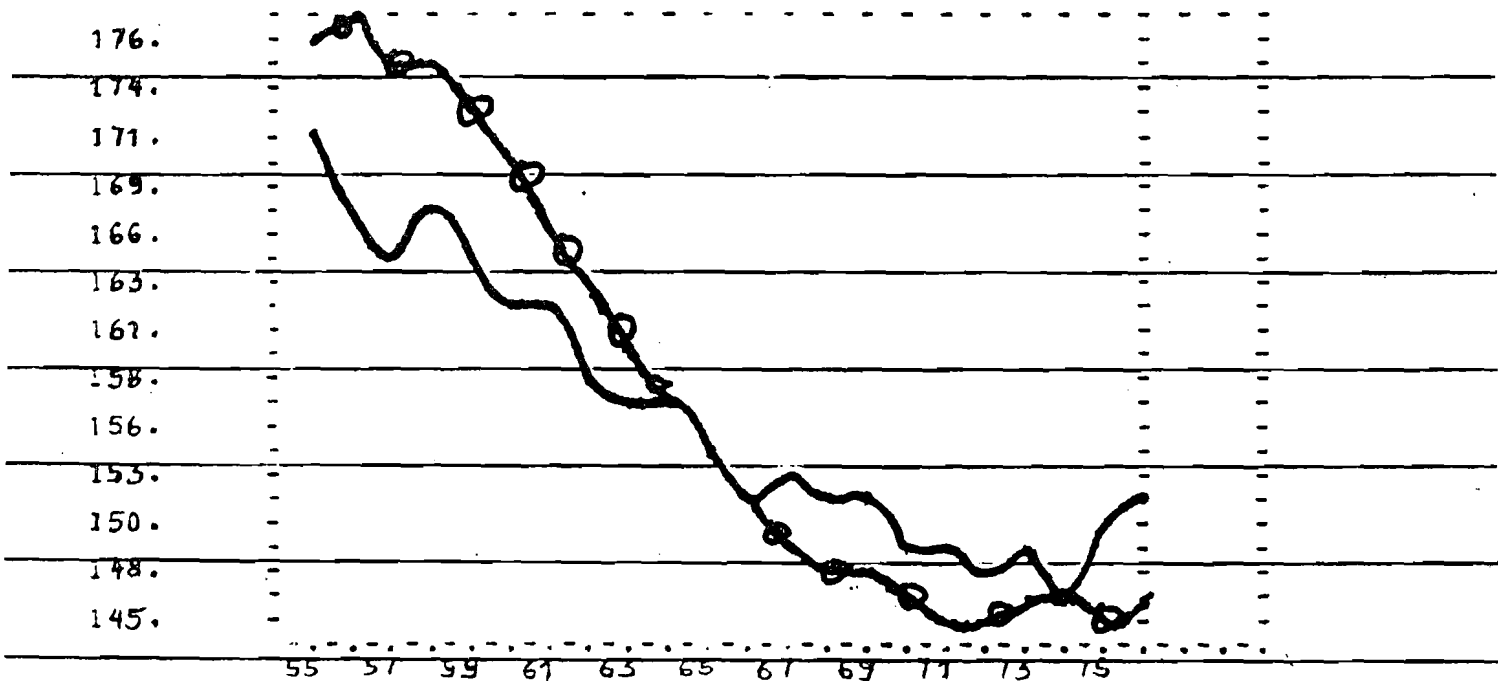
where, again, the summation is over commodities k in group i .

The 20-commodity producer prices are then disaggregated to the 30-commodity level. For example, it is assumed that PP_3 for coarse grains represents the corn price. The farm prices of barley, oats and sorghum are then related to that of corn by equations of the type

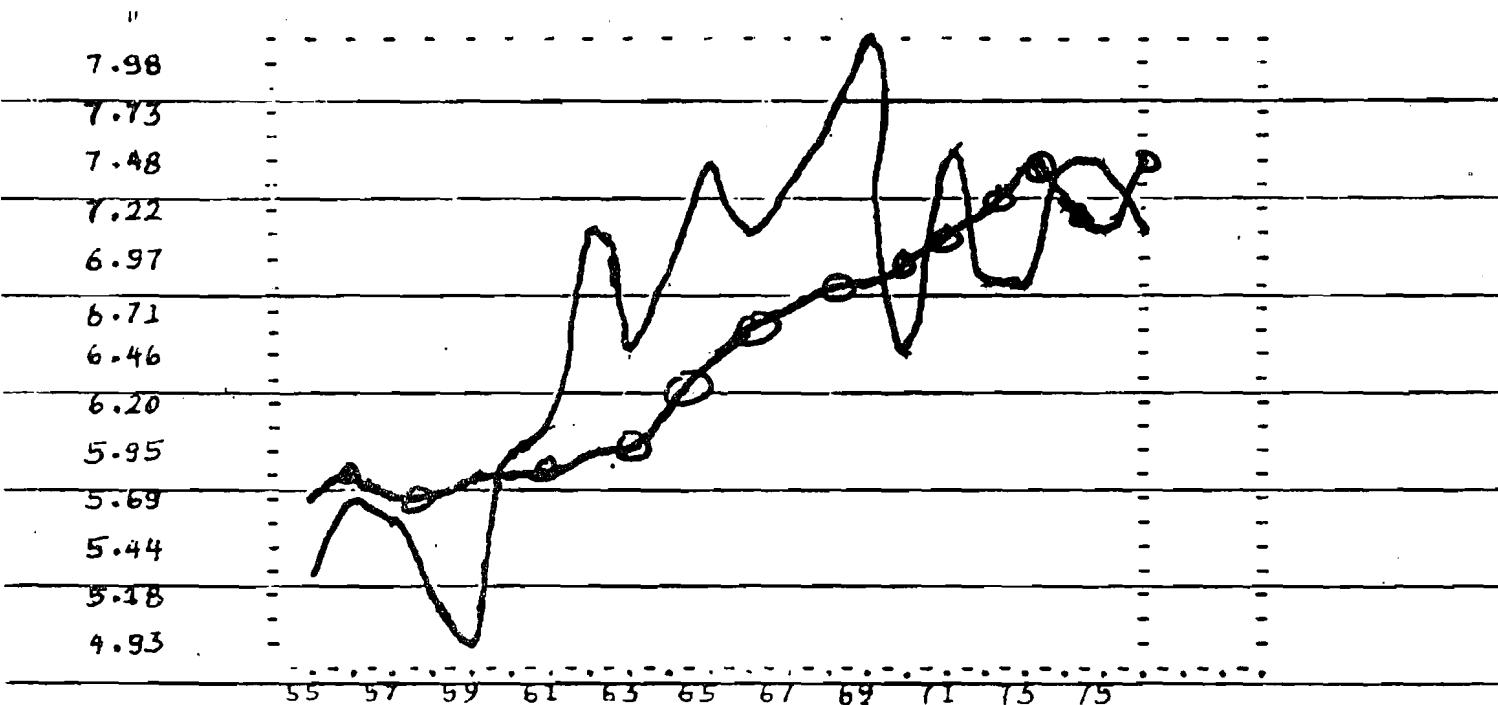
$$(23) \quad PPG_j = \lambda_j PP_3^{\mu_j}$$

Appendix

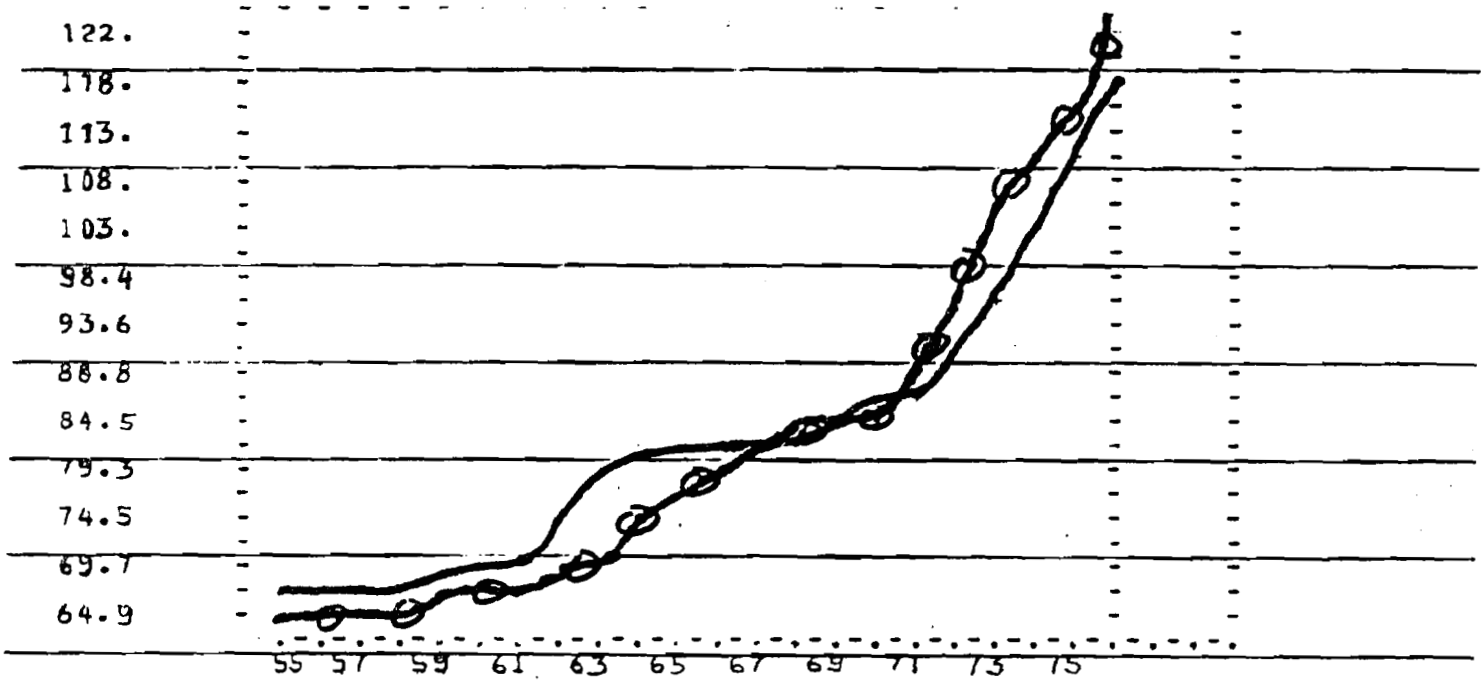
The following charts include plots estimated per capita consumption over the years 1955-1976 using the preliminary data derived as described in the text. The sum of absolute values of proportional errors over all 418 observations (19 commodities and 22 years) is 22.3, or an average of about 5.3 percent per observation. The last two columns in the table of each chart compare the year-to-year percentage change in the two series, where the same sign in the two columns means the estimated (indicated by *) and the actual (indicated by +) change in the same direction. In the plots, the actual series is indicated by — and the estimated by —○—.



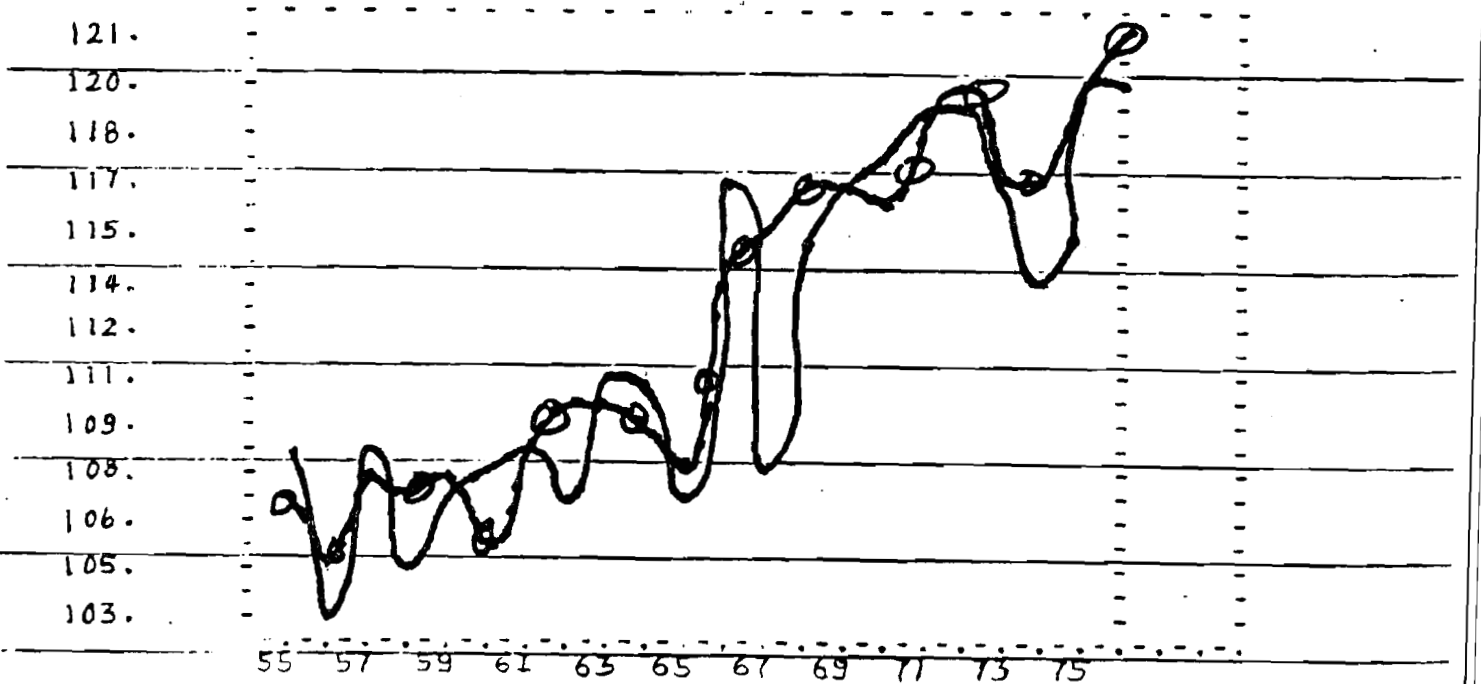
Actual (-) and estimated (⊕) values for 1 - WHEAT



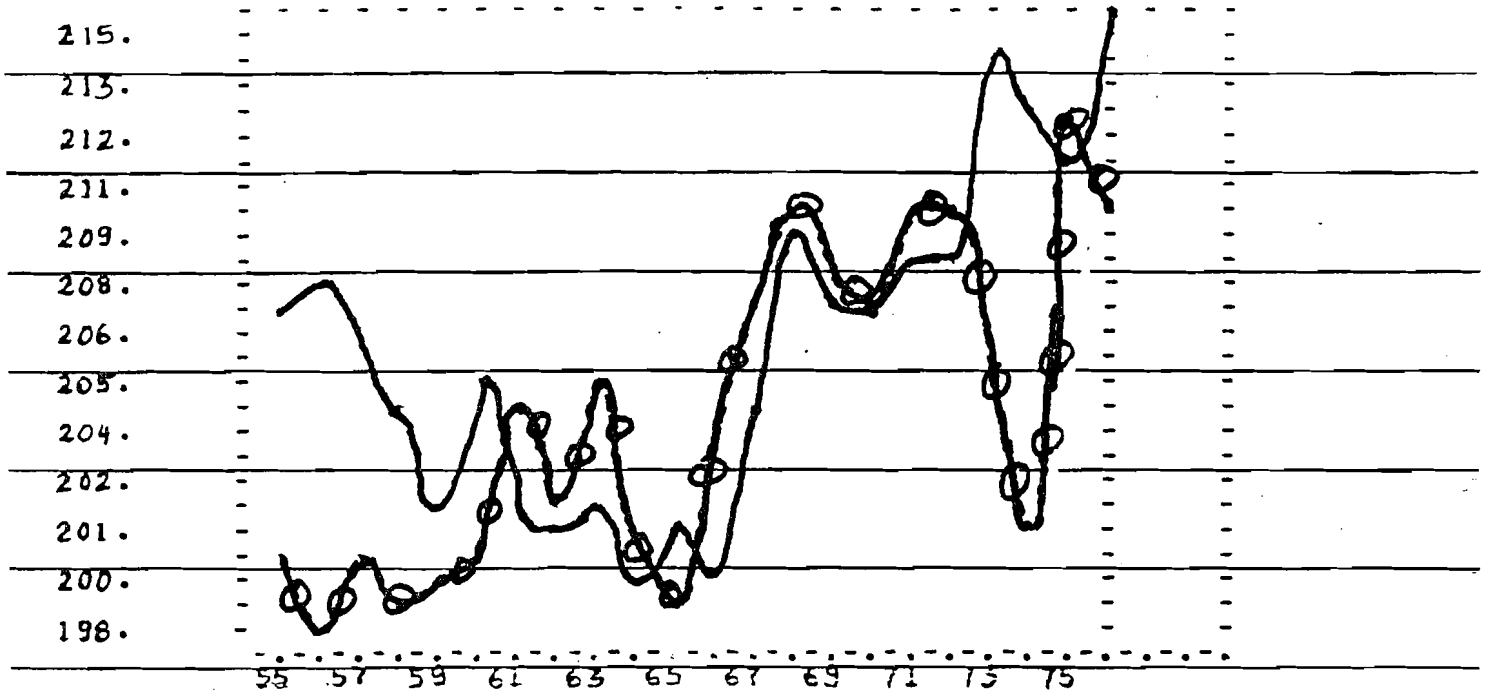
Actual (-) and estimated (⊕) values for 2 - RICE



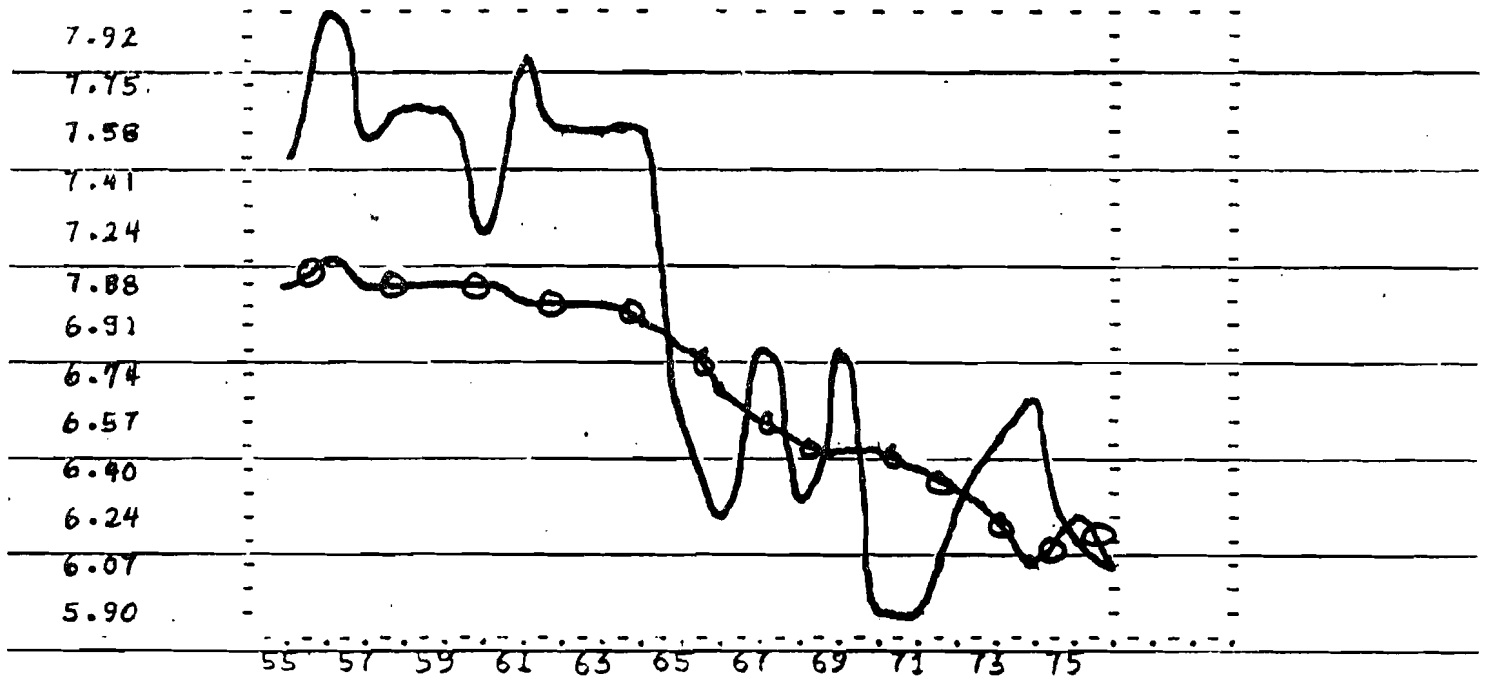
Actual (-) and estimated (⊖) values for 3 - COARSE GRAIN



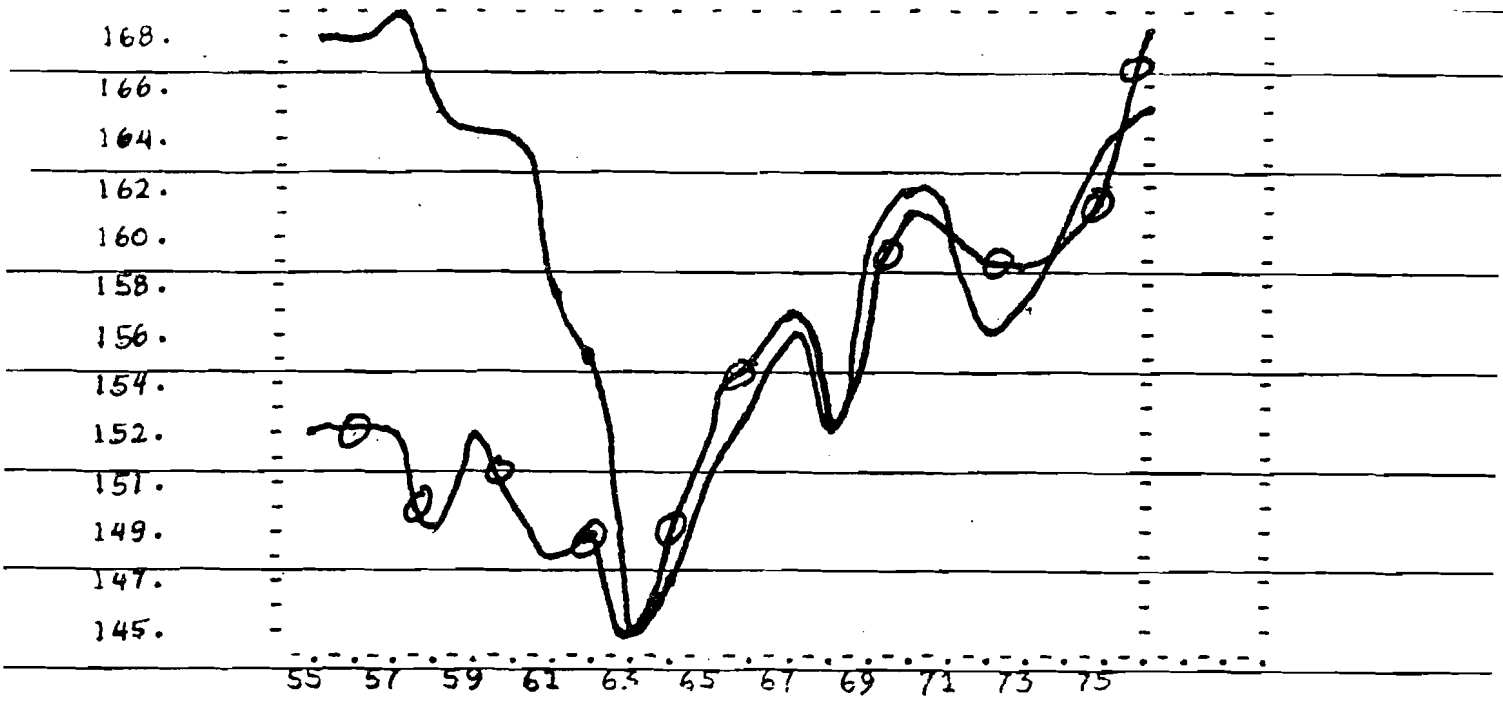
Actual (-) and estimated (⊖) values for 4 - POTATOES



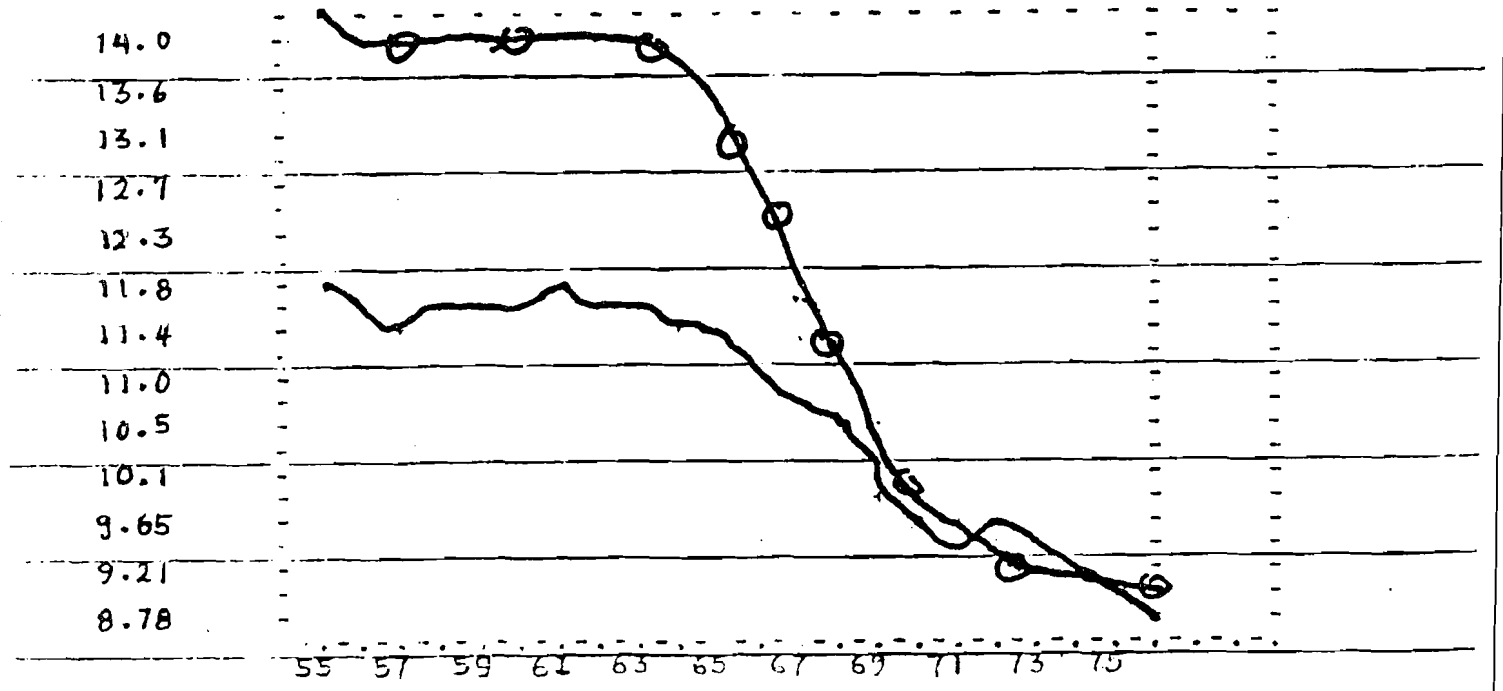
Actual (-) and estimated (⊕) values for 5 - VEGETABLES



Actual (-) and estimated (⊕) values for 6 - BEANS

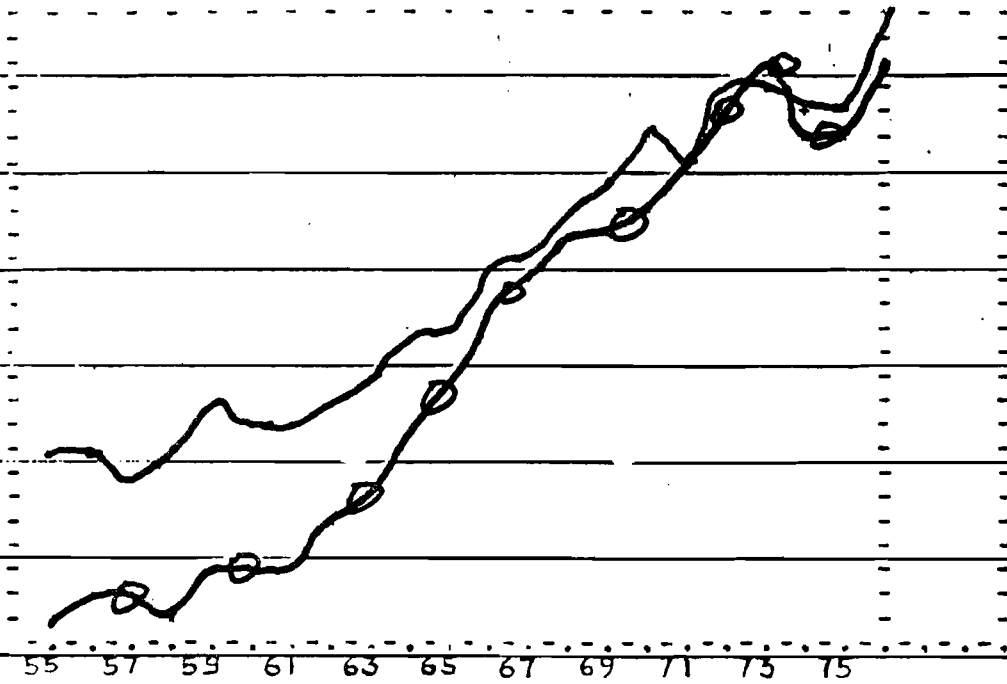


Actual (-) and estimated (⊖) values for 7 - FRUIT



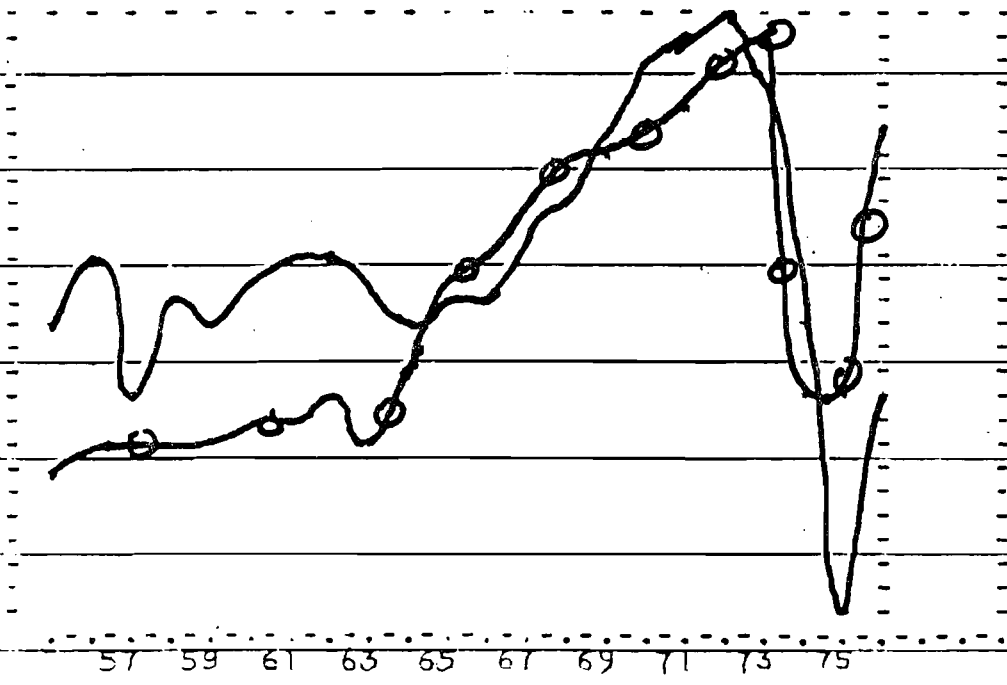
Actual (-) and estimated (⊖) values for 8 - TOBACCO

54.3
52.6
50.9
49.1
47.4
45.6
43.9
42.2
40.4
38.7
36.9
35.2
33.5

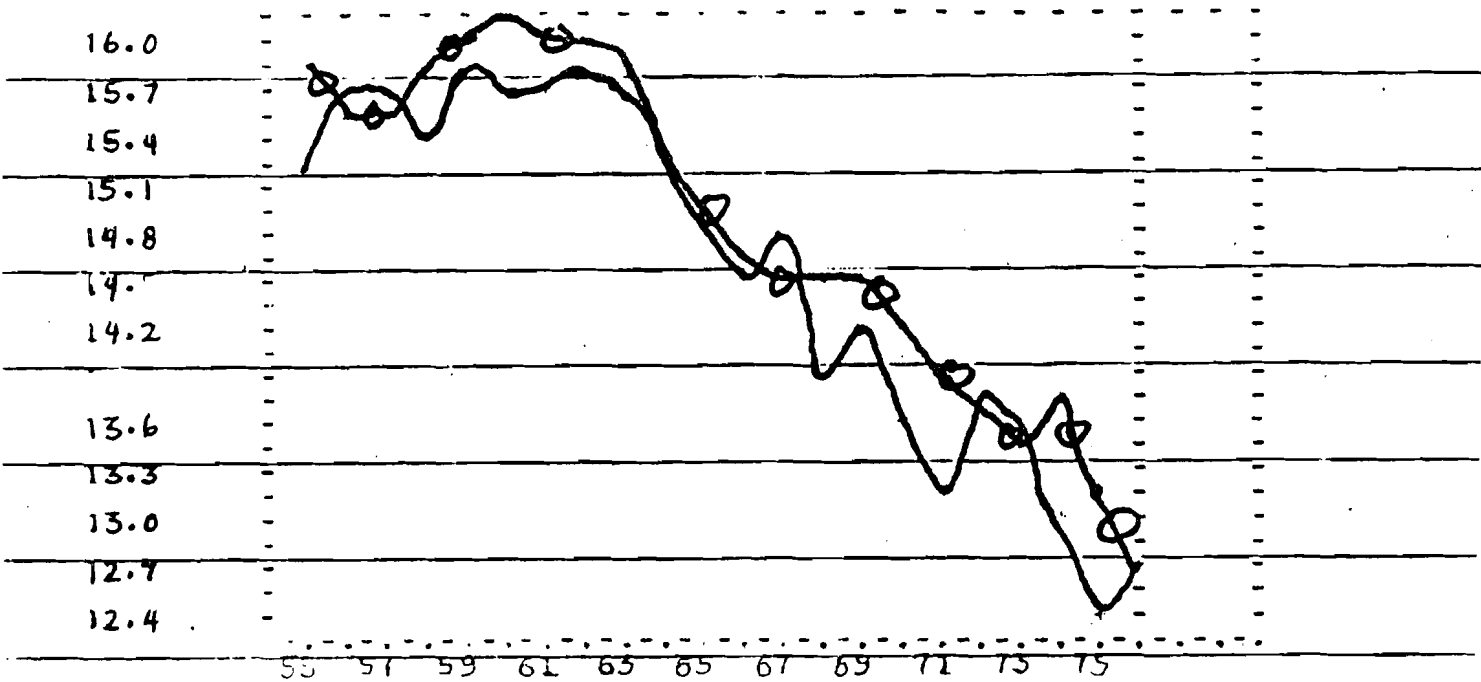


Actual (-) and estimated (⊕) values for 9 - FATS/OILS

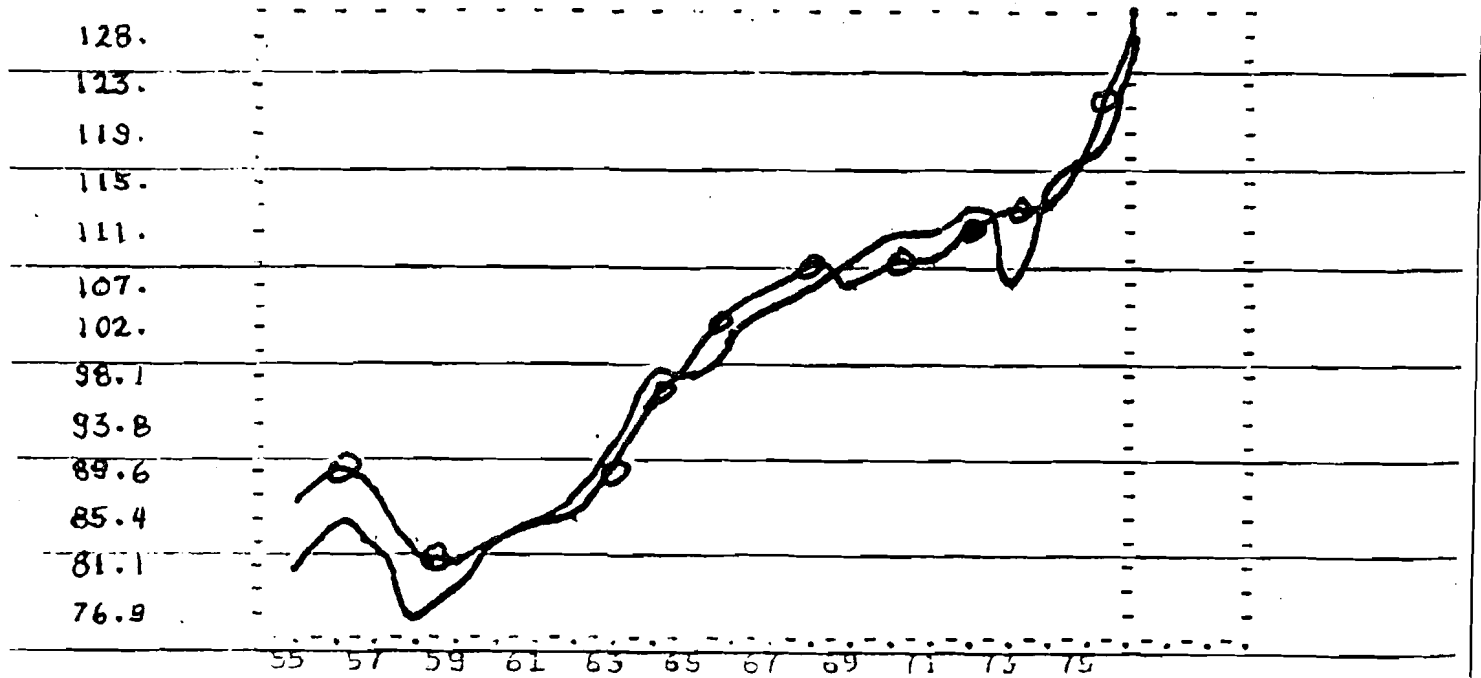
102.
101.
100.
99.3
98.3
97.3
96.2
95.2
94.2
93.2
92.2
91.2
90.2



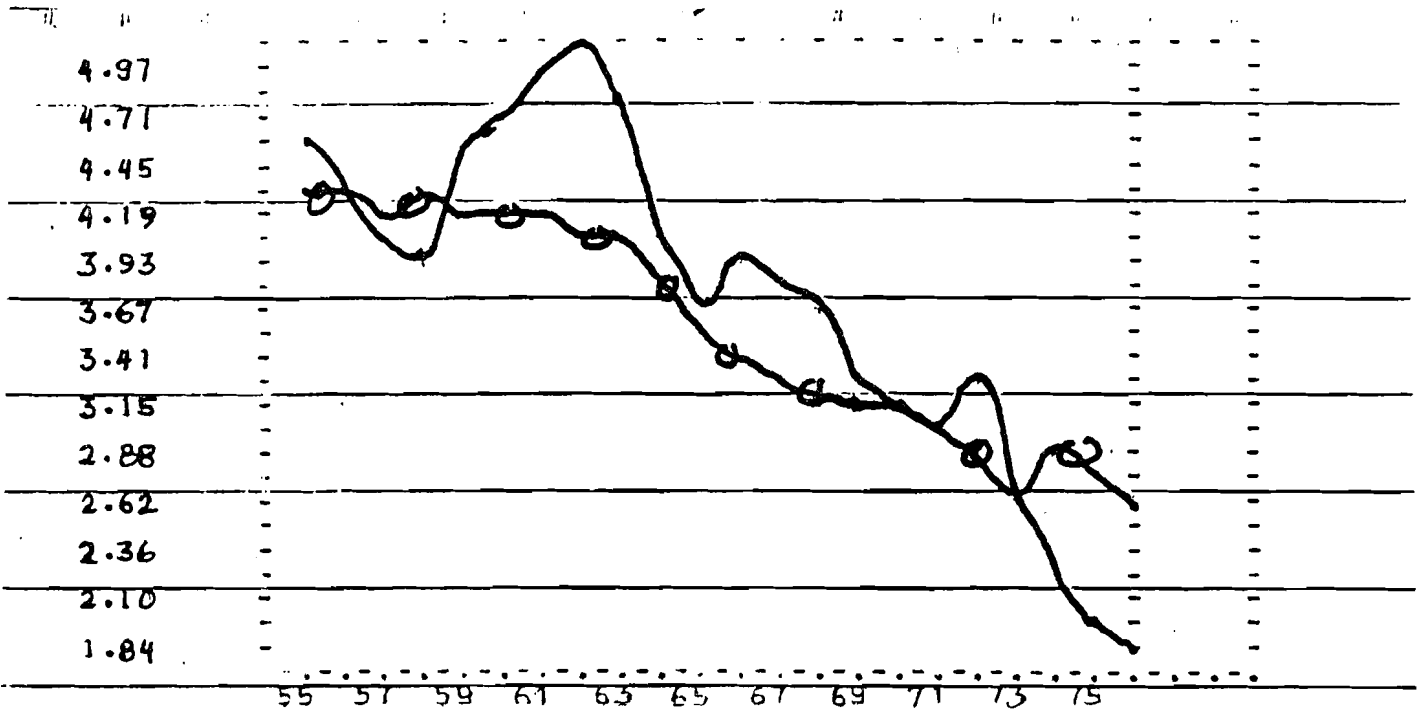
Actual (-) and estimated (⊕) values for 10 - SUGAR



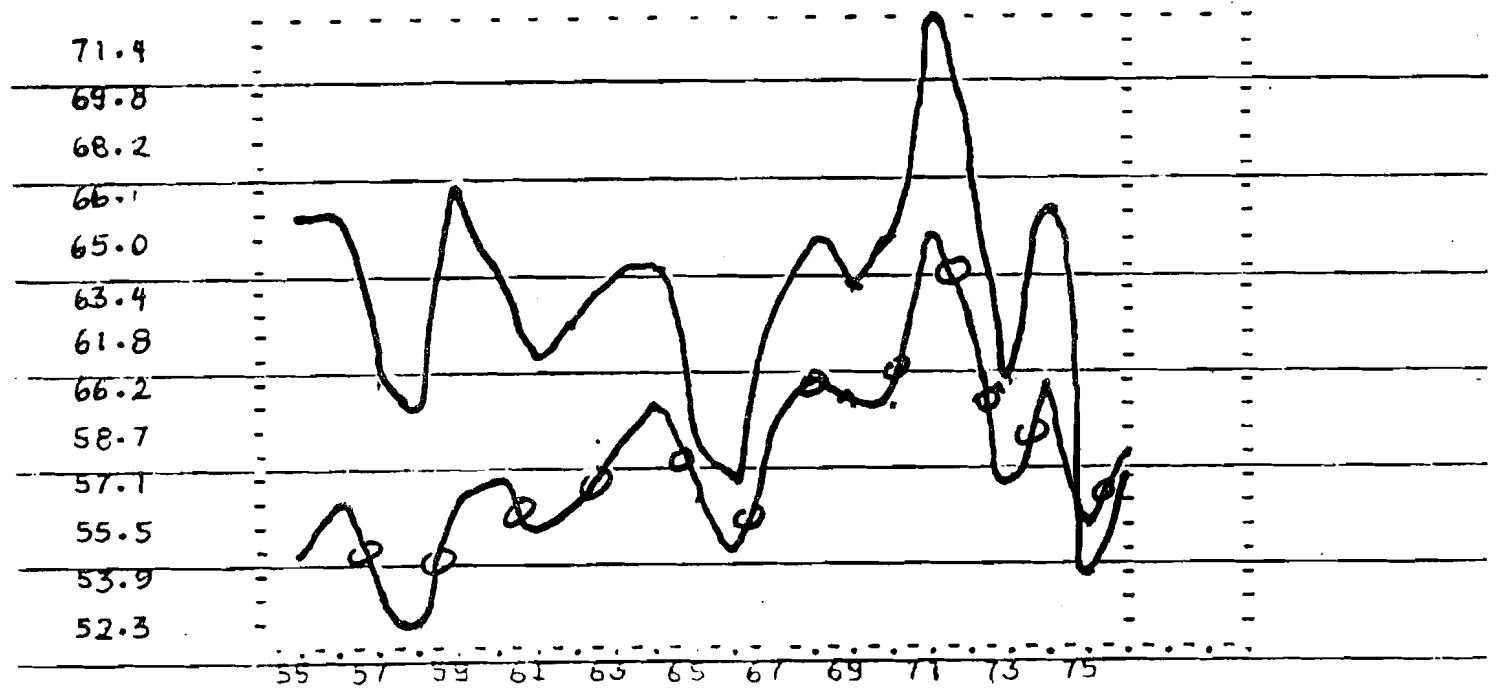
Actual (-) and estimated (⊕) values for 11 - COFFEE



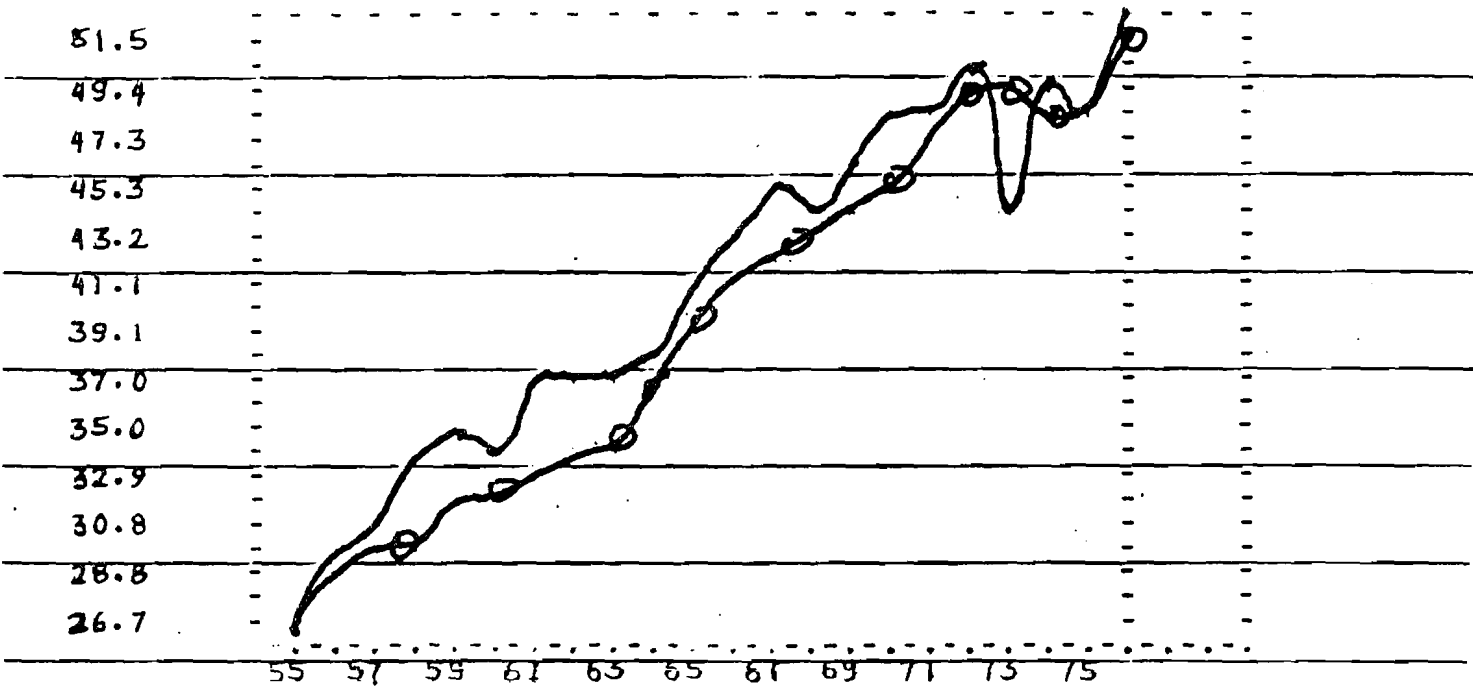
Actual (-) and estimated (⊕) values for 12 - BEEF



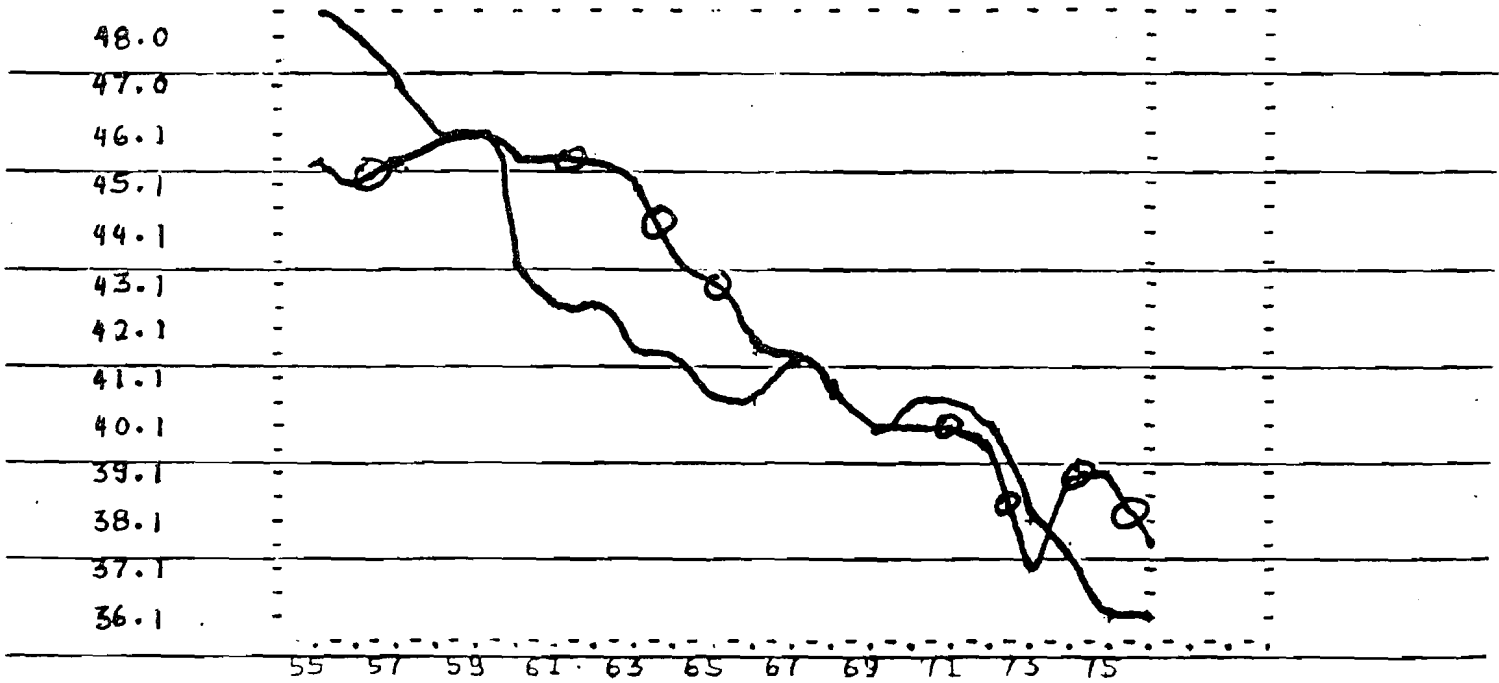
Actual (-) and estimated (⊖) values for 13 - SHEEP



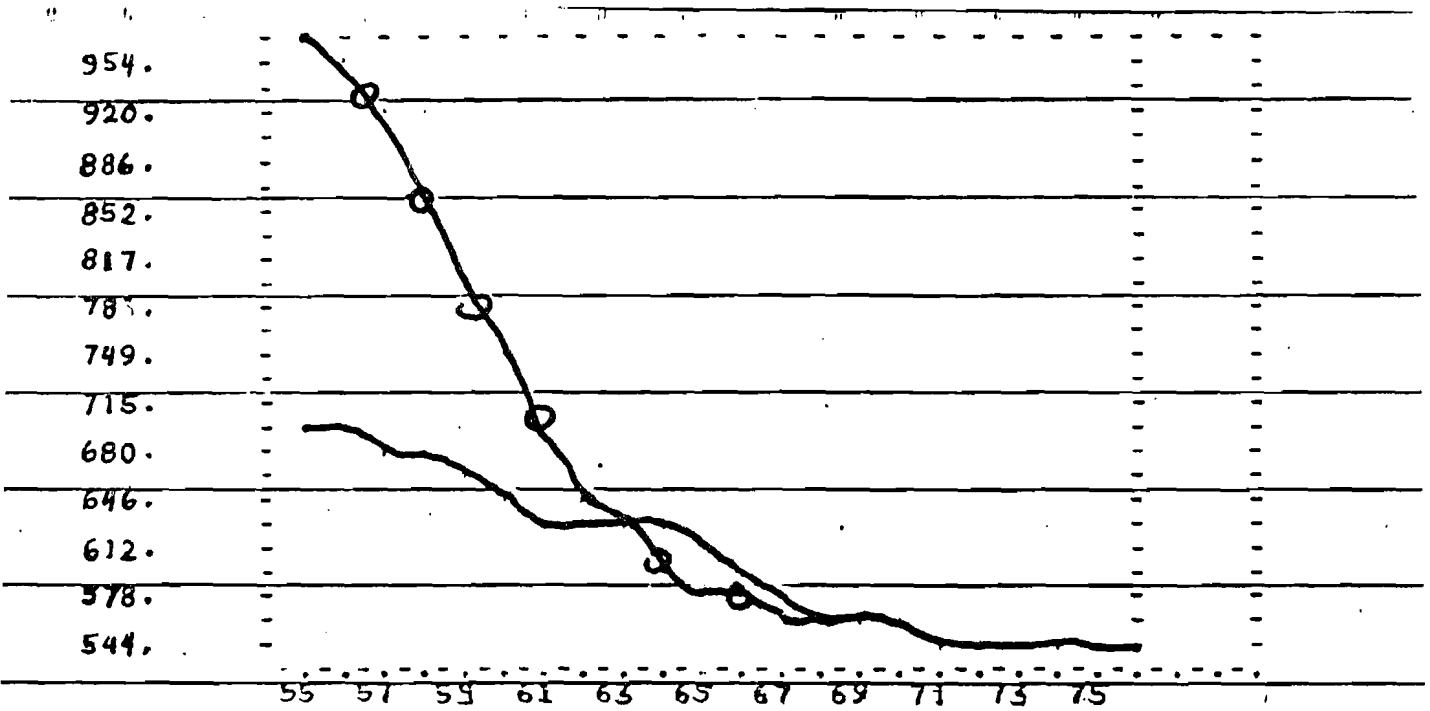
Actual (-) and estimated (⊖) values for 14 - PORK



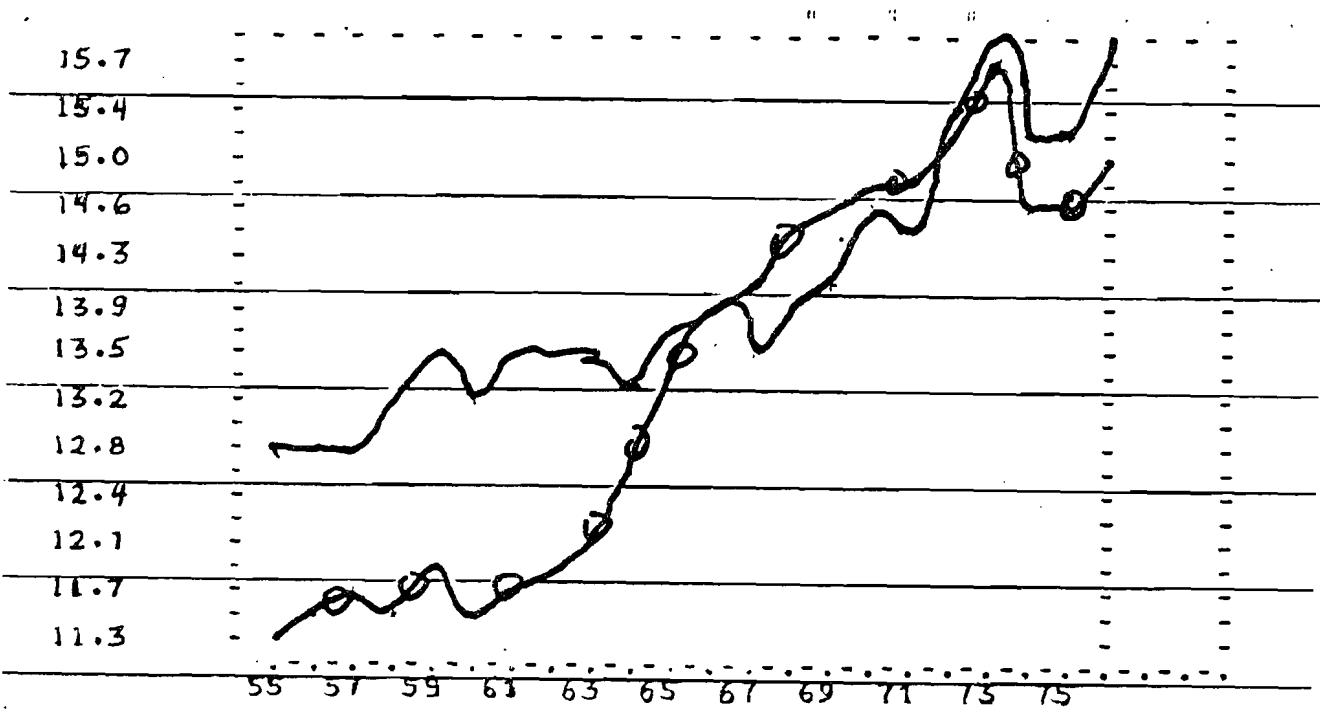
Actual (-) and estimated (⊕) values for 15 - POULTRY



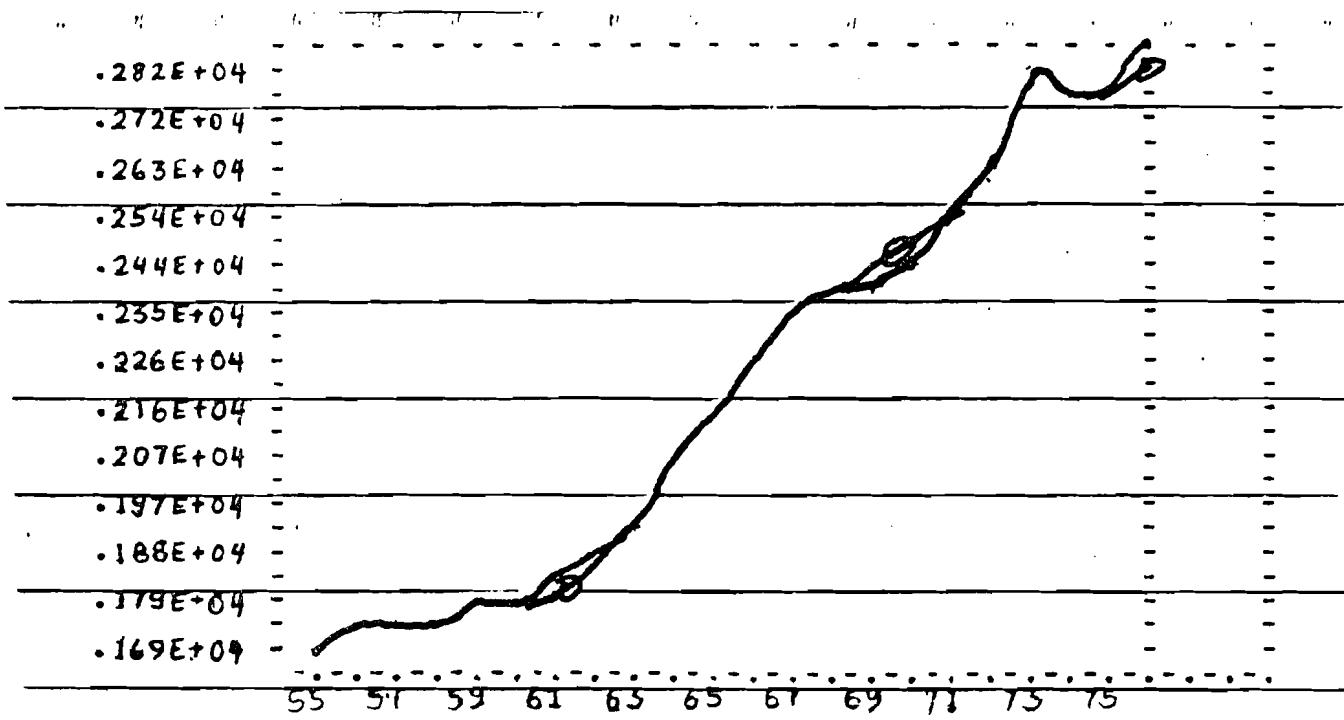
Actual (-) and estimated (⊕) values for 16 - EGGS



Actual (-) and estimated (\ominus) values for 17 - MILK



Actual (-) and estimated (\ominus) values for 18 - FISH



Actual (-) and estimated (⊖) values for 19 - OTHER