SYSTEM DYNAMICS MODELING AND SIMULATION OF FOOD SUPPLY FOR MPANDA DISTRICT IN TANZANIA

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Abstract

The Mpanda District in the Rukwa region is one of many areas in Tanzania which for a long time has faced food supply related problems. This paper has analyzed the problem of food supply for Mpanda district in by using system dynamics modeling and simulation analysis methodology.

The basic methods and definitions of system dynamics were developed by J. W. Forrester. The main objective, original point and contribution of this study is to introduce the application and use of system dynamics modeling and simulation approach in Tanzania and Africa.

To implement the application and use, this study has developed a food supply-analytical tool for Mpanda district, Tanzania. This is an essential component in the programmatic efforts for solving food supply and agricultural production problems to develop an integrated decision support program to assist policy analyses, policy makers, decision makers, regional resource allocation for food supply and agricultural management in the Mpanda district and Tanzania in general.

This research facilitates better understanding of the food supply and agricultural production in Mpanda district and other areas in Tanzania. These areas are likely to be impacted in the short and long term by family farm decisions about agricultural production methods.

The system dynamics approach is a new methodology for food supply in Tanzania. Most research studies have used other analytical methods, such as econometric and optimization models. Unfortunately the research problems analyzed by econometric and optimization models remain unsolved and offer no promising sustainable solutions.

Due to limitations and the merits of system dynamics as compared with other analytical methods, using system dynamics to analyze the food supply problem is a wise choice. For this analysis, the Mpanda system dynamics food supply model (MSDFSM) was developed and simulated. Factors, such as population, agricultural production, and land resources, were modeled and simulated using Vensim, system dynamics computer software, to demonstrate implications through interactions and causative effect of the variables in this study.

The conclusions and summary are the results of six cases, divided into three cases of analysis of the Mpanda system dynamics food supply model and the results of three cases of marginal returns of labor and land resources. This study provides a comprehensive analysis of system dynamics modeling and simulation for the food supply in Mpanda district and concludes with policy recommendations beneficial to both policy and decision makers.

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Keywords : Food supply, System Dynamics, Agricultural Production, Population, Land Resources, Mpanda.

Table of Contents

1. SYSTEM DYNAMICS ANAYLYSIS OF FOOD SUPPLY FOR MPANDA[2)] DISTRICT IN TANZANIA

1.1 System Dynamics[3)] Analysis

System dynamics is a problem-oriented multidisciplinary approach that allows identifying, understanding, and utilizing the relationship between behavior and structure in complex dynamic systems. The underlying concept of system dynamics implies that the understanding of complex system behavior, such as the national food supply, can be achieved only through examining the entire system rather than the isolated individual parts.

The system dynamics approach is a new methodology in Tanzania for the food supply problem. Most research has utilized other analytical methods, such as econometric and optimization models. Unfortunately the problems analyzed by econometric and optimization models remain unsolved and are without promising sustainable solutions.

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2) Mpanda District is one of the four districts in Rukwa Region, located in Western Tanzania.

3) System dynamics is an approach for studying and understanding the behavior of complex systems over time. It addresses internal feedback loops and time delays that influence the behavior of the entire system and the visual representation of the systems. It also involves and makes possible modeling and simulation of the system.

System dynamics is an analytical methodology that allows modeling and simulation of the dynamics of complex systems such as population, ecology, economics, agriculture, environment, climate, management, and business, which usually interact with each other. Systems dynamics was founded in the early 1960s by Jay W. Forrester at the Massachusetts Institute of Technology (MIT) Sloan School of Management with the establishment of the MIT System Dynamics Group.

Forrester and his team developed the initial ideas by applying the concept from feedback control theory to the study of industrial systems (Forrester, 1961). One of the best-known applications of the 1960s was Forrester's (1969) *Urban Dynamics*. The book explained the patterns of rapid population growth and subsequent decline that have been observed in American cities such as Manhattan, Detroit, St. Louis, Chicago, Boston and Newark (Schroeder and Strongman, 1974). Forrester's simulation model showed the city as a system of interacting industries, housing and people (Forrester, 1969).

One of the most widely known applications of system dynamics appeared a few years later in a best-selling book, *The Limits to Growth* (Meadows et al., 1972). This study looked at prospects for human population growth and industrial production in the global system over the next century. A computer model was used to simulate resource production and food supply to keep pace with the growing system. The authors concluded that the world could not support the present rates of economic and population growth much beyond the year 2100. The study was not about a pre-ordained future. It was about making choices to influence the future.

The beginning of system dynamics shows that system dynamics is a method to study the world around us. The central concept is to understand how all the objects in a system interact with one another. System dynamics looks at a system as a whole. A system can be a bank account, population, food supply, company, agriculture, or natural resources. System dynamics attempts to understand the basic structure of a system and therefore to understand the behavior the system will produce. Many of these systems and problems can be built as a computer model. The advantage is that the computer model is flexible and can implement numerous simulations. Hence, many future development paths can be evaluated. With the availability of stock-and-flow software programs, we can concentrate on the realism of the model rather than managing or controlling the analysis. The inclusion of non-linear relationships is one of the most important improvements compared with numerical models.

System dynamics is an approach for understanding the behavior of complex systems over time. It addresses internal feedback loops and time delays that influence the behavior of the entire system. What makes using system dynamics different from other approaches is the use of feedback loops, level or stock, and rates or flows. These elements help describe how even seemingly simple system display baffling nonlinearity. Computer software such as Vensim is used to simulate a system dynamics model of the problem or issue under study. Running what if simulation to test certain policies on such a model can greatly aid in understanding how the system changes over time. System dynamics is similar to system thinking and constructs the same causal loop diagram of systems with feedback. However, system dynamics typically goes further and utilizes simulation to study the behavior of systems and the impact of alternative policies. Important to note is that the approach is not entirely holistic, as it is necessary to use some elements from reductionism to describe the behavior of the various system components (Colin, 1997).

Generally, models developed for food supply used correlations to explain relationships, but the introduction of system dynamics methodology is preferred in the formulation of models for several reasons: (1) Systems dynamics is a methodology that helps understand why things are happening now. (2) Its great interest is on the causation of variables. (3) The main purpose is the evaluation of policies and their long term influence. Such models can be designed to allow the user to analyze and manipulate internal structure as well as study the relationship between the structure and the behavior of the model. Due to their transparency, these models are often tagged "white boxes."

The use of the system dynamics tool for better understanding of the phenomenon of food supply finds its main application in those environments in which complex human decisions, often guided by the logic, are involved and where attempts to stabilize the systems often results in a real destabilization (Sterman, 2000). The simulation of dynamic systems models are more explicit when considering the assumptions of how parts of the system interact with each other. The simulation identifies the critical variables that influence the phenomenon, how they face induced changes and their behavior over time, encouraging the development of more probable scenarios.

The methodology of systems dynamics has been used to address practically every sort of feedback system. While the word "system" has been applied to all sorts of situations, feedback refers to the situation of X affecting Y and Y in turn affecting X, perhaps through a chain of causes and effects. One cannot study the link between X and Y and independently the link between Y and X and predict how the system will behave. Only the study of the whole system as a feedback system will lead to correct results (Sterman, 2000). System dynamics is a methodology for studying and managing complex feedback systems such as one finds in business, agriculture and society (Ford, 1999; Sterman, 2000).

The methodology involves different steps that identify a problem, develop a dynamic hypothesis explaining the cause of the problem, build a computer simulation model of the system defining the root of the problem, test the model to confirm that it reproduces the behavior seen in the real world, devise and test in the model alternative policies that alleviate the problem, and implements this solution (Sterman, 2000). Rarely is one able to proceed through these steps without reviewing and refining an earlier step. The field developed initially from the work of J. W. Forrester. His seminal book *Industrial Dynamics* (Forrester, 1961) is still a significant statement of the philosophy and methodology in the field. Since its publication, the span of applications has grown extensively and now encompasses work in corporate planning and policy design, public management and policy, biological and medical modeling, energy and the environment, theory development in the natural and social sciences, dynamic decision making, and complex nonlinear dynamics.

According to Sterman (2000), normally, the system dynamics view of a system concentrates on the rates at which various quantities change and expresses the rates as continuous variables. The rates of flow[4] are controlled by the decision functions that depend upon conditions in the system. The levels or stocks represent the accumulation of various entities in the system such as inventories of goods and number of employees. The current value of a level at any time represents the accumulated difference between the input and the output flow for that level. Rates are defined to represent the instantaneous flow of that level and to or from that level. Decision functions or, as they

[4] Rates or flow variable is the variable that represents the flow in a system. It is the rate of change of accumulations in a system.

are also called rate equations, determines how the flow rates depend upon the levels.

A set of symbols has been established for indicating the various factors involved in a system dynamic model. Level[5] is represented by boxes, and rates are indicated by a symbol which, as a matter of interest, is adapted from the symbol used in diagrams of hydraulic systems to represent a valve. Likewise, a model has auxiliary variables that lie in the information channels between the levels of the variables and the rates. They are parts of the rate equations, subdivided and separated because they express concepts that have independent meaning. Auxiliary variables[6] are normally represented by a circle, sometimes without any enclosure. A variety of flow lines clarify a diagram by distinguishing between classes of variables.

Mathematically, a rate is represented by the derivative of a variable. Since a system dynamics model relates levels to rates, it follows that a system dynamics model is essentially a set of differential equations, just like the models. The model is constructed from simple linear differential equations with constant coefficients. Growth, decay and oscillations are the fundamental dynamic patterns of systems. One of the most important and fundamental patterns in nature is exponential growth.

The function can be simplified by the following notation:

$R = Ci\ (So-S)$, and $S = 0$ at $t=0$

Where R = Rate Variable

Ci = Constant

So = Initial variable, say x

S = Stock variable, and

t = Time.

Different models have been developed worldwide to understand the interaction of various factors and how to implement the optimization of demographic, economic, industrial and agricultural systems among others. Among the pioneering works are *World Dynamics, Counterintuitive Behavior of Social Systems, The Limits of Growth*

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5) Level or stock variable is the accumulations within a system.

6) An auxiliary variable is variables other than level or stock variable and rates or flow variable in the system.

Dynamics, Dynamics of Growth in a Finite World, Mankind at the Turning Point and Catastrophe of New Society (Deutsch, 1984), all designed through the use of different software tools. The question is which behavior is the best scenario for the future. The answer depends on the policies chosen (Forrester, 1971). Section 2 continues this discussion on system dynamics.

As they are more transparent and appropriate for policy evaluation, descriptive causal models tend to make more useful contributions to the study of the phenomenon of food supply. An added model has been proposed and developed a food supply-analytical tool for Mpanda district, Tanzania (MSDFS Model). This is an essential component in the programmatic efforts for solving food supply and agricultural production problems to develop an integrated decision support program. Such a program would assist policy analyses, policy makers, decision makers, and regional resource allocation on food supply and agricultural management in Mpanda district. Also, such program would enable studying the performance of the system structure and how to assess implications of proposed policies in a time-horizon of 20 years, that is, from 2005 to 2025. This study is based, as indicated in the initial part of this paper, on the study of the interaction between the three major components for the food supply: agricultural production, population, and land resources and the means to utilize them.

Three basic levels in the system related to the stock of agricultural production, population, and land resources have been identified. From this assertion a proposed hypothesis is now designed. If the representation of food is understood as the mixture of food products, it would be easy to predict that the system will not change in the future and, if it changes, such changes would not influence the dynamics of the system. Prices of food commodities as well as the prices of nonfood commodities determine the flow between the type of land use and food production.

1. 2 Assumptions of the Mpanda District System Dynamics Food Supply Model

The following are the assumptions of the model:

1. Rural economics is the economics of agricultural production and includes agricultural production itself, land and environmental resources, and population and demography. This implies that social and economic growth and development of rural areas depend much in agriculture production, land and environment

resources, and population and demography.

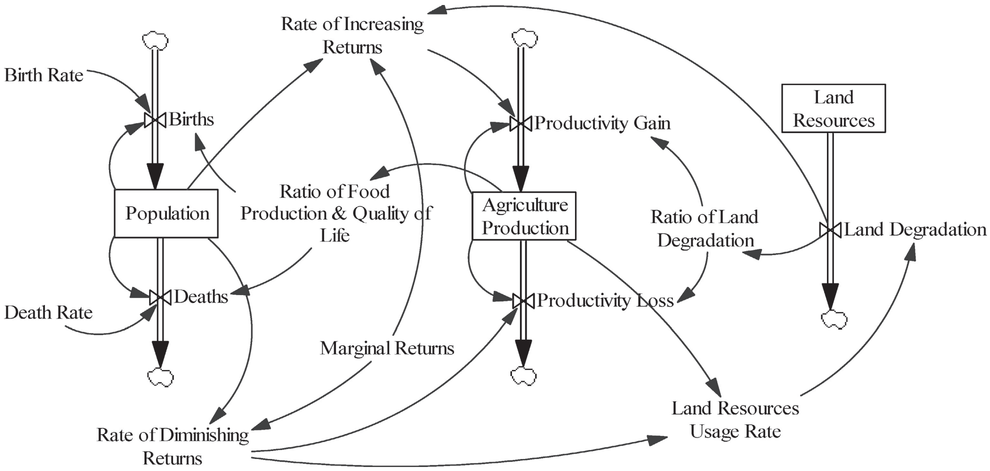
2. Food supply depends on agricultural production. This means that, food supply of this economy depends much on domestic agricultural production, not through importation due to the weak economic ability to afford to import food from other countries. Also, this economy depends on agricultural production.
3. Food supply depends on land and environmental resources. Agricultural production of this economy is influenced and depends on the quality and quantity of land and environment resources, which is the determinant of the land resources productivity per unit area.
4. Food supply depends on population and demography. Agricultural production of this economy also depends much on the labor/working forces that are determined by population and demographic level of that economy.
5. Land is fixed and a non renewable resource. This implies that, there is limit on land resources, and you can not produce other land resources like other industrial products. Also, it is expensive to maintain and improve the quality of land resources. Not only has that, but also land resources had a tendency of depreciation.
6. Population is controlled by birth and death rates. Population of this economy is controlled and determined by birth rates and birth rates. When the number of births is increasing, population also tends to increase, and vice versa. Also when number of deaths is increasing population also tends to decrease, and vice versa.
7. Agricultural production is controlled by increasing returns to scale and decreasing returns to scale through productivity level. Both increasing returns to scale and decreasing returns to scale is controlling and determining the level of agricultural production. Because when the increasing returns to scale is higher, this means that productivity level is too higher, and vice versa. This also is applied to the decreasing returns to scale, when the decreasing returns to scale is higher, this means that productivity level is too lower, and vice versa.
8. Land resources are determined by the land resource usage rate. In this case land resource usage rate is an important factor used to influence and determine land resources quality. If the land resource usage rate is accompanied by the good and proper methods of agriculture production and other human activities, then

quality of land resources will be improved and increase, and vice versa.

9. The agricultural sector refers to both food and export crops. Agricultural sector is the sector of production of both food crops and exports cash crops. Food crops are all crops growing and harvested for the purpose of human consumption. Though, sometimes food crops can be sold, and earn cash. Exports crops are all crops growing and harvested for the purpose of selling in order to get cash and export for the aim of foreign exchange. And mostly export crops are not consumable until they are processed.
10. The economy depends on the agricultural sector. This economy depends heavily on agriculture, which accounts for more than 40% of GDP, provides about 45% of exports, and employs about 80% of the work force, source of raw materials for the domestic industries, and foreign currency.
11. Technological advancement, innovation, and development conditions are different within three cases of simulation model analysis. In case I land resources is fixed without technological advancement. In case II land resources is fixed with technological advancement. In case III land resources is not fixed with technological advancement.
12. This is a labor intensive economy. About 80% of the working forces are from the labor forces. Only 20% of the working forces are from machinery.

1. 3　Descriptions and Structure of the Mpanda District System Dynamics Food Supply Model

Figure 1-1 Mpanda District System Dynamics Food Supply Model (MSDFSM)



Source: Modeled by the present writer, 2009.

1. 4　Feedback Loops[7]– Causal Loops[8] Diagrams

The causal loop diagram shows the technique to portray the information feedback in a system. Causal refers to a cause-and-effect relationship. Loop refers to a closed chain of cause-and-effect.

Feedback is a process through which an indicator goes through a chain of causal relations to re-affect itself. Feedback loops are positive or negative. Feedback is positive if a variable increases, and after a certain delay, leads to a further increase in the same variable. Positive feedback is found in systems that produce exponential behavior. Alternatively, feedback is negative if an increase in a variable leads to a decrease of the same variable. Negative feedback drives balancing or stabilizing systems that produce asymptotic or oscillatory behavior.

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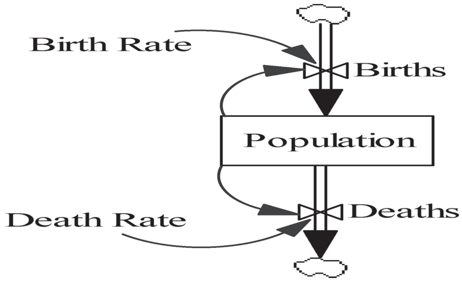
[7] Feedback loop is a closed chain of cause-and-effect of the return of a portion of the output of a process or system to the input, especially when used to maintain performance or to control a system or process. Or feedback look is a process in which a system regulates itself by monitoring its own output. That is, it "feeds back" part of its output to itself. This means a process through which an indicator goes through a chain of causal relations to re-affect itself.

[8] Causal loop refers to a relationship of closed chain of cause-and-effect, through diagram shows the technique to portray the information feedback in a system.

Figure 1-2 Population - Births and Deaths +Ve and -Ve Loops

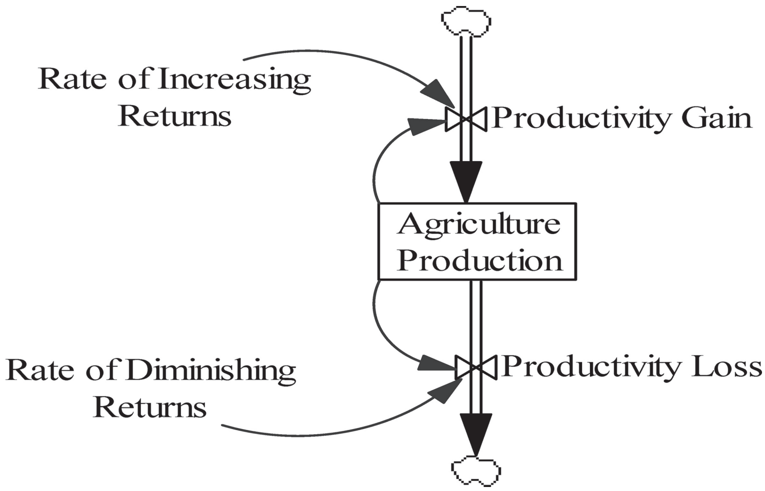


Source: Modeled by the present writer, 2009.

Figure 1-2 shows the population positive loop and the population negative loop. The population positive loop starts from population, goes to births and then ends at the population. This loop is called positive because it increases the value or quantity of population through increasing the number of births.

The population negative loop starts from population, goes to deaths and then ends at the population. This loop is called negative because it decreases the value or quantity of population through increasing the number of deaths.

Figure 1-3 Agriculture Production-Productivity Gain and Productivity Loss +Ve and -Ve Loops

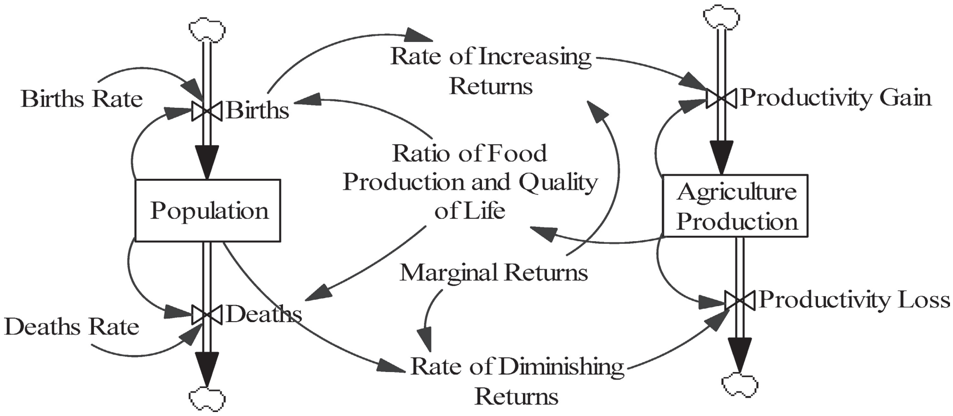


Source: Modeled by the present writer, 2009.

Figure 1-3 shows the agricultural production positive loop and the agricultural production negative loop. The agricultural production positive loop starts from agricultural production, goes to productivity gain and then ends at agricultural production. This loop is called positive because it increases the value or quantity of agricultural production through increasing the productivity gains.

The agricultural production negative loop starts from agricultural production, goes to productivity loss and then ends at agricultural production. This loop is called negative because it decreases the value or quantity of agricultural production through increasing the amount of productivity loss.

Figure 1-4 Population - Increasing Returns to Scale and Decreasing Returns to Scale +Ve and -Ve Loops

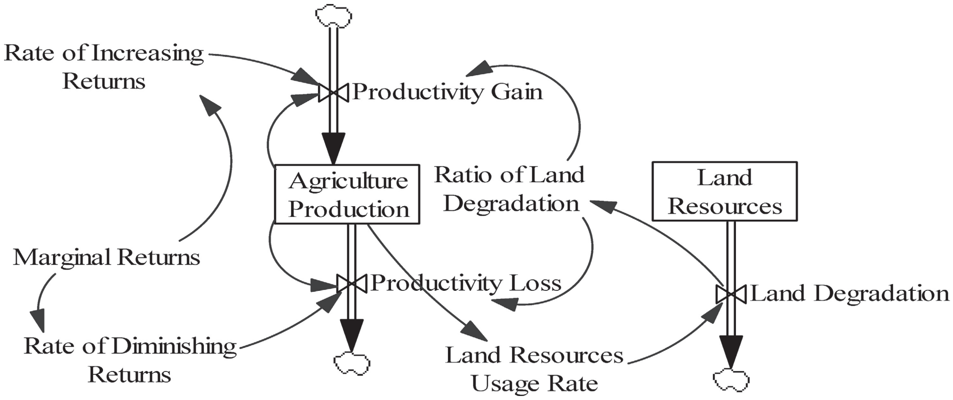


Source: Modeled by the present writer, 2009.

Figure 1-4 shows the population increasing returns to scale positive loop and the population decreasing returns to scale negative loop. The population, increasing returns to scale positive loop starts from population, goes to births and to the rate of increasing returns and productivity gain, goes to agricultural production, hence the ratio of food production and quality of life, and then ends at the population through births. This loop is called positive because it increases the value or quantity of population through increasing the number of births.

The population, decreasing returns to scale negative loop starts from population, goes to deaths and then to rate of diminishing returns and productivity loss then to agricultural production, hence the ratio of food production and quality of life and then ends at the population through deaths. This loop is called negative because it decreases the value or quantity of population through increasing the number of deaths.

Figure 1-5 Agriculture Production – Land Resources Usage Rate- Increasing Returns to Scale and Decreasing Returns to Scale -Ve and –Ve Loops



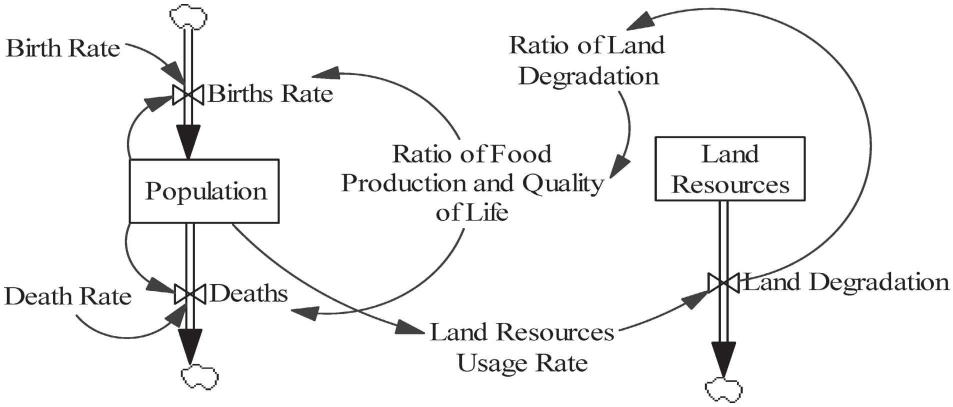
Source: Modeled by the present writer, 2009.

Figure 1-5 shows the agricultural production land resource usage rate productivity gain negative loop and the agricultural production land resource usage rate productivity loss negative loop. The agricultural production, land resource usage rate, productivity gain negative loop starts from agricultural production, goes to land resource usage rate and then to land degradation, hence, to the ratio of land degradation and then ends at agricultural production through productivity gain. This loop is called negative because it decreases the value or quantity of agricultural production through the decrease of productivity gain due to increasing the land resource usage rate and land degradation.

The agricultural production, land resource usage rate, productivity loss negative loop starts from agricultural production, goes to land resource usage rate and then to land degradation, hence, to the ratio of land degradation and then ends at agricultural production through productivity gain. This loop is called negative because it decreases the value or quantity of agricultural production through decreasing the increasing productivity loss due to the increase in the land resource usage rate and land degradation.

Figure 1-6 shows the population, land resource usage rate births negative loop and the population land resource usage rate increasing returns to scale negative loop. The population, land resource usage rate births negative loop starts from population, goes to land resource usage rate and then to land degradation, hence, to the ratio of land degradation and then to the ratio of land degradation, hence, to the ratio of food

Figure 1-6 Population-Land Resources Usage Rate- Births and Deaths -Ve and +Ve Loops



Source: Modeled by the present writer, 2009.

production and quality of life and then ends at population through births. This loop is called negative because it decreases the value or quantity of population through the decrease of births due to the increase in the land resource usage rate and land degradation, hence, reduction of ratio of food production and quality of life.

The population, land resource usage rate deaths negative loop starts from population and then goes to land resource usage rate and then to land degradation, hence, to the ratio of land degradation and then to the ratio of land degradation, hence, to the ratio of food production and quality of life and then ends at population through deaths. This loop is called negative because it decreases the value or quantity of population through increasing deaths due to the increase in the land resource usage rate and land degradation, hence, reduction of ratio of food production and quality of life.

1. 5　Simulation of the Model

For the simulation of Mpanda district system dynamics food supply model, refer to Figure 2-3 Agricultural Production, Land Resource, and Population – Simulation Model Results - Case I, Figure 2-5 Agricultural Production, Land Resources, and Population – Simulation Model Results - Case II, and Figure 2-7 Agricultural Production, Land Resources, and Population – Simulation Model Results - Case III.

1. 6　Simulation Output-Results and Analysis

The following are the simulation output-results and analysis for Mpanda district system dynamics food supply model. Simulation results examined that productivity loss (variable 1) begins to decrease after 2013 down to approximately 7,000 metric tons at the end of simulation in 2025. Agricultural production (variable 2) exhibits significant take-off and reaches 240,000 metric tons. The productivity gain (variable 3) also significantly increases, reaching 90,000 metric tons.

The results show that births (variable 1) for Mpanda district will reach almost half of the total population by the end of simulation in 2025 with 60,000 people. Population (variable 2) constitutes the other half (500,000 people), and deaths (variable 3) gradually disappear.

As the demand for land resource usage rate increases, land degradation will increase, finally, causing the land resources to decrease. By the end of simulation in 2025 land degradation will be at 4,000 hectares, while land resources will decrease up to 350,000 hectares.

By the end of simulation in 2025, agricultural production (variable 1) for Mpanda district will decrease to 30,000 metric tons, and on the other side, the population (variable 2) will increase up to 1,350,000 people.

By the end of simulation in 2025, agricultural production (variable 1) for Mpanda district will decrease to 30,000 metric tons. Alternatively, land resources (variable 2) will also decrease up to 1,000,000 hectares. By the end of the simulation in 2025, land resources (variable 1) for Mpanda district will decrease to 1,000,000 hectares, but the population (variable 2) will also increase up to 1,350,000 people.

Additionally, the results describe that by the end of the simulation in 2025, annual agricultural production (variable 1) for Mpanda district will decline up to 30,000 metric tons. The annual land resources (variable 2) amount to 1,000,000 hectares. Alternatively, the annual population (variable 3) will increase up to 1,350,000 people.

Results showed that as the demand for land resource usage rate increased; land degradation will also increase, causing land resources to decrease. Then by the end of the simulation in 2025, land degradation will be at 4,000 hectares, while land resources will decrease up to 350,000 hectares.

2. Overview of Mpanda District

1. 1　Fundamental Features

The Mpanda district is one of the four districts of Rukwa region. Mpanda district is located in Western Tanzania, bordered to the northwest by Kigoma, the northeast by Tabora region, the east by Mbeya region, the southeast by Sumbawanga Urban district, the southwest by Nkansi district and the west by Lake Tanganyika. Mpanda is one of the largest districts in Rukwa, covering over 60% of the Rukwa region. It is located between geographical coordination of 5 45 South, 32 3 East. The annual agricultural production of Mpanda in 2005 was 38,500 metric tons. According to the 2005 population statistical data, the population of Mpanda was 675,868 people. The population growth rate of Mpanda region is approximately 11% per year. The land area of Mpanda is approximately 4,584,300 hectares, and 2,801,169 hectares are forest reserve. Mpanda region is tropic and rainfall is approximately 857 mm per year. The main economic activities in Mpanda district are agriculture, fishing, mining, and livestock.

Mpanda district faces shortages in food supply caused by population growth, low agricultural productivity, pressure for land, and effects on land degradation and mining, but rural Mpanda depends on agriculture for subsistence. Little attention has been given to sustainable rural development, and the result is that productivity of the land and labor has decreased while food shortage and poverty has continued to increase.

Mpanda District Council is classified into five agro–economic zones:

i. Katumba plain found in Nyimbo Division
   Altitude 1000–1500 m
   Soil and rainfall – soil = sandy loam with moderate good drainage
   - Rainfall = 92 mm – 1000 mm (maize, cassava, tobacco, beans, groundnuts, sunflowers, sugarcane).

ii. Mwese Highlands (Mwele Division)
   Altitude 1100–2500 m
   Soil and rainfall – soil = sandy day warm with good drainage - Rainfall = 10–1100 (maize, cassava, beans, bananas, coffee).

iii. Karema depression (Karema Division)
   Altitude 1000–1300 m

Soil and rainfall - soil = sandy day loam - Rainfall = average is approximately 1200 (maize, cassava, paddy rice).

iv. Lake Rukwa Valley (Mpimbwe Division)
Altitude 1000–1100 m in the north and 800–900 m along lake Rukwa's shores soil and rainfall – soil = sandy loam with moderate good drainage, main crop (maize, paddy rice, fruit, cassava, sorghum, finger millet).

v. Lake Tanganyika (Karema Division)
Altitude 770–1300 m
Soil and rainfall – soil = sandy loan with good drainage
- Rainfall = 950–1200 mm (maize, cassava, palm oil, paddy rice).

The dominant soil is loam with high percentages of sand. The average production under a poor farming system (maize) is 5 bags per acre. Soil rapidly loses fertility and should be supplemented by organic/inorganic fertilizers to support. The common fertilizers are DAP, UREA, CAN, and MRP (Minjingu Rock Phosphate).

According to the population census, the young aged between 5 and 14 years constituted 40.7% of the total population of Mpanda district during 1978, 1988, 2002, and estimated for 2005. The dependent groups (0–4) are 4.3% and people over 65 years old constituted 3.7% of the total population while 51.3% comprised the working group aged between 15 and 64. This suggests a high dependency ratio of 48.7%.

The district has a total land area of 4,584,300 hectares of which 932,136 hectares is crop production; 2,801,163.7 hectares are forest reserve; 860,000 hectares are game reserve; 168,400 hectares are water; and the rest is used for other activities.

The deforestation rate is rapidly increasing because of forest clearing for agriculture, livestock, informal settlement, and other purposes. Many people migrate from Musoma, Tabora, Mbeya, Shinyanga and refugees from democratic republic of Congo; Tobacco production uses a significant amount of firewood for drying tobacco before transportation. In Mpanda district many people use firewood and charcoal as a source of energy, which requires burning trees. Production of Jatropha is also expected to require many hectares, which will increase the forest clearance.

Based on population census reports, Mpanda district had a population of 60,808 in 1967; 146,256 in 1978; 256,487 in 1988; 374,568 in 2002; 412,452 in 2004; and 675,868 in 2005. Currently (2010) the population is estimated at more than 870,000, which is approximately 40% of the total regional population of approximately 1,850,000. These figures show that Mpanda district population increased and shows a large population increase compared as compared with other districts.

Mpanda district has an estimated road network length of 2,056.8 km. Of those 621 km are trunk roads; 634 km are regional roads; 668 km are district roads and 125.8 km are village or feeder roads. Of the feeder roads, 29% are in poor condition and of the district roads, 22% are in poor condition. The lack of regular maintenance and other factors have contributed towards poor road conditions in the district.

Selection of Mpanda District

The reasons I selected Mpanda district for a case study are as follows:

- This is a typical case of study to represent food supply problems in Tanzania. Many rural areas in Tanzania have the same characteristics for the food supply problems as Mpanda district. Therefore, Mpanda is representative of food supply

Figure 2-1　Map of Tanzania Showing Location of Mpanda District in Rukwa Region

Source: Adapted from National Bureau of Statistics, 2003.

problems and agriculture-related problems in Tanzania in general.

- To my knowledge, this is the first research into food supply problems concerning Mpanda district. That is, other research has not addressed the food supply in this area.
- Economic resource potentiality for Mpanda district includes agriculture, mining, fishing, and livestock.

2. 2 Marginal Returns of Labor and Land

Three Cases of Marginal Returns in Rural Households

Marginal return refers to an additional or extra production output produced due to an additional or extra factor input in agricultural production when other factors remain constant. In this study, we are treating the labor force as the variable input. The inputs that vary are the variable inputs. The inputs that are held constant are the fixed inputs. In this case land, income capital, and the technology of agricultural production are fixed inputs. As the quantity of variable labor input continually increases due to population increase, the marginal productivity of the variable labor input or marginal production output will eventually change and may lead to increasing marginal returns (IMR), constant marginal returns (CMR), or diminishing marginal returns (DMR).

Increasing marginal returns refers to and occurs when as the size of the labor force increases due to the increase in population from households, agricultural production output may increase.

Constant marginal returns refers to and occurs when as the size of the labor force increases due to the increase in population from households, agricultural production output may remain constant or unchanged. Diminishing marginal returns refers to and occurs when as the size of the labor force increases, due to the increase in population from households, agricultural production output continuously decreases.

For Mpanda district rural household agricultural production, both variable inputs and fixed inputs have the following characteristics: (1) Land resources are fixed and non renewable. (2) Technology as a method of agricultural production is poor with slow technological development, accompanied by the applications of substandard methods of agricultural production. (3) The income capital of the farmers is marginal so they cannot buy and cannot apply modern or mechanized agricultural production. This means that all factor inputs other than the labor force remain constant. Case I is typical.

Case I: Fixed Land Resources without Technological Advancement[9)]

Case I has the following assumptions:

1. The major economic activity is agriculture, which includes agricultural production itself, land and environmental resources, and population and demography.
2. Agricultural production depends on population and demography.
3. Agricultural production depends on land and environmental resources.
4. Land is fixed and a non renewable resource.
5. The economy depends on the agricultural sector.
6. Technological advancement, innovation, and development are poor and slow.
7. This is a labor intensive economy.

In Case I as the size of the labor force increase, the short run result may be increasing agriculture because at that level the number in the labor force is fully utilized in agricultural production, and there is no wastage or underutilization of the labor force in agricultural production. Then this result may cause an increase in agricultural production output, as the number in the labor force increases in the short run. For Case I, an increasing marginal return occurs from year 1, 2, 3, to 4, when there is additional labor from 0, 1, 2, to 3 laborers, and production output of agriculture continuously increases from 0, 10, 25, to 40 kgs. The productivity of labor increases from 0, 10, 12.5, and 13.3. In addition marginal productivity of labor or marginal production output increased from 0, 10, 15, and 15 at this stage, as shown in Table 2-1 and Figure 2-2. This is a positive short-run effect of population growth on food supply and agricultural production.

This means that as variable labor input increases, in accordance with population increase, agricultural production output also changes but at an increasing rate. The marginal productivity of labor or marginal production output is the rate of change or increase in production output as the variable labor input increases. Therefore,

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9) Technological advancement refers to innovation, design, development, progress, growth, and application of technology.

Table 2-1 Marginal Returns for Rural Households Agriculture Production

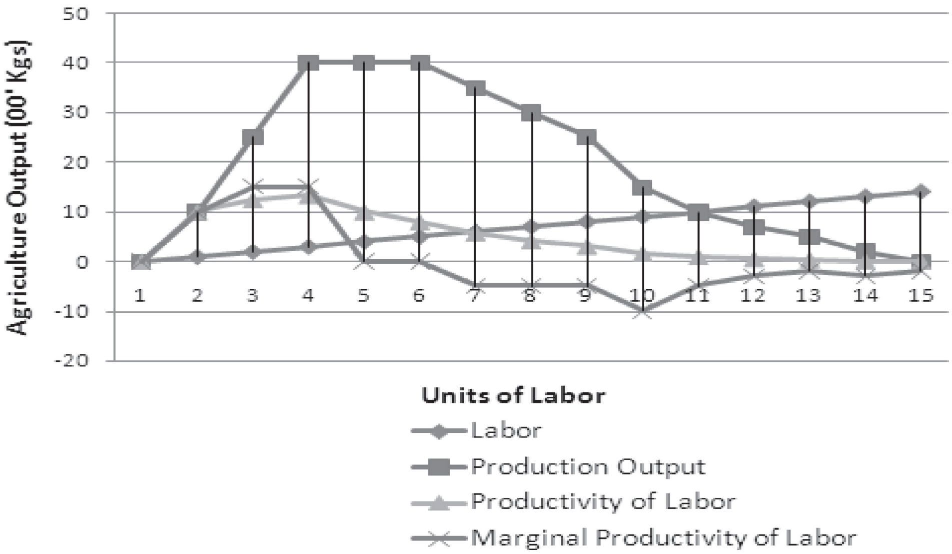
Case I: Land Resources is Fixed Without Technological Advancement

Year	Labor (Person)	Production Output (MT)	Productivity of Labor (MT/Person)	Marginal Productivity of Labor Δ(MT/Person)
Year 1	0	0	0	0
Year 2	1	10	10	10
Year 3	2	25	12.5	15
Year 4	3	40	13.3	15
Year 5	4	40	10	0
Year 6	5	40	8	0
Year 7	6	35	5.8	-5
Year 8	7	30	4.2	-5
Year 9	8	25	3.1	-5
Year 10	9	15	1.6	-10
Year 11	10	10	1	-5
Year 12	11	7	0.6	-3
Year 13	12	5	0.4	-2
Year 14	13	2	0.1	-3
Year 15	14	0	0	-2

Source: Compiled by the present writer, 2009.

Figure 2-2 Marginal Returns for Rural Households Agriculture Production

Case I: Land Resources is Fixed Without Technological Advancement



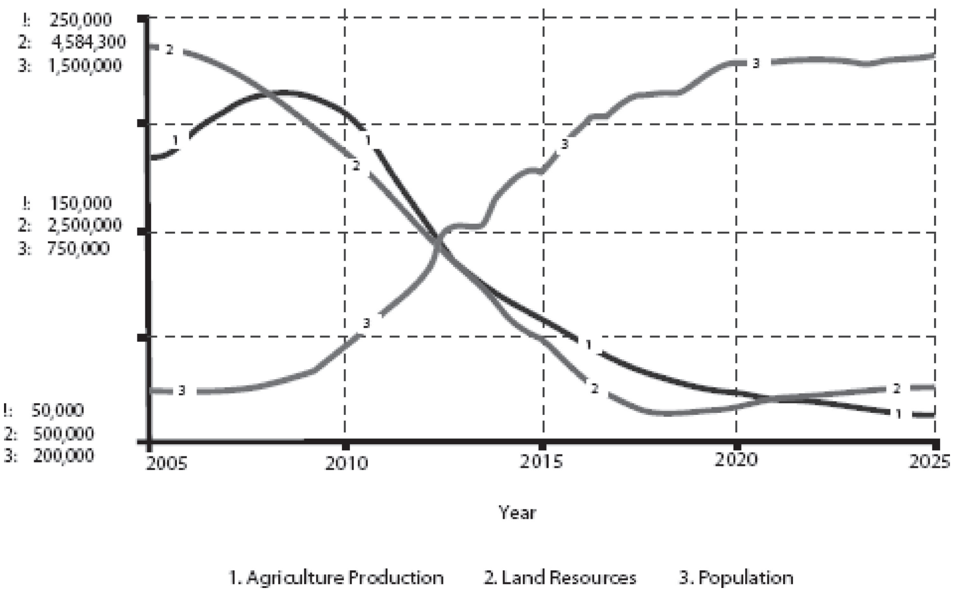
Source: Compiled by the present writer, 2009.

production output changing or increasing at an increasing rate when the variable labor input increases is another way to say that the marginal productivity of labor or marginal production output is increasing.

Additionally, production output experiences a constant marginal return sometime between the short run and the long run when the size of the labor force increases. This increase is due to the increase in population at the household level, and agricultural production output may remain constant or unchanged. Because in this period between the short and the long run the land under cultivation has a slight or minimal negative impact from the application of poor methods of agricultural production. This application may result in land degradation and reduction of soil fertility. The result then becomes reduction of both labor and land productivity.

In the period between the short and the long run as the size of the labor force increases, the results may be neither increase nor decrease in agricultural production output because at that level the size of the labor force is starting to be underutilized in agricultural production. Underutilization is a starting point for wastage and underutilization of the labor force in agricultural production is because of population

Figure 2-3 Agriculture Production, Land Resources, and Population-Simulation Model Results - Case I



Source: Simulation by the present writer, 2009 growth at the household level. Then change in the size of the labor force may cause neither increase nor decrease in agricultural production output as the size of the labor force increases in this period between the short and the long run. In this sense, a constant marginal return occurs from year 5 to 6 when there is additional or extra labor from 4 to 5 laborers, production output of agriculture remains constant and unchanged with 40 kgs, and productivity of labor decreases from 10 to 8. The marginal productivity of labor or marginal production output decreases and remains constant to 0 in both two years at this stage, as shown in Table 2-1 and Figure 2-2. This is the effect of population growth on food supply and agricultural production in the period between the short and the long run.

Once again, this shows that as variable labor input increases in accordance with population increase, the agricultural production output also changes or increases, but at a constant rate. The marginal productivity of labor or marginal production output is the rate of change or increase in production output as the labor input increases. Therefore, production output changing or increasing at a constant rate when the variable labor input increases is another way to suggest that the marginal productivity of labor or marginal production output is constant.

Further, diminishing marginal returns occur sometimes in the long run when as the size of the labor force increases at the household level, agricultural production output continuously decreases. In the long run the land under cultivation is negatively impacted by application of poor agricultural methods, which may result in land degradation and reduction of soil fertility. This degradation then leads to reduction in both the size of the labor pool and land productivity. The negative influence has greater impact and takes place to a greater extent in the long run because during this period all problems accumulated in the short run through the long run come into play. With the strong negative impact in agricultural production, the cause is diminishing marginal returns.

Sometimes the diminishing marginal returns may immediately impact all agricultural farms. Whether they impact depends on other factors, such as the quality of the land and the number of years the land was cultivated before the new farmers start to cultivate that land. For the purpose of this study, we assume that diminishing marginal returns do not immediately impact all agricultural farms. Instead the DMR takes effect in the long run when the household farmers start agricultural production on a certain piece of land. Diminishing marginal returns occur when the size of the labor force increases because of the population increase. Eventually the point is reached where increasing marginal returns stop. Then constant marginal returns may take place and finally diminishing marginal returns continuously take place. This is shown in Table 2-1 and Figure 2-2.

In the long run, as the size of the labor force increases, the results may decrease in agricultural output because at that level the size of the labor force is underutilized in agricultural production because of population growth at the household level. In this period there is a large extent of wastage or underutilization of labor force in agricultural production. Then the wastage causes continuous decrease in agricultural production output because of the increase in the size of the labor force in the long run. For these reasons, a decreasing marginal return occurs from year 7, 8, 9, 10, 11, 12, 13, 14, to 15, when there is additional or extra labor from 6, 7, 8, 9, 10, 11, 12, 13, 14, to 15 laborers. Production output of agriculture continuously decreased from 35, 30, 25, 15, 10, 7, 5, 2, to 0 Kg. Productivity of labor decreases from 5.2, 4.2, 3.1, 1.6, 1, 0.6, 0.4, 0.1, and 0. In addition, marginal productivity of labor or marginal production output has decreased from -5, -5, -5, -10, -5, -3, -2, -3, and -2 at this stage, as shown in Table 2-1 and Figure 2-2. This is a long run negative effect of population growth on food supply and agricultural production.

This implies that as variable labor input increases, in accordance with population increases, agricultural production output also changes or increases, but at a decreasing rate. The marginal productivity of labor or marginal production output is the rate of change or increase in production output as the labor input increases. Production output change or increase at a decreasing rate when the variable labor input increases is another way to indicate that the marginal productivity of labor or marginal production output is declining.

Case II: Land Resources Fixed with Technological Advancement

Case II has the following assumptions:

1. The major economic activity is agriculture, which includes agricultural production itself, land and environmental resources, and population and demography.
2. Agricultural production depends on population and demography.

3. Agricultural production depends on land and environmental resources.
4. Land is fixed and a non renewable resource.
5. The economy depends on the agricultural sector.
6. Technological advancement, innovation, and development are very rich and growing faster.
7. This is labor and semi capital intensive economy.
8. High level of capital accumulation and investment.

In Case II, as the size of the labor force increases, the result is increase in agriculture because at that level the size of the labor force is fully utilized in agricultural production from the population growth at the household level and advantages of technological advancement. In this period there is a large extent of full utilization of the labor force in agricultural production. Then it causes a continuous increase in agriculture production output because of the increasingly size of the labor force in a long run period. For these reasons, a increasing marginal return occurs from year 1, 2, 3, 4, 5, 6, 7, 8 to 9, when there is additional labor from 1, 2, 3, 4, 5, 6, 7, 8, to 9 laborers, production output of agriculture continuously increased from 20, 35, 50, 55, 60, 65, 70, to 75 Kg, and productivity of labor decrease from 20, 17.5, 16.6, 13.7, 12, 10.8, 10, and 9.3. In addition, the marginal productivity of labor or marginal production output decreases from 20, 15, 15, 5, 5, 5, 5, and 5 at this stage as shown in Table 2-2 and Figure 2-4.

Case II experiences a constant marginal return which starts from year 10, 11, 12, 13, 14, and 15. When there is additional or extra labor from 9, 10, 11, 12, 13, to 14 laborers, production output of agriculture continuously remains constant or unchanged at 75 Kg. This happened when as the size of the labor force increased because of the increase in population at the household level, and the combination of the level of technological advancement, agricultural production output remains constant. Due to the negative effects of the long run utilization and application of advanced technology and excess labor force required for agricultural production, considering that land resources are fixed.

Table 2-2 Marginal Returns for Rural Households Agriculture Production

Case II: Land Resources is Fixed With Technological Advancement

Year	Labor (Person)	Production Output (MT)	Productivity of Labor (MT/Person)	Marginal Productivity of Labor Δ(MT/Person)
Year 1	0	0	0	0
Year 2	1	20	20	20
Year 3	2	35	17.5	15
Year 4	3	50	16.6	15
Year 5	4	55	13.7	5
Year 6	5	60	12	5
Year 7	6	65	10.8	5
Year 8	7	70	10	5
Year 9	8	75	9.3	5
Year 10	9	75	8.3	0
Year 11	10	75	7.5	0
Year 12	11	75	6.8	0
Year 13	12	75	6.2	0
Year 14	13	75	5.7	0
Year 15	14	75	5.3	0

Source: Compiled by the present writer, 2009.

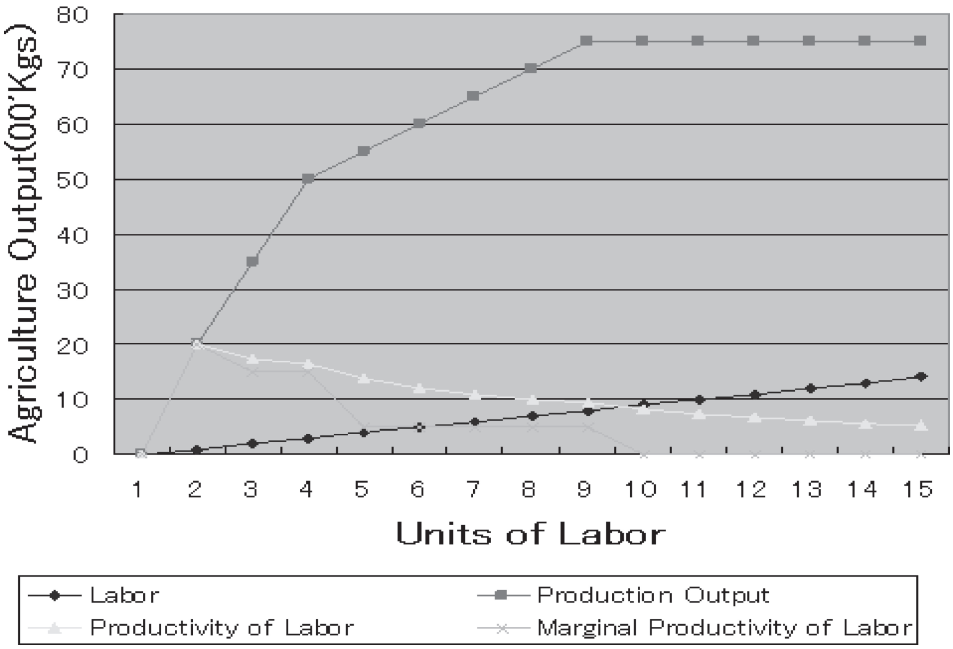
Case III: Land Resources are not Fixed with Technological Advancement

Case III has the following assumptions:

1. The major economic activity is agriculture and includes agricultural production itself, land and environmental resources, and population and demography.
2. Agricultural production depends on population and demography.
3. Agricultural production depends on land and environmental resources.
4. Land is not fixed.
5. The economy depends on the agricultural sector.
6. Technological advancement, innovation, and development are very rich and growing slowly.
7. This is labor and capital intensive economy.
8. High level of capital accumulation and investment.

Figure 2-4 Marginal Returns for Rural Households Agriculture Production

Case II: Land Resources is Fixed With Technological Advancement



Source: Compiled by the present writer, 2009.

In Case III, as the size of the labor force increase, the result is continuous increase in agricultural output due to the fact that at any level the size of the labor force is fully utilized in agricultural production because of the population growth at the household level and advantages of technological advancement. In this case there is a large extent of full utilization of the labor force agriculture production. Agricultural production output increases and both productivity of labor and marginal productivity of labor increase consecutively as shown in Tables 2-3 and Figure 2-6. For agricultural production, Case III is the optimal recommendation. Case III provides sustainable, maximum agricultural production, acquired from full utilization of all resources, such as the population as the labor force, land resources and technological advancement.

Fundamental Conditions for Case II and Case III for Rural Household Agricultural Production

For many years rural household agricultural production in Tanzania in large extent has faced problems of diminishing marginal returns of both labor and land. Case I demonstrated in one way or another, diminishing marginal returns has caused great effects on both food supply and agricultural production related problems.

Case II showed that the extent of diminishing returns and the extent of wastage of the labor force and land resources decreased, and the production output increased and thereafter remain constant, without decreasing. This is due to full utilization of both labor and land, resulting from application of technological advancement.

Case III demonstrated that only continuation of increasing return exists. In this case there is neither diminishing return nor constant return. Only persistent increase

Table 2-3 Marginal Returns for Rural Households Agriculture Production

Case III: Land Resources is not Fixed With Technological Advancement

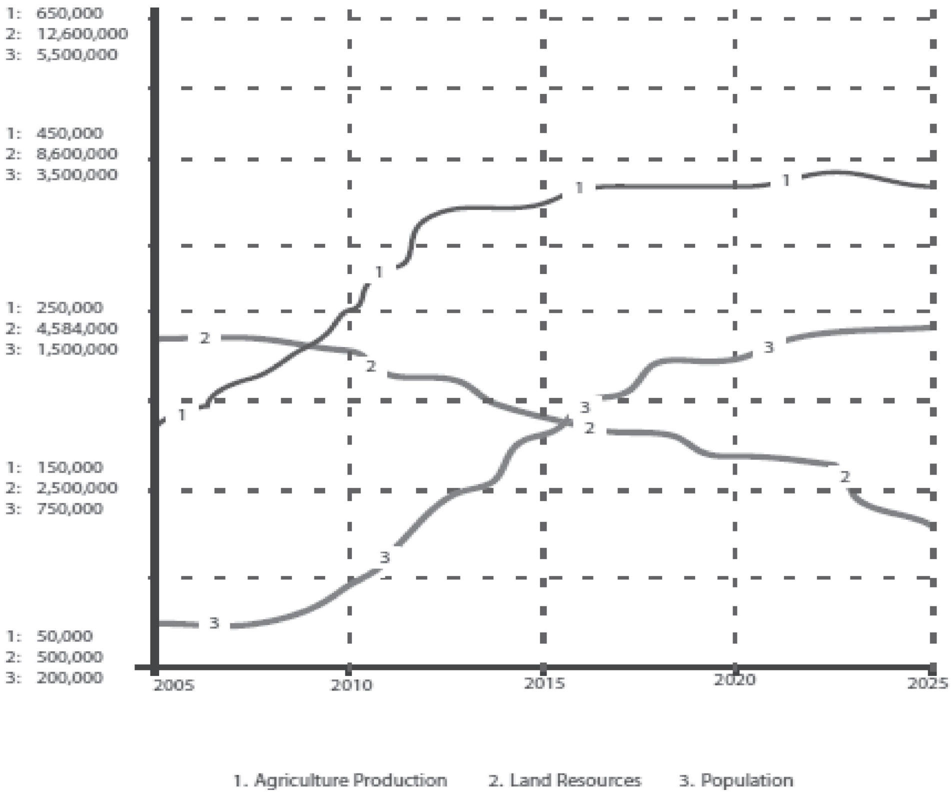
Year	Labor (Person)	Production Output (MT)	Productivity of Labor (MT/Person)	Marginal Productivity of Labor Δ(MT/Person)
Year 1	0	0	0	0
Year 2	1	20	20	20
Year 3	2	50	25	30
Year 4	3	90	30	40
Year 5	4	140	35	50
Year 6	5	200	40	60
Year 7	6	270	45	70
Year 8	7	350	50	80
Year 9	8	440	55	90
Year 10	9	540	60	100
Year 11	10	650	65	110
Year 12	11	770	70	120
Year 13	12	900	75	130
Year 14	13	1040	80	140
Year 15	14	1190	85	150

Source: Compiled by the present writer, 2009.

of agricultural production as the size of the labor force increase has been revealed. This shows that there is no wastage of the labor force and land resources because of the full utilization of all resources such as labor, land, developed technology, capital accumulation and investment.

Therefore, from the analysis of the three cases of marginal returns for rural household agricultural production, to solve food supply and agricultural related problems, it is important and necessary to select and start with Case II and then shift to Case III. This can be possible because of many benefits from the application of developed technology, capital accumulation and capital investment, and the combination of labor and land resources. This approach is possible maximization of agricultural production output through full and effective utilization of all resources in rural agriculture. Hence, there will be a sustainable development in the food supply and agriculture production,

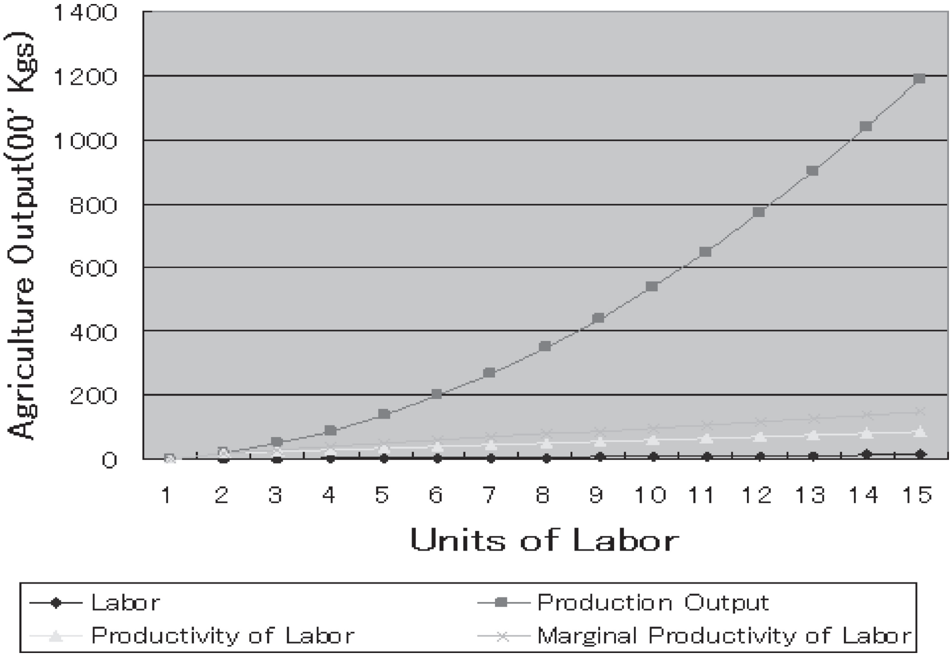
Figure 2-5 Agriculture Production, Land Resources, and Population - Simulation Model Results - Case II



Source: Simulation by the present writer, 2009

Figure 2-6 Marginal Returns for Rural Households Agriculture Production

Case III: Land Resources is not Fixed With Technological Advancement



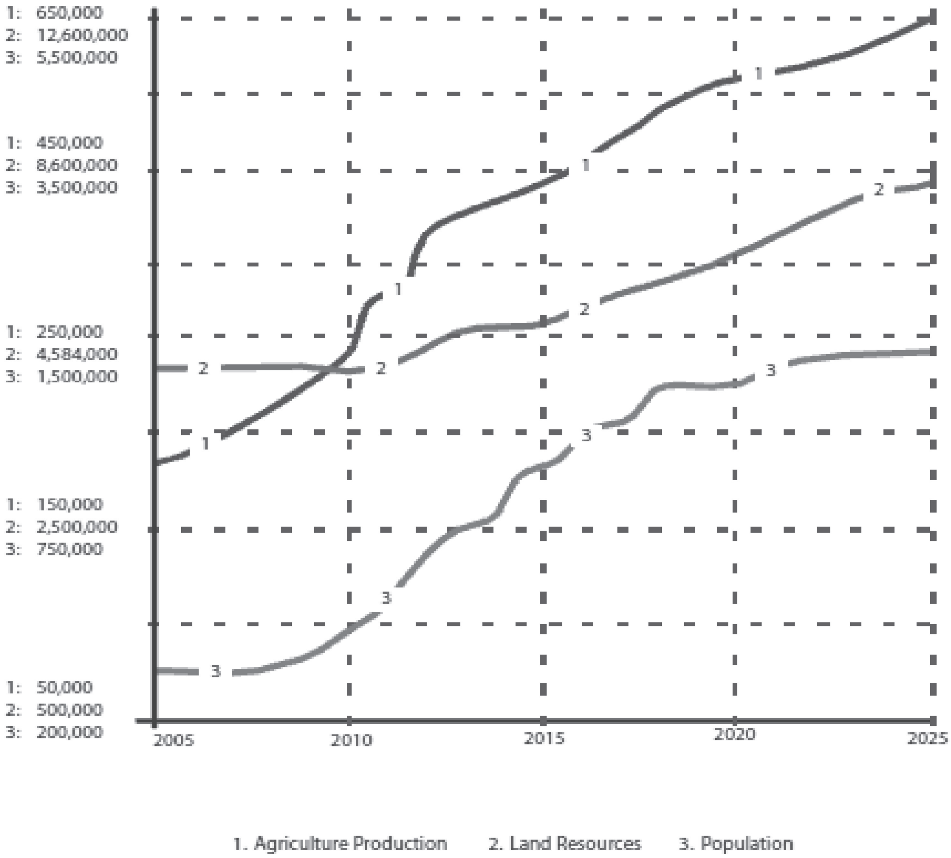
Source: Compiled by the present writer, 2009.

together with friendly use and sustainable development of our non renewable land and other natural resources.

Lastly, the following are the fundamental conditions for Case II and Case III of marginal returns in rural household agricultural production:

- Capital accumulation and investment from both domestic and foreign sources.
- Attracting, motivating, and boosting both domestic and foreign investors in the agricultural sector.
- Attracting, motivating, and boosting both domestic and foreign investors in technological innovation and advancement in the rural agricultural sector.
- Reform and restructuring of agricultural infrastructure such as rural roads.
- Reform and restructuring of small agricultural credit facilities.
- Reform and restructuring of agricultural product storage facilities.
- Reform and restructuring of agricultural product processing facilities.
- Reform and restructuring of agricultural product marketing facilities.
- Reform and restructuring of education for rural households.

Figure 2-7 Agriculture Production, Land Resources, and Population - Simulation Model Results - Case III



Source: Simulation by the present writer, 2009

3. SUMMARY AND CONCLUSIONS

First, section 1.5 presents the simulation of Mpanda district system dynamics food supply model. In section 1.6 I emphasized the simulation output results and analysis of Mpanda district system dynamics food supply model. It had been observed from simulation analysis that as the population continues to increase, agricultural production decreases. Then, the simulation showed that when land resources decline, the trends in agricultural production follow the same decreasing direction. Simulation analysis reveals that as the population continues increasing, land resources will decrease. This analysis and simulation of Mpanda district demonstrate that as population continues increasing, the results are continued decrease in both agricultural production and land resources of Mpanda district.

Second, in section 2.2 I explain marginal return. Then I analyze three cases of marginal returns in rural households and compare the results of the three cases of the simulation model. I described how the food supply for Mpanda district is impacted by agricultural production, population, and land resources, and show how the food supply takes place through the mechanism of marginal returns of labor and land. I examined three cases:

Case I: Land resources are fixed without technological advancement

Case II: Land resources are fixed with technological advancement

Case III: Land resources are not fixed with technological advancement.

Third, as observed in Case I for both marginal returns and simulation model, rural household agricultural production in Tanzania for many years, in large extent faces problems of diminishing marginal returns of both labor and land, accompanied by underutilization and poor utilization of labor and land resources. Case I shows in one way or another, diminishing marginal returns have caused significant impact on both the food supply and agricultural production related problems.

Fourth, Case II demonstrates the extent of diminishing returns and the extent of wastage of the labor force and land resource decrease, and the production output increases and thereafter remains constant, without decreasing. This is due to full utilization of both labor and land, resulting from application of technological advancement.

Fifth, Case III shows that only continuation of increasing return exists. In this case there is neither diminishing return nor constant return. Only persistent increase of agricultural production as the size of the labor force increase reveals. Case III demonstrates that there is no wastage of the labor force or land resources. This is because of full utilization of all resources such as labor, land, developed technology, capital accumulation and investment.

4. POLICY RECOMMENDATIONS

In this chapter, I present recommendations, which are based on my research, analysis, and findings in using system dynamics modeling and simulation of Mpanda district in Tanzania.

First, for the current situation of agricultural production, Mpanda district should select the application of affordable, cheap and productive methods of agricultural production. When it is possible and manageable mechanized agricultural production should be applied to enable cultivating a large area, with application of scientific agricultural methods. This will then improve and increase productivity per unit of land and per laborer. Massive agricultural production would be possible without negatively impacting our land and other natural resources. Hence, both Mpanda district households and national agricultural output will increase. The results would be more stability of food supply and surplus to be exported to generate more social and economic stability and at the same time, increasing the welfare and quality of life for the people. An additional benefit is reducing economic dependency from other regions and countries. Then, social and economic self reliance in Mpanda district and Tanzania in general will be possible.

An option for the application of affordable, cheap and productive methods of agricultural production, and when possible and manageable mechanized agricultural production will serve as a necessary and important policy for reducing and controlling the land degradation and its effects on land resources and other natural resources. Therefore, there will be no loss of agricultural production resulting from diminished productivity of land.

Another option for the application of affordable, cheap and productive methods of agricultural production, and when possible and manageable mechanized agricultural production, will play a significant role as a policy reducing and controlling the loss of unnecessary labor force and its effects on the population as labor resources. Therefore, there will be no loss of agricultural production resulting from diminishing labor productivity.

Second, according to the analysis of the three cases of marginal returns for rural household's agricultural production as concerned, to solve food supply and agriculture related problems, it's very important and necessary to choose and start with Case II, and thereafter with Case III. This can be possible because of the many benefits from the application of developed technology, capital accumulation and capital investment, and the combination of labor, and land resources. Only through this will maximization of agricultural production output, through full and effective utilization of all resources in the rural agricultural sector. Hence, there will be sustainable development of the food supply and agricultural production, together with friendly use and sustainable development of our non renewable land and other natural resources.

Third, I recommend that both government and the private sector should give priority to developing and investing in technological advancement especially in the agricultural sector. Agricultural technological advancement will enable sustainable increase in agricultural production output, and at the same time, will facilitate friendly land and environment resource use and full utilization of an available and increased labor force resulting from population growth.

Fourth, a concrete plan of agriculture complex industries is necessary. The plan must address boosting all agricultural producers at all levels by assuring sustainable availability and supply of all agricultural equipment, such as production, storage and processing equipment; marketing centers and facilities; and transportation infrastructure in different districts, regions or zones, depending on the potentiality and predicted demand of each area. Both government and the private sector can invest in this endeavor.

Fifth, for the current situation for the population point of view, and the level of technology, I recommend that both the population growth and population dependency ratio for the Mpanda district be closely and carefully monitored due to their complications and effects upon the food supply, agricultural production, land resources and the economy in general. The following should be done to control, reduce and maintain the population to a required level:

(a) Family planning and birth control through
  - Family education to be conducted by family planning personnel.
  - Distribution of effective contraceptives.

(b) Sports and leisure activities after work such as sports and entertainment for the adult population to avoid unproductive blocks of time, which may lead to temptation and participation in sexual activities.

(c) Discourage early marriage and pregnancy.

(d) Discourage some traditional and cultural practices that accelerate early marriages and pregnancy.

Such sports and leisure activities are necessary because there is large extent of wastage of labor resources due to the underutilization of the labor force as analyzed in Case I.

Sixth, there is a need to identify and control internal migration in Mpanda district, which is caused by migration from neighboring districts, regions, and countries. This migration contributes to food supply and agricultural production problems in Mpanda district. To control and solve this problem, I suggest that both government and the private sector work together to empower the rural community by developing and investing in districts and the regional rural sector. The focus would be developing and investing in districts and the regional rural social and economic infrastructures, such as roads; electricity; educational centers and facilities; health centers and facilities; production, storage and marketing facilities; credit bureaus; and entertainment centers. When the social and economic infrastructure in districts and the regional rural sector, a large number in the labor force will be convinced and attracted to remaining in their districts and regional rural area. People would then proceed with their daily responsibilities in agricultural production. They would decide to stay where they are rather than migrating, leaving an unproductive labor force in district rural areas. Their remaining in their own areas would reduce food supply problems in other districts because of the negative influence in agricultural production and land resources. Through this solution, gradually we will reach a time where this problem will be controlled and fully resolved.

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APPENDIX

Equations of the Model

(01) Agriculture Production= INTEG (Productivity Gain-Productivity Loss, 3.85e+004)

Units: Metric Tons

Agriculture Production is equal to the integration of Productivity Gain-Productivity Loss, at the initial value of Agriculture Production of 3.85e+004, with its units measure of Metric Tons.

(02) Birth Rate=38.16/1000

Units: Fraction/Year

Birth Rate is equal to the 38.16/1000, with its unit's measure of Fraction/Year.

(03) Births=Birth Rate*Population*" Ratio of Food Production & Quality of Life"

Units: People/Year

Births are a product of Birth Rate, Population, "Ratio of Food Production & Quality of Life", with its unit's measure of People/Year.

(04) Death Rate=16.71/1000

Units: Fraction/Year

Death Rate is equal to the 16.71/1000, with its unit's measure of Fraction/Year.

(05) Deaths=Death Rate*Population*" Ratio of Food Production & Quality of Life"

Units: People/Year

Deaths are a product of Death Rate, Population, "Ratio of Food Production & Quality of Life", with its unit's measure of People/Year.

(06) FINAL TIME = 2025

Units: Year

The final time for the simulation.

FINAL TIME is the final or ending time for the simulation, which is year 2025, with its unit's measure of Year.

(07) INITIAL TIME = 2005

Units: Year

The initial time for the simulation.

INITIAL TIME is the initial or starting time for the simulation, which is year 2005, with its unit's measure of Year.

(08) Land Degradation=Land Resources*Land Resources Usage Rate

Units: Hectares/Year

Land Degradation is the product of Land Resources and Land Resources Usage Rate, with its unit's measure of Hectares/Year.

(09) Land Resources= INTEG (Land Degradation, 4.5843e+006)

Units: Hectares

Land Resources is equal to the integration of -Land Degradation, at the initial value of Land Resources of 4.5843e+006, with its units measure of Hectares.

(10) Land Resources Usage Rate=Agriculture Production*Rate of Diminishing Returns

Units: Fraction/Year

Land Resources Usage Rate is the product of Agriculture Production and Rate of Diminishing Returns, with its unit's measure of Fraction/Year.

(11) Marginal Returns=5000

Units: Metric Tons/Year

Marginal Returns is equal 5000, with its unit's measure of Metric Tons/Year.

(12) Population= INTEG (Births-Deaths, 6.75868e+005)

Units: People

Population is equal to the integration of Births-Deaths, at the initial value of Population of 6.75868e+005, with its units measure of People.

(13) Productivity Gain=Agriculture Production*Rate of Increasing Returns*Ratio of Land Degradation

Units: Metric Tons/Year

Productivity Gain is the product of Agriculture Production, Rate of Increasing Returns, and Ratio of Land Degradation, with its unit's measure of Metric Tons/Year.

(14) Productivity Loss=Agriculture Production*Rate of Diminishing Returns*Ratio of Land Degradation

Units: Metric Tons/Year

Productivity Loss is the product of Agriculture Production, Rate of Diminishing Returns, and Ratio of Land Degradation, with its unit's measure of Metric Tons/Year.

(15) Rate of Diminishing Returns=Marginal Returns*Population

Units: Fraction/Year

Rate of Diminishing Returns is the product of Marginal Returns and Population, with its unit's measure of Fraction/Year.

(16) Rate of Increasing Returns=Land Degradation*Marginal Returns* Population

Units: Metric Tons/People/People

Rate of Increasing Returns is the product of Land Degradation, Marginal Returns, and Population, with its unit's measure of Metric Tons/People/People.

(17) "Ratio of Food Production & Quality of Life" =Agriculture Production units: Dmnl

"Ratio of Food Production & Quality of Life" is determined by Agriculture Production, with its unit's measure of Dmnl = Dimensionless.

(18) Ratio of Land Degradation=Land Degradation

Units: Fraction/Year

Ratio of Land Degradation is determined by Land Degradation, with its unit's measure of Fraction/Year.

(19) SAVEPER=TIME STEP

Units: Year [0,?]

The frequency with which output is stored.

SAVEPER shows the TIME STEP for which the frequency with which output is stored, with its unit's measure of Year.

(20) TIME STEP = 0.25

Units: Year [0,?]

The time step for the simulation.

TIME STEP is the time step for the simulation, which is 0.25, with its unit's measure of Year.