AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

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BATCH #14

1. SUBJECT CLASSIFICATION

A. PRIMARY: Agriculture — AA00-0000-G214

B. SECONDARY: General--Nigeria

2. TITLE AND SUBTITLE

Modification of the northern regional model to account for a variable proportion of food self-sufficiency

3. AUTHOR(S)

Gibson,F.T.

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1972	24p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS

Mich.State

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

(In Project working paper 72-1)

9. ABSTRACT

10. CONTROL NUMBER

PN-RAA-716

11. PRICE OF DOCUMENT

12. DESCRIPTORS

Food supply
Models
Nigeria
Simulation

13. PROJECT NUMBER

14. CONTRACT NUMBER

CSD-1557 Res.

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

NOTE: APPENDIX AVAILABLE UPON REQUEST.

BKY

A SIMULATION MODEL OF THE NIGERIAN AGRICULTURAL ECONOMY

Contract No. AID/csd-~~1557~~ 2975

Modification of the Northern Regional Model to Account for a Variable Proportion of Food Self-Sufficiency

Project Working Paper 72-1

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January 24, 1972

East Lansing, Michigan

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MODIFICATION OF THE NORTHERN REGIONAL MODEL TO ACCOUNT FOR A VARIABLE PROPORTION OF FOOD SELF-SUFFICIENCY

Motivation

The Northern Nigerian agricultural population tends to be completely food self-sufficient. The northern regional simulation model was designed to reflect this tendency and there seemed no real need to deal with circumstances other than this actual 100 percent food self-sufficiency behavior.

One of the purposes of refining the Nigerian simulation model has been to develop generalized discrete agricultural sector component simulation models which may readily be adapted to situations in countries other than Nigeria. The present modification to the model is a step toward these ends; it enables the investigator to account for a variable proportion of food self-sufficiency in the North. This proportion may be specified prior to the simulation run or may be generated within the model endogenously.

When tuned to the present Northern Nigerian situation, there should be no differences in the system output variables between this and the previous less flexible version of the model. However, because of its more general nature, the northern model will stand more ready for adaptation to situations in other countries.

Description of the Modification

This description of the modification is directed toward those individuals working directly with the computer simulation program.

In order to minimize confusion and facilitate its use, the following format is used in describing the modification.

1. Equations will be written in FORTRAN format with variables taking on the exact mnemonic names used in the computer program.
2. Each variable will be identified directly below the FORTRAN statement in which it occurs. Word descriptions will not be repeated for variables occurring in successive equations; however, units of measure will be expressed for every variable.
3. The subroutine in which each change occurs is indicated at the upper left of the FORTRAN statement representing the change.
4. A glossary of <u>all</u> variables occurring in the modification is given at the end of this report. This glossary identifies in which subroutine each variable is initialized and/or calculated. It also identifies each variable as being newly created, structurally altered or unaltered by the modification.
5. A complete FORTRAN listing of the modified subroutines is given under Appendix A.
6. Several simulation runs were made to verify that the modified version of the northern model was operating properly. These runs are included under Appendix B, and are annotated to assist the reader in making a quick review.

It should be pointed out that neither tuning nor validation of the modification has been done; nor have any experiments been performed with this new version of the model. The objective of this effort has been to develop the 'capability' within the model. Further effort

(possibly by other persons) will be required to refine the modification to an operational state. It is for this reason that such a detailed description of the modification is given here—along with such a bulky set of appendices.

Food Demand

The proportion of food self-sufficiency is reflected in the variable DEMR, the rural demand for subsistence calories. In order to account for a variable proportion of food self-sufficiency, it is necessary to modify DEMR as follows:

POPOUT

XDEMR(KAREA)=DEMR(KAREA) (1)

DEMR(KAREA)=FSSR(KAREA)*XDEMR(KAREA) (2)

where:

XDEMR = unmodified value of DEMR, i.e., demand rate for subsistence calories (assuming 100 percent food self-sufficiency) from the agricultural population in each northern subregion—K cal/yr.

DEMR = modified demand rate for subsistence calories from the agricultural population in each northern subregion, reflecting percentage of food self-sufficiency—K cal/yr.

FSSR = proportion of food self-sufficiency of each northern subregion—dimensionless[1/]

With less than 100 percent food self-sufficiency, the agricultural population of the North will require supplemental food staples from

---

[1/] FSSR may be initialized at the beginning of the simulation run and remain constant throughout or it may be treated as an endogenous variable. Both modes of operation are demonstrated in Appendix B of this report.

the cash market. There is no reason to believe that the farm population will alter its basic consumption of subsistence calories or follow a demand behavior similar to the nonagricultural population. The rural demand for cash food staples from the market is therefore calculated for each northern subregion by

POPOUT

```
DSCFR(KAREA)=XDEMR(KAREA)-DEMR(KAREA)                    (3)
```

where:

DSCFR = demand rate for supplemental (cash) food staples from the agricultural population in each northern subregion—K cal/yr.

XDEMR = see above—K cal/yr.

DEMR = see above—K cal/yr.

The total northern requirement for supplemental cash food staples is obtained by

POPOUT

```
      DSCFN = 0.                                         (4)

      DO 10 KAREA = 1,4                                  (5)
      :
      DSCFN=DSCFN+DSCFR(KAREA)                           (6)
      :
   10 CONTINUE
```

where:

DSCFN = demand rate for supplemental (cash) food staples from the agricultural population of Northern Nigeria—K cal/yr.

DSCFR = see above—K cal/yr.

The modified overall northern demand for cash food staples is given by

POPOUT

DEMCFN=DEMCFN+DSCFN (7)

where:

DEMCFN = demand rate for cash food staples for Northern Nigeria—K cal/yr.

DSCFN = see above—K cal/yr.

Land Allocation

It is desirable to have knowledge of the amount of land that would be needed to support complete food self-sufficiency. This variable, XSFL, may be used to determine the amount of cash crop land each unit of labor is able to cultivate, XAPL, after subsistence requirements are satisfied.

LANDN

XSFL(K)=XSFL(K)+DT/S3*(XDEMR(K)/CALA-XSFL(K)) (8)

where:

XSFL = total land required for subsistence food (assuming 100 percent food self-sufficiency) in each northern subregion—K acres.

DT = time increment of the model—years.

S3 = adjustment lag—years.

XDEMR = demand rate for subsistence calories (assuming 100 percent food self-sufficiency) from the agricultural population in each northern subregion—K cal/yr.

CALA = production rate of calories for each northern subregion—K cal/acre yr.

LANDN

XAPL(K)=AMAX1(APLO(K)*CM(K)-XSFL(K)/LABA(K),0.) (9)

where:

XAPL = acres of cash crops per unit of labor (assuming 100 percent food self-sufficiency) in each northern subregion—K acres/man-unit yr.

APLO = total acres cultivatable per unit of labor in each northern subregion at a given level of mechanization—K acres/man-unit.

CM = a mechanization coefficient greater than or equal to one that introduces the effect of labor saving investments—dimensionless.

XSFL = see above—K acres.

LABA = total agricultural labor available in each northern subregion—K man-units.

AMAX1[a,b] = a function that takes the maximum of the terms in the brackets.

Note that the two variables XSFL and XAPL both are calculated assuming 100 percent food self-sufficiency, as reflected by the variable XDEMR.[1/] Two more variables retained in the model, SFL and APL, are calculated in exactly the same manner as above with the exception that the actual percentage of food self-sufficiency is reflected by the variable DEMR.

LANDN

```
SFL(K)=SFL(L)+DT/S3*(DEMR(K)/CALA-SFL(K))                    (10)

APL(K)=AMAX1(APLO(K)*CM(K)-SFL(K)/LABA(K),0.)                (11)
```

where:

[1/] For consistency, all variables based on 100 percent food self-sufficiency are preceded by an X.

SFL = total land required for subsistence food in each northern subregion—K acres.

DEMR = demand rate for subsistence calories from the agricultural population in each northern subregion, reflecting actual percentage of food self-sufficiency—K cal/yr.

APL = acres of cash crops per unit of labor in each northern subregion—K acres/man-unit yr.

Subregional Accounting

Income

Accounting for northern subregional average gross returns per acre is accomplished through the following additions to the model.

MARKET

```
AVGRAR(1)=(PPGR*PYAVGR*TLNF(1)+PP(3)*PYAVG(3)*TLCF(1))/
          (TLNF(1)+TLCF(1))                                    (12)
```

where:

AVGRAR(1) = average gross returns per acre in northern subregion 1—£/acre yr.

PPGR = producer price received by farmer for groundnuts—£/lb.

PYAVGR = average productivity of groundnuts—lbs/acre yr.

TLNF(1) = total non-food (groundnuts) land in northern subregion 1—K acres.

PP(3) = producer price received by farmer for food grains—£/lb.

PYAVG(3) = average productivity of food grains—lbs/acre yr.

TLCF(1) = total cash food land in northern subregion 1—K acres.

MARKET

AVGRAR(2)=(PPCOT*PYAVCT*TLNF(2)+PP(3)*TLCF(2))/
(TLNF(2)+TLCF(2)) (13)

where:

AVGRAR(2) = average gross returns per acre in northern subregion 2—£/acre yr.

PPCOT = producer price received by farmer for cotton—£/lb.

PYAVCT = average productivity for cotton—lb/acre yr.

TLNF(2) = total non-food (cotton) land in northern subregion 2—K acres.

PP(3) = see above—£/lb.

PYAVG(3) = see above—lbs/acre yr.

TLCF(2) = total cash food land in northern subregion 2—K acres.

MARKET

AVGRAR(3)=(PPGR*PYAVGR*TLJG+PPCOT*PYAVCT*TLJC+PP(3)*PYAVG(3)*
TLJF)/(TLJG+TLJC+TLJF) (14)

where:

AVGRAR(3) = average gross returns per acre in northern subregion 3—£/acre yr.

PPGR = see above—£/lb.

PYAVGR = see above—lb/acre yr.

TLJG = total land in groundnuts in northern subregion 3—K acres.

PPCOT = see above—£/lb.

PYAVCT = see above—lb/acre yr.

TLJC = total land in cotton in northern subregion 3—K acres.

PP(3) = see above—£/lb.

PYAVG(3) = see above—lb/acre yr.

TLJF = total land in cash food in northern subregion 3—K acres.

MARKET

AVGRAR(4)=PP(4)*PYACG(4) (15)

where:

AVGRAR(4) = average gross returns per acre in northern subregion 4—£/acre yr.

PP(4) = producer price received by farmer for food roots--£/lb.

PYAVG(4) = average productivity of food roots--lb/acre yr.

The expression for subregional disposable income must be modified to account for the variable percentage of food self-sufficiency.

CONSN

ADUM(I)=ADUM(I)-PRFD(1)*DSCFR(I)/CPLBN (16)

where:

ADUM = subregional disposable income in the absence of supplemental credit--thousand £/yr.

PRFD(1) = market price of food in Northern Nigeria--£/lb.

DSCFR = demand rate of supplemental (cash) food staples from agricultural population in each northern subregion—K cal/yr.

CPLBN = average number of calories in the aggregate root-grain food bundle--cal/lb.

Costs

The last term on the right hand side of Equation (16) represents the farmers' outlay for supplemental (cash) food staples. This term is required in subsequent calculations and is therefore assigned the following variable name.

MARKET

CSCFR(K)=PRFD(1)*DSCFR(K)/CPLBN (17)

where:

CSCFR = cost of supplemental (cash) food staples in each northern subregion—thousand £/yr.

) = see above—£/lb.

= see above—K cal/yr.

= see above—cal/lb.

The above food costs may be expressed relative to the amount of cash crop land in each northern subregion.

MARKET

CFPAR(K)=CSCFR(K)/AL(K) (18)

where:

CFPAR = cost of supplemental (cash) food staples relative to the amount of cash crop land in each northern subregion—£/acre yr.

CSCFR = see above—thousand £/yr.

AL = total land allocated to cash crops in each northern subregion—K acres.

Net Returns

The following expression represents actual net cash returns per unit of labor for each northern subregion.

MARKET

CRL(K)=APL(K)*(AVGRAR(K)-CFPAR(K)) (19)

where:

CRL = actual net cash returns per unit of labor in each northern subregion—£/man-unit yr.[2]

CFPAR = see above— £/yr.

APL = acres of cash crops per unit of labor in each northern subregion—K acres/man-unit yr.

AVGRAR = average gross returns per acre in each northern subregion—£/acre yr.

It is desirable to have some indication of what the net cash returns per unit of labor would be under 100 percent food self-sufficiency.[1/]

MARKET

XCRL(K)=XAPL(K)*AVGRAR(K) (20)

where:

XCRL = psuedo-net cash returns per unit of labor in each northern subregion (assuming 100 percent food self-sufficiency)—£/man-unit yr.[2]

XAPL = acres of cash crops per unit of labor (assuming 100 percent food self-sufficiency) in each northern subregion—K acres/man-unit yr.

AVGRAR = see above—£/acre yr.

Performance Criteria

There is a need for a measure of the goodness of various proportions of food self-sufficiency. A possible profitability criterion of the relative (actual versus complete food self-sufficiency) net cash returns to labor is given by

NOT INCLUDED

PCSF(K)=CRL(K)/XCRL(K) (21)

1/ To get an exact calculation would require knowledge of the average gross returns per acre, AVGRAR, in each subregion under 100 percent food self-sufficiency. Calculation of the independent variables in Equations (12)-(15) under these conditions would require a separate pass through the land allocation component of the model for each time increment. At present, it does not seem necessary to forfeit this much efficiency in order to generate one variable.

where:

PCSF = profitability criterion of each northern subregion for existing proportion of food self-sufficiency—dimensionless.

CRL = see above—£/man-unit yr.^{2}

XCRL = see above—£/man-unit yr.^{2}

This criterion has proved to be inadequate for the purposes of this modification. As mentioned previously, the variable XCRL is not necessarily a true value of the net cash returns under complete food self-sufficiency. As the disparity between the actual and complete food self-sufficiency increases, the validity of XCRL decreases markedly. Even if the true value of PCSF was available (and it is at the expense of model efficiency) a much more pragmatic criterion has been incorporated into the modification.

Proportionate Gain From Change

This profitability criteria is not based on a fixed proportion of food self-sufficiency, as is the criteria in Equation (21). It is based on the existing proportion of food self-sufficiency, FSSR, and measures the profitability of changing FSSR in the 'best' direction. The proportionate gain from change, PGFC, Equation (22), measures the profitability of changing FSSR in a direction that gives the largest net cash returns to labor.

```
PGFC(K)=AMAX1((AMAX1(CRLA(K),CRLB(K))-
        CRL(K))/ABS(CRL(K)),0.)                    (22)
```

where:

PGFC = proportionate gain from a change in the existing proportion of food self-sufficiency FSSR—dimensionless.

CRLA = net cash returns per unit of labor in each northern subregion, reflecting an increase in FSSR above the existing proportion (subject to $0 \leq FSSR \leq 1$)—£/man-unit yr.[2]

CRLB = net cash returns per unit of labor in each northern subregion, reflecting a decrease in FSSR below the existing proportion (subject to $0 \leq FSSR \leq 1$)—£/man-unit yr.[2]

CRL = actual net cash returns per unit of labor in each northern subregion—£/man-unit yr.[2]

AMAX1[a,b] = a function equal to the maximum of the terms within the brackets.

ABS[·] = the absolute function.

The calculations of CRLA and CRLB in Equation (22) are accomplished through the following sequence of symmetrical equations.

MARKET

```
FSSRA(K)=AMIN1(FSSR(K)+.1,1.)                                  (23)
FSSRB(K)=AMAX1(FSSR(K)-.1,0.)                                  (24)

DEMRA(K)=FSSRA(K)*XDEMR(K)                                     (25)
DEMRB(K)=FSSRB(K)*XDEMR(K)                                     (26)

SFLA(K)=SFLA(K)+DT/S3*(DEMRA(K)/CALA-SFLA(K))                  (27)
SFLB(K)=SFLB(K)+DT/S3*(DEMRB(K)/CALA-SFLB(K))                  (28)

APLA(K)=AMAX1(APLO(K)*CM(K)-SFLA(K)/LABA(K),0.)                (29)
APLB(K)=AMAX1(APLO(K)*CM(K)-SFLB(K)/LABA(K),0.)                (30)

DSCFRA(K)=XDEMR(K)-DEMRA(K)                                    (31)
DSCFRB(K)=XDEMR(K)-DEMRB(K)                                    (32)

CSCFRA(K)=PRFD(1)*DSCFRA(K)/CPLBN                              (33)
CSCFRB(K)=PRFD(1)*DSCFRB(K)/CPLBN                              (34)

CFPARA(K)=CSCFRA(K)/AL(K)                                      (35)
CFPARB(K)=CSCFRB(K)/AL(K)                                      (36)
```

```
CRLA(K)=APLA(K)*(AVGRAR(K)-CFPARA(K))        (37)
CRLB(K)=APLB(K)*(AVGRAR(K)-CFPARB(K))        (38)
```

It is not necessary to give a description of each of the above equations. The letter A or B at the end of a variable name (with the exception of CALA and LABA) indicates that it has been calculated on a basis of an increase above or a decrease below the existing proportion of food self-sufficiency FSSR. Each of these variables, calculated on the basis of the actual FSSR, has been described earlier in this report.

It will be noted from Equations (23) and (24) that perturbations above and below FSSR are limited to ±10 percent. These amounts may be easily changed if desired; however, they should be kept as small as possible. Just as with XCRL, Equation (20), CRLA and CRLB are pseudo, becoming more invalid the greater the disparity in the proportions of FSSR.

Endogenous Determination of the Proportion of Food Self-Sufficiency

The exponential average of PGFC, Equation (22), better represents the farmers' perception of the profitability of changing the existing proportion of food self-sufficiency. This is accomplished through the following statement.

MARKET

```
CALL DELAY(PGFC(K),PCFCA(K),ROUTF(K),DELF,DT,1.)        (39)
```

where:

PGFC = proportionate gain from a change in the existing proportion of food self-sufficiency FSSR—dimensionless.

PGFCA = exponential average of PGFC, representing the farmers' perception in each northern subregion—dimensionless.

ROUTF = internal variable required by the DELAY subroutine.

DELF = a constant (time) that determines the weight farmers give to past experience.

DT = time increment of model.

For the endogenous determination of FSSR, a function is needed which will

i) cause FSSR to tend toward a level yielding maximum net cash returns to labor yet,

ii) reflect the inertia of human behavior.

Such a function is given by the following sequence of FORTRAN statements.

MARKET

```
      IF(CRLA(K).GT.CRLB(K)) GØ TØ 1                                  (40)
      FSSRC(K)=FSSRB(K)-FSSR(K)                                       (41)
      GØ TØ 2
    1 FSSRC(K)=FSSRA(K)-FSSR(K)                                       (42)
    2 CONTINUE
      FSSR(K)=FSSR(K)+                                                (43)
     1        FSSRC(K)*AMAX1((1.-EXP(-E202(K)*(PGFCA(K)-E203(K)))),0.)
```

where:

CRLA,B = net cash returns per unit of labor in each northern subregion, reflecting an increase (decrease) in FSSR above (below) the existing proportion (subject to $0 \leq FSSR \leq 1$)—£/man-unit yr.[2]

FSSRC = the change in FSSR which (among those considered) will give the largest net cash returns to labor—dimensionless.

FSSRA,B = proportion of food self-sufficiency 10 percent above (below) the existing proportion FSSR (subject to $0 \leq FSSR, B \leq 1$)—dimensionless.

FSSR = actual proportion of food self-sufficiency of each northern subregion—dimensionless.

PGFCA = an exponential average of the proportionate gain from a change (FSSRC) in the existing proportion of food self-sufficiency FSSR—dimensionless.

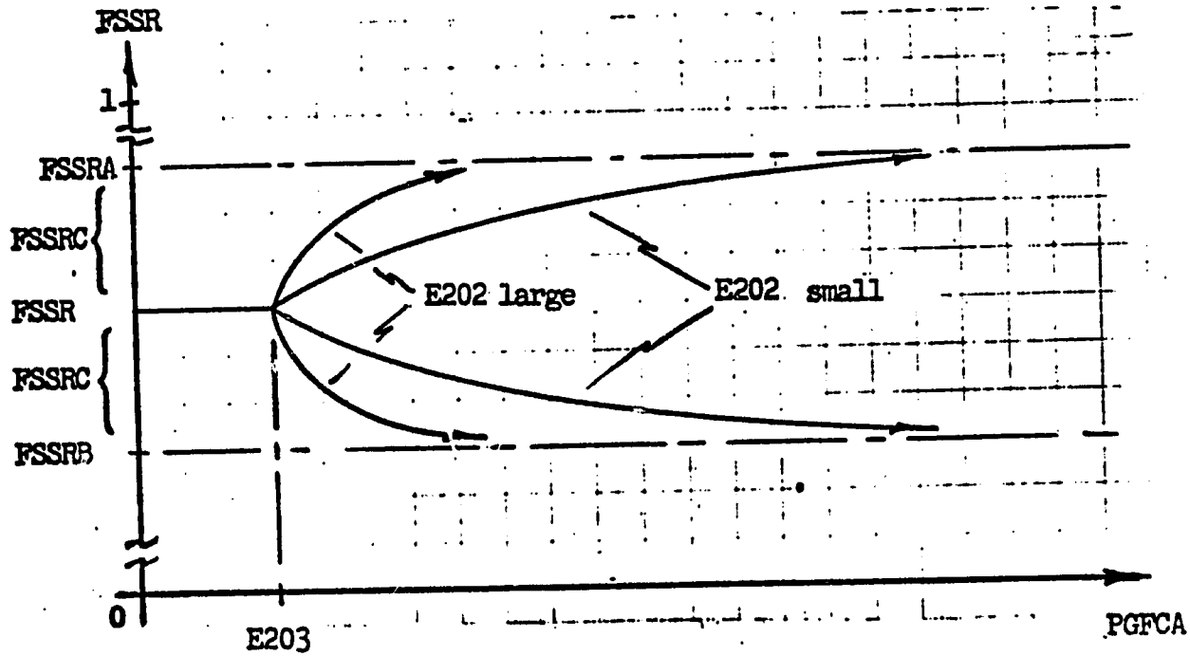
E202 = a parameter controlling the rate of change at which FSSR actually changes in each northern subregion—dimensionless.

E203 = a parameter controlling the threshold of profitability, PGFCA, below which the existing level of food self-sufficiency remains unchanged—dimensionless.

EXP = the exponential function.

AMAX1[a,b] = a function equal to the maximum of the terms within the brackets.

Statements (40) through (42) determine the magnitude and direction of the change to be considered. Equation (43) adjusts the existing value of FSSR in the direction of the change according to the perceived proportionate gain from the change, PGFCA. The illustration below depicts the general shape of the function described by Equation (43).



Testing of the Modification

Several simulation runs were made to verify that the modification was operating properly and not interfering with other parts of the model. An obvious built-in check was made by letting FSSR = 1, the value assumed by the unmodified version of the model. The output from this run was exactly identical to the output from a 'straight' run of the model without the modification.

Six runs were made to check the behavior of the modification under the following conditions.

1. FSSR = 1 ; exogenously determined (remaining at this value throughout the run)
2. FSSR = ·5 ; exogenously determined (remaining at this value throughout the run)
3. FSSR = 0. ; exogenously determined (remaining at this value throughout the run)
4. Initial FSSR = 1 ; endogenously determined thereafter
5. Initial FSSR = ·5 ; endogenously determined thereafter
6. Initial FSSR = 0. ; endogenously determined thereafter

Several WRITE statements were included in the modification for this testing stag [illegible] se are unimportant once checked out and should be removed [illegible] e.

As mentioned earlier, it was not the objective of this study to perform any experiments with the new modification. The objective was to develop the 'capability' within the model. The test runs indicate that the modification does, indeed, function as would be expected. These runs are included under Appendix B and are annotated to assist the interested reader in making a quick review.

GLOSSARY

The following glossary is provided for the convenience of those individuals working with this modification. Variables preceded by a double asterisk (**) are created by the modification, those preceded by a single asterisk (*) are structurally altered by the modification, and those variables appearing with no asterisk are structurally unaltered, but used by the modification.

*ADUM = subregional disposable income in the absence of supplemental credit--thousand £/yr.
(Eqn 16)
(CONSN)

AL = subregional total land allocated to cash crops--K acres
(Eqn 18)
(LANDAT; LANDN)

APL = subregional acres of cash crops per unit of labor--K acres/man-unit yr.
(Eqns 11, 19)
(LANDAT; LANDN)

**APLA = (APLB) see APL; reflects a 10 percent increase (decrease) above (below) the existing level of FSSR ($0 \leq FSSR \leq 1$)--K acres/man-unit yr.
(Eqns 29, 30, 37, 38)

APLO = subregional total acres cultivatable per unit of labor at a given level of mechanization--K acres/man-unit yr.
(Eqns 9, 11, 29, 30)
(SENDAT)

**AVGRAR = subregional average gross returns per acre--£/acre yr.
(Eqns 12, 13, 14, 15, 19, 20, 37, 38)
(MARKET)

CALA = subregional production rate of calories--K cal/yr.
(Eqns 8, 10, 27, 28)

**CFPAR = subregional cost of supplemental (cash) food staples relative to the amount of subregional total cash crop land--£/acre yr.
(Eqns 18, 19)
(MARKET)

**CFPARA = (CFPARB) — see CFPAR; reflects a 10 percent increase (decrease) above (below) the existing level of FSSR ($0 \leq FSSR \leq 1$)—£/acre yr.
(Eqns 35, 36, 37, 38)
(MARKET)

CM = — subregional mechanization coefficient greater than or equal to one that introduces the effect of labor saving investments—dimensionless
(Eqns 9, 11, 29, 30)
(SENDAT)

CPLBN = — average number of calories in the aggregate root grain food bundle—cal/lb.
(Eqn 16, 17, 33, 34)
(MARKET)

**CRL = — subregional net returns per unit of labor—£/man-unit yr.[2]
(Eqns 19, 21, 22)
(MARKET)

**CRLA = (CRLB) — see CRL; reflects a 10 percent increase (decrease) above (below) the existing level of FSSR ($0 \leq FSSR \leq 1$)—
(Eqns 22, 37, 38, 40)
(MARKET)

**CSCFR = — subregional cost of supplemental (cash) food staples—thousand £/yr.
(Eqns 17, 18)
(MARKET)

**CSCFRA = (CSCFRB) — see CSCFR; reflects a 10 percent increase (decrease) above (below) the existing level of FSSR ($0 \leq FSSR \leq 1$)—thousand £/yr.
(Eqns 33, 34, 35, 36)
(MARKET)

**DELF = — a constant (time) that determines the weight farmers give to past experience related to food self-sufficiency—yrs.
(Stmt 39)
(MARKET)

*DEMCFN = — demand rate for cash food staples for Northern Nigeria—K cal/yr.
(Eqn 7)
(POPOUT)

*DEMR = — subregional demand rate for subsistence calories from the agricultural population reflecting actual percentage of food self-sufficiency—K cal/yr.
(Eqns 1, 2, 3, 10)
(POPOUT)

**DEMRA = (DEMRB) — see DEMR; reflects a 10 percent increase (decrease) above (below) the existing level of FSSR ($0 \leq FSSR \leq 1$)—K cal/yr.
(Eqns 25, 26, 31, 32)
(MARKET)

**DSCFN = demand rate for supplemental (cash) food staples from the agricultural population of Northern Nigeria—K cal/yr.
(Eqns 4, 6, 7)
(POPOUT)

**DSCFR = subregional demand rate for supplemental (cash) food staples from the agricultural population—K cal/yr.
(Eqns 3, 16, 17)
(POPOUT)

**DSCFRA = (DSCFRB) — see DSCFR; reflects a 10 percent increase (decrease) above (below) the existing level of FSSR ($0 \leq FSSR \leq 1$)—K cal/yr.
(Eqns 31, 32, 33, 34)
(MARKET)

**E202, E203 = subregional parameters controlling the endogenous determination of the proportion of food self-sufficiency (FSSR)—dimensionless
(Eqn 43)
(SENDAT)

**FSSR = subregional proportion of agricultural population food self-sufficiency—dimensionless
(Eqns 2, 23, 24, 41, 42, 43)
(SENDAT; MARKET)

**FSSRA = (FSSRB) — subregional proportion of food self-sufficiency 10 percent above (below) the existing proportion FSSR (subject to $0 \leq FSSR \leq 1$)—dimensionless
(Eqns 23, 24, 25, 26, 41, 42)
(MARKET)

LABA = subregional agricultural labor available—K man-units
(Eqns 9, 11, 29, 30)
(POPOUT)

PCSF = (Not included) subregional profitability criterion for existing proportion of food self-sufficiency—dimensionless
(Eqn 21)

**PGFC = subregional proportionate gain from a change in the existing proportion of food self-sufficiency FSSR—dimensionless
(Eqns 22, 39, 43)
(MARKET)

**PGFCA = exponential average of PGCFA, representing the farmers' perception of the profitability of a change—dimensionless
(Eqns 39, 43)
(MARKET)

PP(3) = producer price received by farmer for food grains—£/lb.
(Eqns 12, 13, 14)
(MODAT; AMP)

PP(4) = producer price received by farmer for food roots—£/lb.
(Eqn 15)
(MODAT; AMP)

PPCOT = producer price received by farmer for cotton—£/lb.
(Eqns 13, 14)
(MODPRP)

PPGR = producer price received by farmer for grain—£/lb.
(Eqns 12, 14)
(MODPRP)

PRFD(1) = market price of food in Northern Nigeria—£/lb.
(Eqns 16, 17, 33, 34)
(MKTSET; MARKET)

PYAVCT = average productivity of cotton—lbs/acre yr.
(Eqns 13, 14)
(MODAT; MODPRP)

PYAVG(3) = average productivity of food grains—lbs/acre yr.
(Eqns 12, 13, 14)
(AMPDAT; MOD)

PYAVG(4) = average productivity of food roots—lbs/acre yr.
(Eqn 15)
(AMPDAT; MOD)

PYAVGR = average productivity of groundnuts—lbs/acre yr.
(Eqn 12, 14)
(MODAT; MODPRP)

**ROUTF = internal variable required by the DELAY subroutine when employed to obtain exponential average of profitability
(Eqn 39)
(MODAT; MARKET)

S3 = adjustment lag—years
(Eqns 8, 10, 27, 28)
(LANDAT)

SFL = subregional total land required for subsistence food—K acres
(Eqn 10)
(LANDAT; LANDN)

**SFLA = (SFLB) see SFL; reflects a 10 percent increase (decrease) above (below) the existing level of FSSR ($0 \leq FSSR \leq 1$)—K acres.
(Eqns 27, 28, 29, 30)
(MARKET)

TLCF(1) = total cash food land in subregion 1—K acres
(Eqn 12)
(LANDAT; LANDN)

TLCF(2) = total cash food land in subregion 2—K acres
(Eqn 13)
(LANDAT; LANDN)

TLJC = total land in cotton in subregion 3—K acres
(Eqn 14)
(LANDAT; LANDN)

TLJF = total land in cash food in subregion 3—K acres
(Eqn 14)
(LANDAT; LANDN)

TLJG = total land in groundnuts in subregion 3—K acres
(Eqn 14)
(LANDAT; LANDN)

TLNF(1) = total non-food (groundnuts) land in subregion 1—K acres
(Eqn 12)
(LANDAT; LANDN)

TLNF(2) = total non-food (cotton) land in subregion 2—K acres
(Eqn 13)
(LANDAT; LANDN)

**XAPL = subregional acres of cash crops per unit of labor (assuming 100 percent food self-sufficiency)—K acres/man-unit
(Eqns 9, 20)
(LANDN; MARKET)

**XCRL = subregional net cash returns per unit labor (assuming 100 percent food self-sufficiency)—£/man-unit yr.[2]
(Eqns 20, 21)
(MARKET)

**XDEMR = subregional demand rate for subsistence calories (assuming 100 percent food self-sufficiency)—K cal/yr.
(Eqns 1, 2, 3, 8, 25, 26, 31, 32)
(POPOUT)

**XSFL = subregional land required for subsistence food (assuming 100 percent food self-sufficiency)—K acres
(Eqns 8, 9)
(LANDAT; LANDN)