# A SYSTEM DYNAMICS MODEL OF FOOD GRAIN PRODUCTION IN KOREA

—糧穀生産의 動的 모델에 關한 研究—

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要　約

食糧 穀物의 安定的 生産은 國家的으로 큰 比重을 차지하는 問題로서 食糧生産計劃 樹立과 政策決定을 위해서는 向後의 食糧生産에 影響을 미칠 諸要因들의 有機的인 關係와 時間에 따른 變異를 勘案한 '動的인 考察'이 必要하다.

本 研究에서는 食糧生産에 影響을 미치는 諸要因 即 農村人口, 耕作規模, 農業投資, 研究 및 技術開發投資, 農業技術水準, 農家所得, 人口動向, 氣候變異등을 考慮하여 食糧生産動向을 豫測하기 위한 system dynamic model을 作成하였고 이를 通하여 2008年까지의 動向을 推定하였다.

向後人口, GNP, 技術水準등은 時間이 經過함에 따라 增加 할것이나 耕作面積은 農村人口의 流出增加 趨勢에 따라 점점 減少할 것으로 推定되었다. 또한 農村人口는 農村人口 流出, 流入의 指標로 삼은 Income Ratio의 變異에 따라 本 Simulation Model의 基準年度인 1978年부터 1983年까지는 減少趨勢를 보이다가 以後부터 2006年頃까지는 增加 趨勢를 보일 것으로 推定되었다.

食糧生産量은 耕作面積의 減少率增加에도 不拘하고 技術水準이 向上됨에 따라 變化가 없을 것으로 예상되나 氣候의 變異에 크게 影響을 받게 될 것으로 豫測되었다.

따라서 食糧의 絕對量 確保를 위해서는 耕作面積의 擴大, 農業機械化를 通한 不足勞動力의 代替, 農業技術의 研究·開發과 氣象變異에 對處하기 위한 用水 및 灌漑施設의 擴充등 持續的이며 長期的인 對策이 講究되어야 할 것으로 思料되었다.

## 1. INTRODUCTION

Agriculture in Korea has been heavily depended on the weather in the past. Until the beginning of the 1960's, nearly half of the paddy field were inadequately irrigated relying on rainfall.

The existing water utilization system did not work well due to shortage of construction. As of the end of 1961, the ratio of irrigated paddy field to total was 54.9%.

In 1962 the Government enacted the Law on Land Improvement Projects and in 1965, the government also formulated the Nine-Year Water Resource Development Plan for all-weather agriculture. From the middle of the 1960's, agricultural mechanization started in earnest together with the promotion of the domestic farm machinery industry and high-yield varieties such as Tongil and Yushin, have been developed.

Due to the government policy mentioned above and measures placing emphasis on the increase of grain production, food production showed a

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steady growth during the past two decades.

As a result, food grain production attained its highest record in the history of Korea during 1975, and its self-sufficient in rice and barley was achieved a year ahead of the original schedule (rice yield 6.3 ton/ha, FAO, 1977).

## 2. PROBLEM

### A. Problem Statement

The agricultural contribution to the gross national product (GNP) was so weak compared with those of other sectors of industry.

This fact is generally considered being dark from the agricultural point of view. Under present circumstance, it might be meaningful to review agricultural system, so that we, agricultural engineer or agricultural administrators, can take advantages to formulate the agricultural policy and decision based on the food grain system simulation.

The problems state as follows;

1. The farm population has been sharply decreased from 56.9% in 1961(farm population/total population) to 28.9% in 1979.
2. The cultivated land has been remained more or less same due to encroachment of the other sector of industry in spite of the enlargement of arable land through reclamation.
3. Lack of labor accelerates the mechanization of agriculture.
4. Extensive and substitutional technology, and pollution will be increased, as more food is needed.
5. Investment on agriculture has to be increased to develop the technology and enlarge the arable land.
6. Energy consumption will be increased, as the demand of technology and mechanization will increase.
7. As total population increase, more food will be needed.

### B. Objective

This study was performed to forecast on the food grain production in Korea up to year 2000 and to determine the interrelationships among factors which will be listed under the MODEL STRUCTURE. This study might be helpful to set up the policy for making decision of food grain affairs involved.

## 3. MODEL STRUCTURE

### A. Causal Relationships

The inherent relationsh ip among five primary factors contributing to food grain production was considered in formulating the systems dynamic model; Those are;

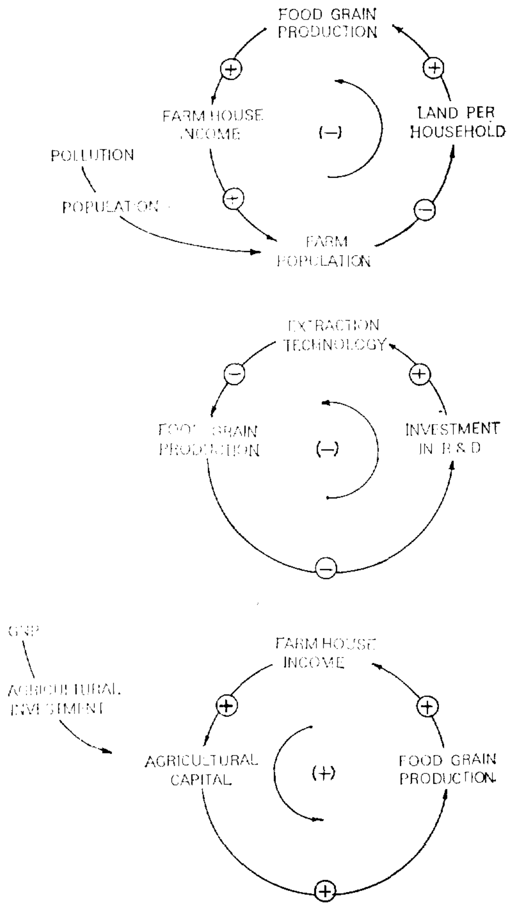


**Fig. 1, Causal relationships among foctors**

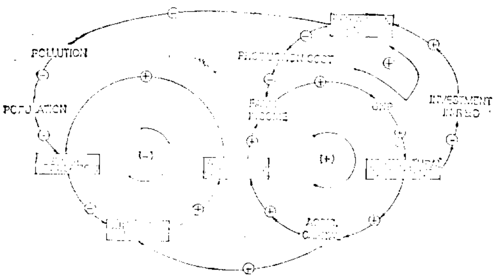

**Fig. 2. Sign-diagram for food grain production model**

—Farm population
—Investment on agriculture (GNP)
—Arable land
—Extensive technology(Substitutional technology invloved)
—Weather

Three feed-back loops could be structured out of the interrelationship of those five levels, which could be integrated to form the signed diagram of the system dynamics model.

### B. Data Needed

1. Land area
2. Population
3. Average life span
4. Gross national product
5. Saving and investment ratio
6. No. of farm household, farm population
7. Area of cultivated land and cultivated land by year
8. The tendency of farm household, farm population
9. Total agricultural production
10. Food grain production by year
11. Income and expenditure of farm household
12. Planted area of food grain by year
13. Production cost of food grain
14. Production cost of food grain per cultivated land
15. Food grain consumption per capita and year
16. Value of farm production
17. Price of farm products received by farmers
18. Agricultural income and expenditure in average

### C. Notations of Terms Used in the Model Equations

The following is a list of notations of terms which will be used throughout the dynamic models. These were patterned after the terms used by N.W. Chan and J.W. Forrester for standardization purpose.

AGR Average Growth Rate(Fraction/year)
AI Average Investment for Agficulture (Fraction/year)
AMM Attractiveness for Migration Multiplier(D, less)
AMMP Attractiveness for Migration Multiplier Perceived(D, less)
BR Birth Rate(Peoples/year)
BRN Birth Rate Normal(Fraction/year)
BRNI Birth Rate Normal 1(Fraction/year)
BRPM Birth Rate from Multiplier Pollution (D, less)
BRPMT Birth Rate from Pollution Multiplier Table
CL Cultivated Land(ha)
CLAMD Cultivated Land Availability Multiplier for Development(D, less)
CLAMR Cultivated Land Removal Multiplier (Fraction/year)
CLAMT Cultivated Land Multiplier for Removal Table
CLDR Cultivated Land Development Rate (ha/year)
CLI Initial Cultivated Land(ha)
CLPHF Cultivated Land Per Farm Household (ha/unit)
CLRR Cultivated Land Removal(ha/year)
CTA Cost of Technology Advanced(₩/Technology Unit-year)
CTAT Cost of Technology Advanced Table
DI Desired Income(₩/people)
DMMI Departure Migration Multiplier(D, less)
DR Death Rate(Peoples/year)

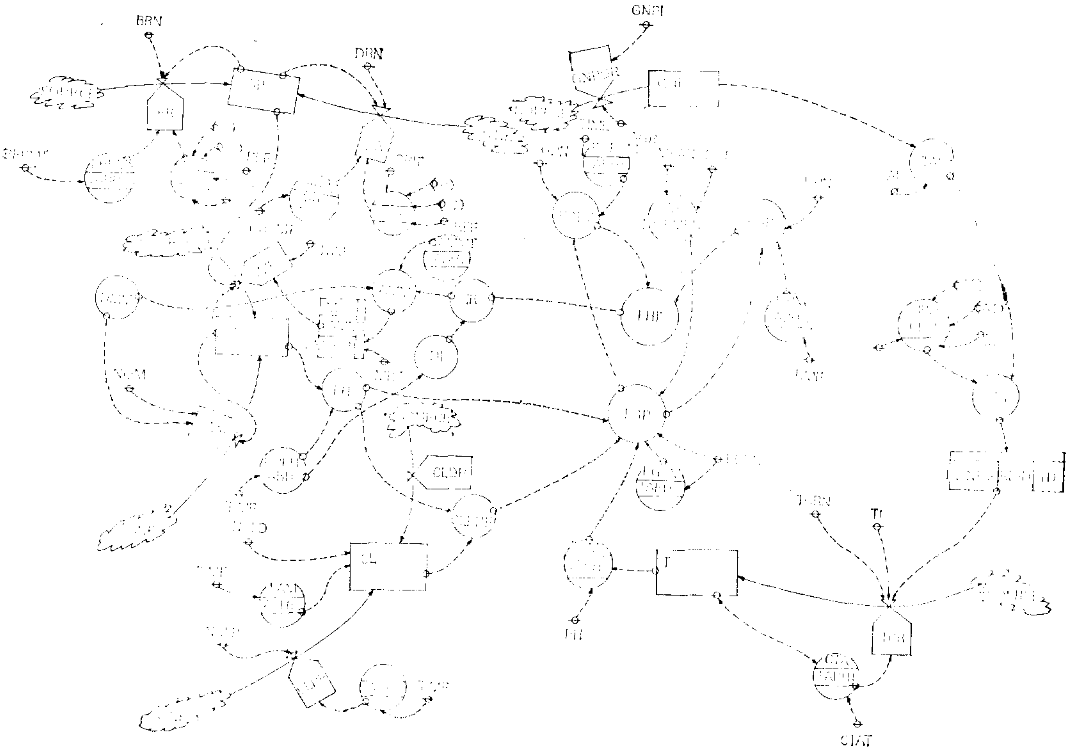

**Fig. 3. Food grain prodution system**

| | |
|---|---|
| DRN | Death Rate Normal(Fraction/year) |
| DRN1 | Death Rate Normal 1(Fraction/year) |
| DRPM | Death Rate from Pollution Multiplier (D, less) |
| DRPMT | Death Rate from Pollution Multiplier Table |
| FGP | Food Grain Production(Ton/ha/year) |
| FGPC | Food Grain Production Cost(₩/ha) |
| FGPCM | Food Grain Production Cost Multiplier (Fraction/ha) |
| FGPM | Food Grain Production Multiplier(Fraction/year) |
| FGPMT | Food Grain Production Multiplier Table |
| FGPN | Food Grain Production Normal(Ton/ha) |
| FGR | Food Grain Production Revenue(₩/Unit Household) |
| FH | Farm Household(Units) |
| FHI | Farm Household Income(₩/Unit Household) |
| FP | Farm Population(persons) |
| FPI | Intial Value of Farm Population(persons) |
| FPS | Farm Population at Standard Year (persons at 1978) |
| GNP | Gross National Product(₩/year) |
| GNPGR | GNP Growth Rate(₩/year) |
| GNPI | Initial GNP(₩/year) |
| IMR | In-Migration Rate(peoples/year) |
| IR | Income Ratio(D, less) |
| MPT | Migration Perception Time(years) |
| NCLD | Normal Land Development(Fraction/year) |
| NCLR | Normal Land Removal(Fraction/year) |
| NIM | Normal In-Migration(Fraction/year) |
| NOM | Normal Out-Migration(Fraction/year) |
| OMR | Out-Migration Rate(persons/year) |
| P | Population(persons) |
| PIRD | Percentage Investment in Research and Development(D, less) |
| PLR | Population Ratio(D, less) |

| | |
|---|---|
| PPFH | Population Per Farm Household(persons) |
| PPFHT | Population Per Farm Household Table |
| RDI | Investment in Research and Development (₩/year) |
| RDID | Research and Development Delay(₩/year) |
| SWT1 | Switch Time No.1 for Birth Rate Normal(year) |
| SWT2 | Switch Time No.2 for Birth Rate Normal(year) |
| T | Technology(Unit) |
| TAI | Total Investment for Agriculture(₩/year) |
| TCR | Technology Change Rate(Unit/year) |
| TCRN | Technology Change Rate Normal (Unit/year) |
| TD | Technology Delay(year) |
| TI | Technology Initial(Unit/year) |
| UPM | Unit Price Multiplier(Fraction/year) |
| UPMT | Unit Price Multiplier Table |
| UPN | Unit Price of Food Grain(₩/Ton) |
| WF | Weather Factor(D, less) |

## 4. SYSTEM DYNAMICS FORMULATION(MODEL DIAGRAM & DYNAMO STATEMENTS)

On the basis of aggregated sign diagram Fig. 3 presents the systems dynamics diagram of food grain production system model. Five levels interact in such a manner that it was described in the three feedback loops previously mentioned. The interaction of these will be discussed in the succeeding sections.

### A. Population(P)

The population of Korea was computed at the population at the proceeding points in time plus the number born during the interval considered, minus those people removed due to death. The level equation thus becomes;

L P.K=P.J+(DT)−(BR.JK−DR.JK)

N P=PI

C PI=37.019E6

**1) Birth rate (BR)**

The basic birth rate, BR, is a function of the population, a coefficient, BRN and the population effects as reflected by the birth rate from pollution multiplier, BRMP. Birth rate normal, BRN, states the birth rate per year as a function of the population under 'normal' condition.

R BR.KL=(P.K) (CLIP(BRN, BRNI, SWTI, TIME.K)) (BRP)

C BRN=.034

C BRNI=.034

C SWTI=1978

A BRPM.K=TABHL (BRPMT, PLR.K, O, 10, 1)

T BRPMT=1/.95/.9/.85/.8/.75/.7/.65/.6/.55/.5

**2) Death rate (DR)**

Similarly, the death rate, DR, is a function of population, a coefficient, DRN and pollution effects as reflected by the death rate from pollution multiplier, BRPM.

R DR.KL=(P.K) (CLIP(DRN,DRNI, SWT2, TIME.K)) (DRPM.K)

C DRN=.015

C DRNI=.015

C SWT2=1978

A DRPM.K=TABHL(DRPMT,PLR.K, O, 10, 1)

T DRPMT=1.0/1.1/1.2/1.3/1.4/1.5/1.6/1.7/1.8/1.9/2.0

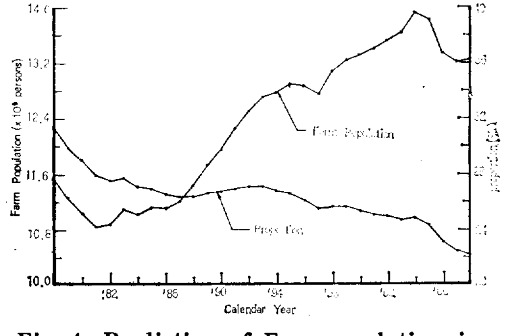


**Fig. 4. Prediction of Farm population in persons and the proportion of Farm population to total population in percent by year**

A PLR.K=FPS/FP.K

C FPS=11.527E6

## B. Farm population (FP)

The level of farm population is altered by two flow rate; in-migration rate and out-migration rate.

L FP.K=FP.J+(DT) (IMR.JK−OMR.JK)

N FR=FPI

C FPI=11.527E6

**1) In-migration rate(IMR)**

The in-migration rate, IMR, is the product of population, FP, the attractiveness for migration multiplier perceived, AMMP, and the normal in-migration, NIM.

R IMR.KL=NIM* AMMP.K* P.K

C NIM=.145

When AMMP equals to 1, migration into the farm will be .145% of farm population, FP per year. AMMP represents a 5-year delay smooth of attractiveness for migration multiplier, AMM. The delay accounts for the assumed information lag between actual farm income and urban work income perceived by potential migrants outside the farm.

A AMMP.K=SMOOTH(AMM.K, MPT)

C MPT=5

C DI=3.7E5

A AMM.K=TABHL(AMMT, IR.K, 0.2,.25)

T AMMT=0.05/0.1/0.2/0.4/1.0/1.6/1.8/1.9/2.0

A IR.K=FHI.K/((PPFH.K) (DI))

**2) Out-migration rate(OMR)**

The departure migration multiplier, DMM, equals the reciprocal of AMM. That is, we assume that the same farm population inducing people to move into the urban would tend to keep residents in the area from moving out.

A DMM.K=1/AMM.K

The out migration rate, OMR, is the product of the departure migration multiplier, DMM, farm population, FP and normal out-migration, NOM.

R OMR.KL=NOM*DMM.K*P.K

C NOM=.02

**3) Farm household(FH)**

The number of household will be obtained by dividing farm population by people per farm household, which is the function of people per farm household.

A FH.K=FP.K/PPFH.K

A PPFH.K=TABHL (PPFHT, TIME.K, 0, 12,1)

T PPFHT=5.18/5.17/5.1/5.08/4.99/4.9/4.8/4.62/4.5/4.35/4.18/4.03/4

## C. Cultivated land(CL)

The level of cultivated land, CL, is the net accumulation over land of cultivated land development rates, CLDR and cultivated land removal rate, CLRR.

L CL.K=CL.J+(DT)(CLDR.JK−CLRR.JK)

N CL=CLI

C CLI=2.222E6

**1) Cultivated land development rate(CLDR)**

The cultivated land development rate, CLDR, is a multiplicative function of the cultivated land development multiplier, CLAMD, the initial cultivated land and normal cultivated land for development, NCLD.

R CLDR.KL=NCLD*CLAMD.K*CL.K

C NCLD=.01

A CLAMD.K=1/1.02/1.04/1.06/1.08/1.1

**2) Cultivated land removal rate(CLRR)**

The cultivated removal rate, CLRR, is also a multiplicative function of the cultivated land removal multiplier rate, CLRMR, the initial cultivated land and normal cultivated for removal, NCLR.

R CLRR.K=NCLR*CL.K*CLAMR.K

C NCLR=.0136

A CLAMR.K=TABHL(CLAMRT, TIME.K, 0,12,1)

T CLAMRT=1.0/1.2/1.3/1.4/1.45/1.5

**3) Size of cultivated land**

Size of cultivated land per farm household, CLPFH, is the function of the total available cultivated land divided the number of farm house, in average, which will fluctuate

A CLPFH.K=CL.K/FH.K

## D. Gross National Products(GNP)

The GNP at any time is computed to be the GNP at the proceeding period plus its Growth Rate, GNPGR, multiplier by the time interval. The Growth Rate is a function of the Average Growth Rate, AGR and GNP will affect the investment over agriculture.

L GNP.K=GNP.J+(DT)(GNP.JK)

N GNP=GNPI

C GNPI=1.369E13

R GNPGR.KL=(GNPI)(AGR)

C AGR=.1057

**1) Total Investment on Agriculture(TAI)**

The Total Investment on Agriculture, TAI will be depend upon the GNP at that year. In average the fraction of average investment over GNP is 0.05%.

A TAI.K=(GNP.K)(AI)

C AI=.05

## E. Technology(T)

Technology represents all accumulated research and knowledge pertaining to extraction processing, substitution. It was assumed that initial level technology was one Technology unit. This level is increased by the technology change rate, TCR. The expression for this level is therefore,

L T.K=T.J+(DT)(TCR.K)

N T=TI

C TI=1

## F. Technolgy Change Rate(TCR)

It is assumed that actual rate of change of technology is function of the normal change of technolgy, TCRN, the cost of advancing technology, CTA and research and development delay, RDID. The expression for TCR is formulated as follows;

R TCR.KL=(TCRN)(1. 0/CTA.K)(RDID.K/TI)

C TCRN=.1

## G. Cost of Technology Advanced(CTA)

Normally, technology is assumed to proceed at a pace of 10% a year. However, if the cost of advancing technology increases, then the pace would be retarded. In similar manner, should R & D delays diminish, then the change rate would be decreased.

It is actually very difficult to obtain any data on how much money will be needed to increase the level of technolgy by a stated amount.

One can only venture on a reasonable off the cuff estimate.

A CTA.K=TABHL(CTAT, T.K, 1,6,0.5)

T CTAT=5E8/13E8/21E8/29E8/38E8/45E8

A RDI=(TAI.K)(PIRD.K)

A PIRD.K=CLIP(0.02, 0.05, 1.1, TIME.K)

A RDID.K=DELAY3(RDI,K,TD)

C TD=10

It was assumed that the economy of developing country like Korea would allocate 5% of total agricultural sales(GNP assigned for agriculture).

## H. Food grain production(FGP)

Food grain production is the function of cultivated land per farm household and production per hectare and weather. Weather was considered by using NORMRN function which has expected value is 1 and standard deviation equals 1.

A FGP.K=CLPFH.K*FGPN*FGPM.K*WF.K

C FGPN=3.3

A FGPM.K=TABHL (FGPMT, TIME.K, 1, 5,1)

T FGPMT=1.0/1.05/1.1/1.15/1.2

## I. Food grain production revenue (FGPR)

one unit of advanced technology was assumed to increase 1% of the production of food grain.

A TBM.K=(1+(T.K/100))

A FGR.K=UPN*UPM.K*TBM.K*FGP.K

C UPN=4.057E5

A UPM.K=TABHL(UPMT, TIME.K, 0,9,2)

T UPMT=1.0/1.3/1.4/1.6/2.2

### J. Food grain production cost(FGPC)

Food grain production cost, FGPC, is the product of food grain production cost normal and cost multipler and cultivated land per farm household.

A FGPC.K=(FGPCN)(FGPCM.K)(CEPFH.K)

C FGPCN=6.0293E5

A FGPCM.K=TABHL(FGPCT, TIME.K, 1, 4,1)

T FGPCT=1/1.5/2.2/2.5

A WF.K=NORMRN(1.0,1)

C DI=3.7E5

N TIME=1978

### K. Farm House Income (FHI)

Farm house income, FHI, was considered only the income through the harvest of food grain production because it is obvious that these two factors are strongly linearly related.

The rate of farm house income, FHI, is altered by two flow rates, food grain production revenue, FGR, and food grain production cost, FGPC.

A FHI.K=FGR.K−FGPC.K

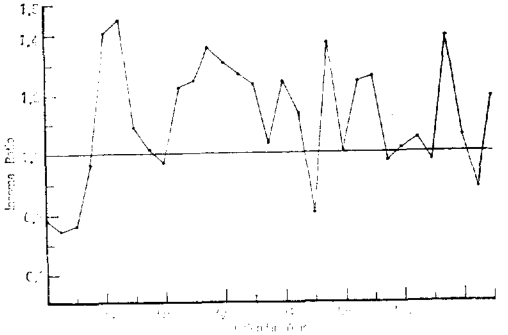

**Fig. 5. Prediction of income Ratio by year**

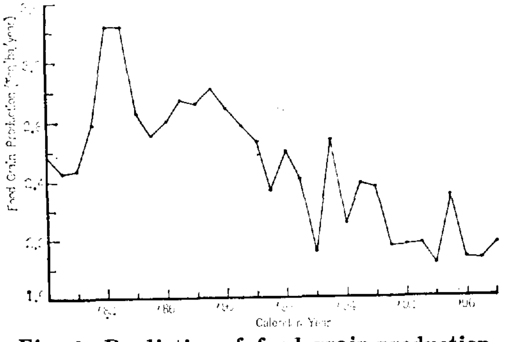

**Fig. 6. Prediction of food grain production by year**

## 5. Discussion and Conclusions

The model developed in this study may be a useful tool for predicting the food grain production under the consideration of the production inputs and circumstances such as farm population, investment on agriculture, arable land, extensive technology and weather.

The model output suggest that the population, GNP, technology will increase with time, but cultivated land will gradually decrease due to the increase of out-migration.

Until 1983 from 1978 at which the basic year in this simulation system, the farm population will be decreased, after then, farm population will start to increase because Income Ratio will be greater than 1 (Fig.5) which means people are willing to migrate into the farm area. Again, around 2006 it will start to decrease (Fig.4).

The prediction shows that food grain production will stay steadily in spite of the increasing removal rate of cultivated land. This means advanced technology will be very much associated with food grain production (Fig.6).

Also it shows that the food grain production will be much affected by weather which was introduced by using NORMRN function.

Therefore, it is desirable that the persistent and long-term program should be studied to produce food grains sufficiently and safely regardless of the shocks from the variational inputs and circumstances for food grain production.

## Summary

A system dynamic model was developed to predict food grain production under the dynamic consideration of the production circumstances

and inputs such as farm population, investment on agriculture, arable land, extensive technology and weather.

By using the model, the variation of the food grain production from 1978 to 2008 was examined.

The results of the model output says it is desirable that the persistent and long-term program should be studied to get necessary food grain production under the variational inputs and circumstances.

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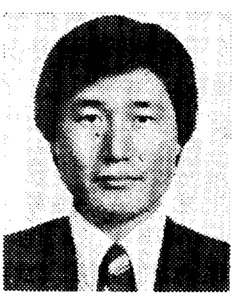

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