Temporal and Spatial Changes of Agricultural Regions in Terms of the Energy Efficiency of Crop Production

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Contents

Abstract

A large amount of fossil fuel energy is used in modern agriculture. From an ecological point of view, the fossil fuel energy fixed in industrial products such as chemical fertilizers and herbicides makes agriculture inefficient. Agricultural practices need to be aware of energy efficiency to implement low input management and to reduce the environmental impact. This study presents a method to calculate the input-output energy ratio for crop production, and examines the changes in the energy efficiency of regional crop production based on the data of recent Japan and the Kanto Region.

Input-output energy ratio that is calculated by input fossil fuel energy and output food energy has been used as an index to explain the efficiency of agriculture. This study contrives a simplified method by means of input-output analysis and process analysis, and calculates the input-output energy ratio for 32 crops every five years from 1970 to 1990. The calculation takes statistical data from the "*Yearbook of Production, Supply and Demand of Petroleum, Coal and Coke,*" "*Linked Input-output Tables*" and "*Production Cost Crops.*" As a result, the energy efficiency of crop production is classified into four grades, i.e., high efficiency (potatoes: input-output energy ratio in 1990 is 6.8), middle efficiency (grain and beans: 2.7 and 2.1), low efficiency (fruits and field vegetables: 0.7 and 0.6) and very low efficiency (greenhouse vegetables: 0.04).

Next, this study establishes a standard of regional energy efficiency by examining typical combination of crops. As a result, regional energy efficiency is also classified into four grades, i.e., the high efficiency region that is represented by paddy rice, wheat and potato (regional input-output energy ratio in 1990: more than 2.7), the middle efficiency region that is represented by paddy rice and wheat (1.6-2.6), the low efficiency region that is represented by paddy rice and field vegetables

(0.6-1.5), very low efficiency region that is represented by field and greenhouse vegetables (under 0.5).

This classification is applied to the prefectures in Japan and the municipalities in the Kanto Region. The input-output energy ratio of Japanese agriculture changed from 2.0 in 1970 to 1.2 in 1990. High efficiency prefectures are applied to Kagoshima and Hokkaido in 1970, whose production of sweet and white potatoes is largest in Japan. Very low efficiency prefectures are applied to Tokyo, Yamanashi, Shizuoka, Osaka, Kochi and Kumamoto Prefectures in 1990, which have high planted percentage of field vegetables, fruits and greenhouse crops. The input-output energy ratio of the Kanto Region declined from 1.8 in 1970 to 1.1 in 1990. Middle efficiency municipalities that occupied a broad area in the western part of the region in 1970 changed into low efficiency municipalities in 1990. Very low municipalities emerged in urban and suburban, and some parts of the outer suburbs in 1990. The spatial pattern substantiates the regional patterns of "center and periphery" and "east and west" that are explained by former geographical studies. The results suggest that the aspect of energy efficiency can be used as a general index to examine the regional characteristics of agriculture as it contains the point of view ecology and economy.

The reason for the decline of the energy efficiency in the Kanto Region is due to the increase of seven thousand hectares in the production of greenhouse vegetables, which demands a great amount of input fossil fuel energy (12-22GJ/10a), and also to the decrease of 274 thousand hectares in the production of paddy rice and wheat, which yields a considerable amount of output food energy (4-8GJ/10a). The results presented imply that agriculture in Japan has increased its impact on the natural environment through an increased use of fossil fuel energy.

Key words: input-output energy ratio, crop systems, fossil fuel energy, food energy, environmental impact

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Chapter 1

Introduction

1.1 Purpose of the present study

One of the essential aims of agriculture is that of producing foods and fibers for humans and animals, and other basic materials for industries by using solar energy efficiently. However, since farmers select the management that brings them a higher economic return, agricultural activities often result in inefficiency in terms of energetics. In developed countries in particular, fossil fuel energy such as chemical fertilizers and agricultural equipment are used in agricultural activities to promote the growth of crops and domestic animals, and to reduce manual labor. It is said that the fossil fuel energy fixed in industrial products diminishes the energy efficiency of agriculture considerably (Odum, 1971).

We should be anxious that the energy efficiency of Japanese agriculture is declining with the input of fossil fuel energy. Since the period of high growth of the Japanese economy, working hours of paddy rice production has been reduced largely because of the wide adoption of industrial products such as chemical fertilizers, pesticides and agricultural machines. Since the enactment of the Agricultural Basic Act in 1961, capital-intensive horticultural sectors such as vegetables and fruits flourished through subsidies for the Selected Expansion Sectors (Ito, 1997). It is indispensable to the horticultural farms that they introduce new technology and industrial products one after another to sustain their productivity (Nihei, 1998).

It needs to examine the characteristics of agricultural region in terms of energy balance, judging from the recent increase of the input of fossil fuel energy in agricultural production. In the sense of ecology, the increase of input fossil fuel energy implies the reinforcement of impact on the natural environment, because it modifies natural formation of land, natural growth of plants and domestic animals (Giampietro, Gerretelli and Pimentel, 1992). Presenting the energy efficiency of agriculture with specific values is one of the first steps to examine the low-input practice and the sustainable agriculture that doesn't depend much on the input of fossil fuel energy (Lockeretz, 1988).

However, there are few geographical studies that take researches on agricultural regions in terms of energy efficiency. Geography is the science that examines human activities on the surface of the earth and the natural environment by means of regional aspects (Tezuka, 1991). In the context of the regional aspects, this study regards agricultural regions as homogeneous regions that are distinguished by indices about agricultural activities. Therefore, agricultural regions are not always in accordance with the places that are active in the production of crops and animal husbandry. This study applies the energy efficiency of crop production to the index for examining the characteristics of agricultural regions.

Input-output energy ratio is one of the indices that shows the energy efficiency of agriculture. In particular, the input-output energy ratio that is calculated by input fossil fuel energy and output food energy has been used to express the ineffectiveness of crop production in developed countries (Lockeretz, 1977: Bayliss-Smith, 1982). For example, in the United States, the input-output energy ratio for the wheat production in Nebraska was of the order of 3.8 (Briggle, 1980). This values show only 23 percent of efficiency as compared with the order of 16.5 in yam, taro and cassava production by slush and burn farming in Papua New Guinea (Rappaport, 1971). The input-output energy ratio of corn production in the United States declined from 5.8 in 1910 to 2.9 in 1985, because of the increasing in the usage of industrial goods, e.g., tractors, combine harvesters, agricultural chemicals and hybrid seeds (Pimentel et al., 1990). Still more, the input-output energy ratio of cantaloupe production in California was of the order of 0.1 in the mid 1970s (Johnson and Chancellor, 1980). Vegetables and fruits, which contains less glucose than grain and potatoes, results in smaller values in input-output energy ratio inevitably.

This study pays attention to all crops cultivated in a region and calculates "regional input-output energy ratio" from the input fossil fuel energy and the output food energy of the crop production. The values of regional input-output energy ratio will change temporally and spatially in accordance with the amount of industrial goods used in crop production and the kinds of crops, and it is expected to be used as a comprehensive index to examine the characteristics of agricultural regions. This study presents a method of calculating input-output energy ratio for crop productions in Japan, and examines the cause of the temporal-spatial changes in agricultural regions in terms of energy efficiency, from the cases of prefectures in Japan and municipalities in the Kanto Region.

1.2 Review of previous studies

The analysis of input-output energy ratio for crops was originally developed in ecological studies. Solar energy is fixed into the plant's body by photosynthesis. The photosynthetic rate differs in the kind of crop and the relative intensity of solar radiation (Shantz and Piemeisel, 1927: Phillipson, 1966). From the ecological aspect, therefore, the regions located in low latitude, in which a plentiful amount of direct solar radiation arrives, can gain larger output energy from the vegetation than the regions located in middle latitude. Kawakita (1949) divided a region from Sakhalin to Taiwan into eight districts, and explained that the potential index of harvesting (i.e., output food energy per one hectare) was directly proportional to the warmth index (i.e., a kind of cumulative temperature). His results showed that the potential index of harvesting (84MJ/ha) and the warmth index (204.0°) in Okinawa Prefecture were respectively four times larger than these indices in Hokkaido.

However, we cannot comprehend the energy efficiency of agriculture based only on the ecological aspects of crop production because agriculture is always accompanied by the energy substitution such as human labor and fossil fuel energy (Norum, 1983). The fossil fuel energy fixed in industrial products, such as pesticides, chemical fertilizers and many kinds of fuel for agricultural machines, makes it possible to practice high productive agriculture in middle latitude regions. Furthermore, farmers gain monetary value from the solar energy fixed in the farm product that they transport outside the farm and exchanged for currency (Odum and Odum, 1976).

Since the oil crisis in the 1970s, a considerable number of studies began to examine the input of fossil fuel energy in agriculutre[1]. Some of the studies focused on a single crop or several selected crops in a region in a particular year (Avlani and Chancellor, 1977: Hudson, 1975: Heichel, 1978), and some conducted surveys on the usage of fossil fuel energy in a country or a large scale area (Steinhart and Steinhart 1974: Blaxter, 1975: Newcombe, 1976: Deleage et al., 1979: Zucchetto and Jansson, 1979).

Among the studies focusing on a single crop or several selected crops, Avlani and Chancellor (1977) calculated the input-output energy ratio of wheat production in California using the data from five selected sites. Their results showed the average was of the order of 2.9 in dry land, and 1.9 in irrigated land. Hudson (1975) examined the sugar cane production in Barbados, and indicated the order of 5.4 for the hand and animal power-based cultivation, and 2.7 for the machine-based cultivation. Heichel (1978) paid attention to crop rotation systems of corn and leguminous plants in the southeastern part of Minnesota, and calculate the ratio based on growing days of crops. He explained the efficient of the rotation systems including leguminous plants, as his results showed the order of 6.1 for the continuous cropping of corn, 8.1 for the rotation of corn and alfalfa, and 8.2 for the rotation of corn, soybeans and vetch.

Whereas these studies explained the ineffectiveness of industrialized crop production by their researches on a certain period of time, other studies that examined large scale regions compared the energy efficiency of agriculture with the farming methods practiced in the past or in other countries. Newcombe (1976) presented input-output energy ratio at the order of 1.2 for the crop production in Hong Kong in 1971, and pointed out that the energy efficiency declined in comparison with the order of 24.4 in a selected village in China from 1935 to 1937. Steinhart and Steinhart (1974) exhibited that the input-output energy ratio of food system (i.e., a chain of food production to consumption) in the United States changed from 1.1 in 1910 to 0.12 in 1970. Zucchetto and Jansson (1979) indicated that the input-output energy ratio was of the order of 1.2 in the tractor-tillage agriculture in the isle of Gotland, Sweden, and the values indicated three times more efficiency as compared with the order of 0.4 in Israeli agriculture (Stanhill, 1974). Still more, Blaxter (1975) explained the input-output energy ratio of United Kingdom agriculture was resulted in 0.6 based on "farm gate output," however, the values declined to 0.3 based on "food output" after processing. Deleage et al. (1979) defined the input-output energy ratio of French agriculture as the order of 2.4, however, it would decline into 0.3 if the grain energy consumed in stock raising was taken into account.

The primary reason for the limitation of the kind of crops and the scale of regions in former studies could be attributed to their efforts to estimate precise energy flow in agricultural activities. However, the calculation of input-output energy ratio has to contend with complicated definitions of methodology such as, "*what is the best calculation method to carry out the purpose of study?* (Dovring, 1985)," "*which fossil fuel energy should be counted?* (Jones, 1989)," and "*how to deal with the energy conversion of the body's metabolism?* (Giampietro and Pimentel, 1990)." Although there are some ways of calculation for the input-output energy ratio of crop production, all results are "best presumptions" calculated by a bast method to carry out the purpose of the study (Pimentel, 1980).

Rather than improving the accuracy, recent studies coping with the agricultural energy balance emphasized on ecological aspects (Yamamoto, 1994), e.g., the sustainable development of agriculture by means of low input methods (Gibbon et al., 1995), energy use and environmental impact (Soussan, 1992), and population growth and food productions (Giampietro, Bukkens and Pimentel, 1992). The subjects on environmental impact, food production and the meaning of the input of fossil fuel energy in agriculture are something that this study hopes to address in the discussion about the changes in the energy efficiency of Japanese agriculture.

1.3 Methodology

A specific feature of this study is the way of approaching the regional energy efficiency from the input fossil fuel energy and the output food energy used in the production of more than one crop. It is expected that the regional input-output energy ratio will be indicated by higher values in a region active in grain production than a region active in vegetables production. Even in the region active in grain production, the regional energy efficiency would decline if the farms introduced the cultivation methods that require more industrial products.

To explain the changes of regional energy efficiency in exact values, the methods contrived by former studies are not adequate; i.e., the calculation of input-output energy ratio for single crop production (Kimura, 1993), and for single year's production of crops (Udagawa, 1976: Resources Council, Science and Technology Agency, Japan, 1979). To resolve the problems encountered, this study mentions which energy should be included in the calculation (Chapter 2), and calculate the input-output energy ratio for 32 crops from 1970 to 1990 by means of a simplified method that is devised by the combination of "input-output analysis" and "process analysis" (Chapter 3).

The values of input-output energy ratio can be used as indices that show energy efficiency not only for single crop production but also for regional crop production. For instance, if the input-output energy ratio indicates the order of 2.0 in a region active in grain production, it can be said that the values are twice more efficiency than the order of 1.0 in a region active in vegetable production. However, since each isolate values don't explain regional energy efficiency, it needs some standards to examine the regional energy efficiency. This study attempts to establish a standard for regional energy efficiency by investigating typical combination of crops (Chapter 4).

The regional energy efficiency of crop production is next applied to real regions (Chapter 5). The analysis for a country and prefectures (Section 1) and for the municipalities in the Kanto Region (Section 2) are performed. In the analysis of prefectures and municipalities in particular, the spatial patterns of 1970 and 1990 are mentioned, since the social structure of production, distribution and consumption changed dynamically during the 1970s with a background of the high growth of the Japanese economy. For instance, production centers of horticultural crops were developed by subsidies, and set-aside programs were undertaken severely for paddy rice production in the period. The two years' analysis will provide a dynamic change of regional structure of agriculture. Then, the author explains the development process of crop production in the municipal scale (Section 3). Asahi City in Chiba Prefecture, which is one of the leading horticultural regions developed in the period, is selected as a study area.

In the discussion, the regional divisions of agriculture in the Kanto Region, which are extracted from the changing patterns of energy efficiency, is discussed as compared with the former studies that explained the regional structures of agriculture in the region (Section 1, Chapter 6). Focusing on the Kanto Region is by reason of that there are considerable number of studies examining the regional divisions and the number of unit regions (i.e., municipalities) could be enough to discuss the spatial patterns. Furthermore, a discussion about the meaning of the changes in the energy efficiency is performed from the aspect of ecology, i.e., input energy and output energy (Section 2).

Chapter 2

Framework of Analysis

2.1 Crop systems and energy flow

Regarding agriculture as systems is the beginning of the calculation for the input-output energy ratio of crop production. The energy flow in agricultural systems is varied and complicated. The definition of agricultural systems and the energy flow is discussed below.

Individual croplands are considered to be one of the basic elements of regional agricultural systems. The sub-systems are defined as crop systems (Loomis and Connor, 1992). Crop systems consist of not only crops and croplands but also of resources and cultivation methods, e.g., nutrients, water, plowing and crop rotation. Crop systems are considered as open systems that exchange energy with the outside, and farmers choose and control the elements through their decision makings.

The input energy of the crop systems is divided into two types, namely, primary input energy and secondary input energy (Figure 1). Primary input energy is directly taken up by crops, e.g., solar energy, water and nutrients. Seed and seedlings are also considered as primary input energy as they contain an intrinsic amount of nourishment. Although some primary energy such as oversupplied nutrients will be consumed in the next crop year, the substitution of primary input energy is basically impossible.

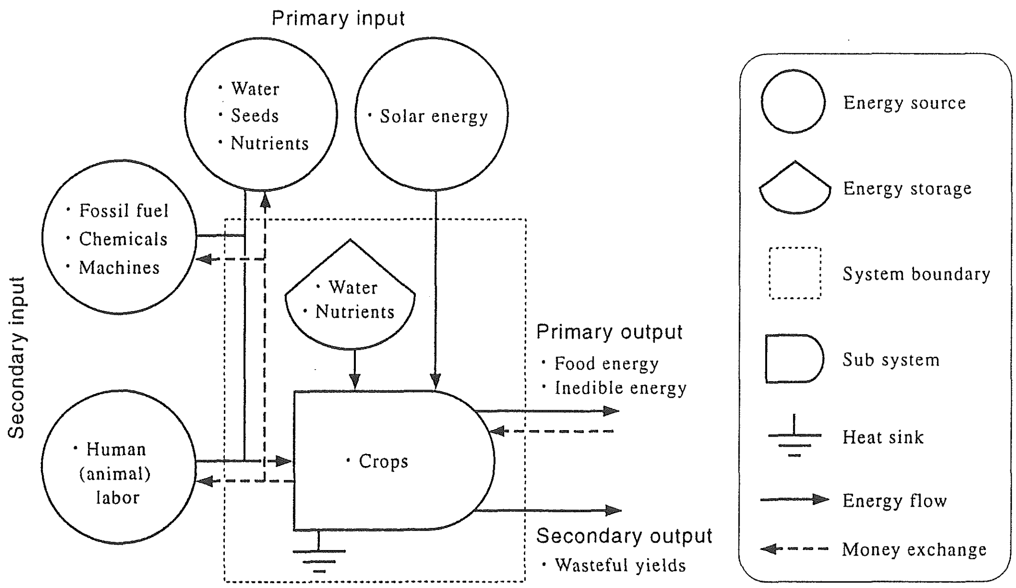


Figure 1. A concept of crop systems

Secondary input energy is not incorporated into the plant body and is mutually exchangeable to a certain extent by human and animal labor, agricultural machines and agricultural chemicals (Van Ittersum and Rabbinge, 1997). Labor and industrial products are consumed in croplands in order to improve productivity per planted area and per hour. Those kinds of energy are regarded as "heat sink" in crop systems.

The output energy of the crop systems is also divided into two types, namely, primary output energy and secondary output energy. Primary output energy is fixed in harvested crops, and can also be divided into food energy and inedible energy. The primary output energy is consumed as food and basic materials in other industries. In particular, food and fibers are important productions in the sense of carrying human metabolism. The secondary output energy is that of wasteful yields, and is considered as the energy emission that is not used as a part of economic activities.

The input energy to which this study pays attention is fossil fuel energy, a part of primary and secondary input energy. Although the substitution of primary input energy is impossible, the fossil fuel energy used in the production and distribution of the products that include primary input energy can be calculated. Because the fossil fuel energy fixed in industrial products flows in the opposite direction to monetary input, the amount of the energy can be estimated from the production cost (Odum and Odum, 1976).

The output energy to which this study pays attention is food energy, a part of primary output energy. Food is digested and absorbed in the human body, and the energy can be counted the calorific value directly from the edible part of crops. However, we cannot count the food energy for some foods such as algae and fungi, e.g., green laver and *shiitake* mushroom, because the digestion rate of the foods in the human body is not determined, though their edible parts contain an intrinsic amount of nourishment (data source: Science and Technology Agency, 1982).

2.2 Limitation of input energy

Open systems maintain their functions by exchanging energy with the outside. According to the system theory, the second law of thermodynamics is applied to open systems (Bertalanffy, 1968). Therefore, some portion of input energy vanishes as energy emission in open systems, and the output energy must be lower than input energy. However, the input-output energy ratio of crop production indicates often over 1.0, though crop systems are considered as open systems. The reason for the contradiction is that not all of the input energy is counted. A detailed explanation of the types of input energy, and the definition of the input energy for the calculation of energy efficiency is required, this is something that this study hopes to address in this section.

Solar energy is the fundamental input energy for crops in the sense that plants convert it to dextrose, and then construct carbohydrates, proteins, lipids, vitamins and other compounds. However, the calculation of input-output energy ratio often omits solar energy. One reason is that the estimation of photosynthesis rate is a complicated procedure. Photosynthesis rate differs in the kinds of plant and relative intensity of light. It is known that C_4 (i.e., dicarboxylic acid cycle) plants such as gramineous crops have the highest gross photosynthesis rate (Krebs, 1972). However, since solar energy is also fixed in the inedible part of yields, photosynthesis rate is not always directly proportional to output food energy.

The other reason for the omission is that solar energy is so great. If the whole solar energy that reached to the earth's surface were taken into account, all other energy would be so small as to be insignificant. Annual solar radiation amounts to as much as about 4.2 million MJ per 10a in Tokyo (data source: National Astronomical Observatory, 1996). Although this is an extreme example, only 0.19 percent of the solar energy will be fixed to paddy rice as food energy. To isolate the impact of fossil fuel energy on crop production, the amount of solar energy and photosynthesis rates are removed from the calculation of energy efficiency of crop production.

Seeds and seedlings are planted to harvest in cropland, so they are considered to be subsystems of the crop systems. Seeds and seedlings contain an intrinsic amount of energy originating from solar energy. Although this natural energy is omitted in this study, the fossil fuel energy consumed in production and shipment can be estimated from the production cost of seeds and seedlings. Most farmers in modern day Japan purchase seeds and seedlings from nursery companies and agricultural cooperatives. In this sense, the energy of seeds and seedlings can be counted as industrial products.

The fossil fuel energy of water use was calculated using the construction fees of waterways and the maintenance fee of irrigation systems (Yoshino, 1980). However, the energy of water use is linked to several types of energy, such as industrial product and human labor. This study excludes such complicated energy use from the calculation of input-output energy ratio.

Nutrients are also an indispensable source for crops. Plants can synthesize proteins with the nitrogen absorbed from their roots. As in the case for seeds and seedlings, this study regards nutrients as industrial products, and calculates the fossil fuel energy included in the products from the production cost of fertilizers.

Other industrial products such as fossil fuel, machines and chemicals are the indices that clearly characterize the energy efficiency of modern agriculture. The energy of the industrial products is estimated from the amount of the fossil fuel energy that is used in manufacturing the products. The mechanical workload by agricultural machinery is considered as the conversion of the fuel oils consumed by agricultural machines.

The energy of human labor and animal power should be considered in self-sufficient agriculture along with the small energy input originating from industrial products. The energy of human labor relates to the living standard of society (Van Heemst et al., 1981). A person depends not only on the food energy, which amounts about 10MJ (2,400kcal) per day, but also to a great extent on the energy that is taken up in the manufacture of clothes, household goods, cars, etc (Giampietro et al., 1993). A worker engaged in an agricultural activity in the United States consumes 594MJ during a day (Fluck, 1981). The estimation by Giampietro and Pimentel (1990) explains that agricultural manpower in the United States can be converted into 151MJ/hour. However, since the energy of human labor differs among individuals, these figures should be avoided from the calculation of input-output energy ratio. Jones (1989) suggests that human power should be treated in a similar way to other indices such as working hours.

With regard to animal power, there are practically no draft animals in Japan nowadays. It is considered that Japanese agriculture depended much on animal power until the 1950s. A research for the energy use of agricultural labor in Japan was conducted by Labor, Medicine and Psychology Institute in the early 1950s. Their report illustrates that horse and ox powers were used especially in plowing and soil preparation for paddy rice and wheat production (Roudou igaku shinrigaku kenkyujo, 1951).

Chapter 3

Calculation of Input-output Energy Ratio

3.1 Energy intensity of fossil fuel

This study regards the energy fixed in the industrial products that are purchased outside the farm as the input energy to crop systems. The procedure for calculating input energy requires three steps, (1) energy intensity of fossil fuel, (2) energy intensity of industrial products, (3) energy intensity of agricultural materials.

Energy intensity is the unit that tells us the amount of energy per production cost (J/yen). It is calculated from dividing whole input energy (or calorific value) by the total production costs. The energy intensity of fossil fuel is obtained by

$$\alpha = \frac{\sum_{i=1}^{n} (X_i + X'_i)}{\sum_{i=1}^{n} (\beta_i x_i + \beta'_i x_i)} \qquad (1)$$

where α is the energy intensity of fossil fuel (J/yen), X_i is the domestic production cost of fossil fuel i (yen), β is the calorific value of domestic fossil fuel i (J/g, J/m^3 and J/liter), x_i is the amount of domestic fossil fuel

i (g, m^3 and liter), n is the number of the product of fossil fuel, the primes denoting those that are imported. This study includes the value of imported fossil fuel, though the former study by Resources Council, Science and Technology Agency, Japan (1979) excluded it. Imported fossil fuel should be included in the calculation as a large amount of energy use in Japan is derived from imported crude oil. It should be noted that they are counted in input tables as materials for domestic products.

The requisite data source for the calorific value is "*General Energy Statistics*" (The Agency of Natural Resources and Energy, 1991), for the amount of fossil fuel it is "*Yearbook of Production, Supply and Demand of Petroleum, Coal and Coke*" (The Ministry of International Trade and Industry, 1977, 1981, 1986, 1991), and for production it is "*Linked Input-output Tables*" (Management and Coordination Agency, 1985, 1995). Although the cycle of crop production is typically of the order of one year, the data limits the results of the calculation to an interval of five years.

In the *Linked Input-output Tables*, there are five classifications of fossil fuel, i.e., (1) coal and lignite, (2) crude petroleum, (3) natural gas, (4) petroleum refinery products, and (5) coal products. Each section is classified into some fossil fuel products according to the *Yearbook of Production, Supply and Demand of Petroleum, Coal and Coke*. Namely, coal and lignite include coking coal, boiler coal, anthracite and lignite; crude petroleum inlcude only crude petroleum; natural gas includes natural gas (domestic only) and NGL (imported only); petroleum refinery products include gasoline, naphtha, jet fuel oil (domestic only), kerosene, gas oil, heavy oil, lubricating oil and LPG; coal products include only coke (domestic only). The figures for lignite are not available for the years 1970, 1985 and 1990. The calorific value of heavy oil is substituted by that for C heavy oil.

The results of calculating the energy intensity of fossil fuel are shown in Table 1. Each of the figures for energy intensity in crude fuel sections, i.e., coal and lignite, crude petroleum and natural gas, are larger than those of processed fuel sections, i.e., petroleum refinery products and coal products. This means that crude fuel is more efficient than the processed fuel in terms of energetics. Processing is accompanied by the energy loss that produces the added value of the products.

Total energy output from fossil fuels increased from 20 PJ ($1PJ=10\times10^{15}J$) in 1970 to 25 PJ in 1990. The value of the output of fossil fuel energy in 1990 can be converted into 3.2 billion 200-liter drums of crude petroleum. In other words, one person in Japan consumes fossil fuel energy an equivalent amount of 15 liters of petroleum per day. According to *General Energy Statistics*, Japan's total energy supply has increased from 13PJ in 1970 to 19PJ in 1990. Since stock changes and statistical differences are not counted in this study, the total output energy shows a larger number.

Table 1. Energy intensity of fossil fuel

Column code		Title	1970	1975	1980	1985	1990
Energy intensity (kJ/yen)							
0711[a]	1101[b]	Coal and lignite	5,488	2,099	2,078	2,141	3,213
0721[a]	1301[b]	Crude petroleum	9,536	1,754	832	924	1,981
0731[a]	1302[b]	Natural gas	5,610	2,155	894	804	1,950
2111[a]	3210[b]	Petroleum refinery products	3,146	1,159	564	511	911
2121[a]	3291[b]	Coal products	1,717	857	659	687	782
		Av.	4,340	1,398	731	739	1,263
Unit price of imported crude petroleum (yen/liter)			4	22	47	42	20

[a] Column code of fossil fuel in *1980-1985-1990 Linked Input-Output Tables.*

[b] Column code of fossil fuel in *1970-1975-1980 Linked Input-Output Tables.*

Data source: Management and Coordination Agency (1985, 1995), The Agency of Natural Resources and Energy (1991), The Ministry of International Trade and Industry (1977, 1981, 1986, 1991).

Although the total energy output from fossil fuel increased moderately, the average of the energy intensity decreased considerably after 1970. The fluctuation is inversely proportional to the unit price of imported crude petroleum. The energy intensity of fossil fuel decreased after the petroleum price rise following the oil crisis in 1973.

3.2 Energy intensity of industrial products

The calculation of the energy intensity of industrial products demands an input-output analysis. Input-output analysis, which analyzes money flow between columns in input-output tables, has been used to estimate the future economic structure of a particular system (Leontief, 1951). It can also be applied to energy flow in input-output tables (Krenz, 1974). The input-output analysis of energy flow was originally developed by Bullard and Herendeen (1975):

$$\gamma_j X_j = \sum_{i=1}^{n} \gamma_i T_{ij} + \delta_j \tag{2}$$

where $\gamma_j X_j$ is the total energy output of product j (J), γ_j is the energy intensity of product j (J/yen), X_j is the total sales of product j to other products (yen), T_{ij} are transactions that represent the amount of product i sold to product j (yen), δ_j is the energy extracted from the earth by product j, and n is the number of product in the transactions matrix.

Since the energy intensity of fossil fuel is calculated beforehand in this study, the equation (2) can be simplified

$$\gamma_j X_j = \sum_{i=1}^{n} \alpha_i T_{ij} \tag{3}$$

where n is the number of the fossil fuel in the transactions matrix. The equation takes account of the direct input energy from fossil fuel, and can present the value of γ_j without converting to matrix notation. A calculation method by Resource Council, Science and Technology Agency, Japan (1979) was guided to contriving the equation. However, the former method took into account not only the direct input energy but also indirect input energy such as primary and secondary (i.e., indirect) input energy. The process including indirect input energy is considered as to be a method of evenness. Namely, if all sources of indirect energy are taken into account, the energy intensity of industrial products will be same values. Counting only direct input energy is simple and may be the best way to estimate the direct impact of fossil fuel energy on the production of agricultural materials.

The data of this study is the *Input Table* of *179 Aggregated Group Classification Tables* in *1980-1985-1990 Linked Input-output Tables* (Management and Coordination Agency of Japan, 1995), and the *Input Table* of *158 Aggregated Group Classification Tables* in *1970-1975-1980 Linked*

Input-output Tables (Management and Coordination Agency of Japan, 1985). To calculate the energy intensity of agricultural materials as the third step, it requires the calculation on six industrial products here, i.e., (1) inedible field crops, (2) Chemical fertilizers, (3) synthetic resins, (4) agricultural chemicals, (5) other special industrial machinery, and (6) electric power for enterprise use. Some product names differ between the two *Linked Input-output Tables*. Synthetic resins (column code in *1980-1985-1990 Linked Input-output Tables*: 2041) are termed plastic, other specialized industrial machinery (3029) is termed industrial machinery, electric power for enterprise use (5111) is termed electric power supply, and chemical fertilizers (2011) and agricultural chemicals (2074) are included in chemical manure and pesticides in *1970-1975-1980 Linked Input-output Tables*. The calculation of the industrial products excludes imported products. It is impossible to estimate the energy intensity of imported industrial products by means of input-output analysis as the data do not exist in these *Linked Input-output Tables*. Therefore, if imported agricultural chemicals are used in crop productions, their energy intensities are assumed to be the same as domestic ones. According to *1980-1985-1990 Linked Input-output Tables*, the rate of imported product in 1990 was seven percent for chemical fertilizers, five percent for synthetic resin, 39 percent for agricultural chemicals, seven percent for other machinery and zero percent for the electric power used by enterprises.

The results of calculating the energy intensity of the industrial products are shown in Table 2. The energy intensity of electric power indicates the largest values (224-849kJ/yen) among each year's column, because electric power is supplied using a large amount of fossil fuel. The transaction rate of fossil fuel in 1990 was calculated at 44 percent in electric power, while being 0.4 to 12 percent in other industrial products. However, the transaction rate of fossil fuel in electric power fell from 70 percent in 1970 to 44 percent in 1990. The cause of the decline is that the rate of thermal power generation fell in proportion to the rise of nuclear and hydroelectric power generation in the Japanese electric power production.

3.3 Energy intensity of agricultural materials

From the results of the energy intensity of industrial products, the energy intensity of six agricultural materials listed in the *Production Cost of Crops* is estimated in this section. These are; (1) seeds and seedlings, (2) fertilizers and manure, (3) agricultural chemicals, (4) fuel, light, heat and power, (5) horticultural facilities, and (6) agricultural implements. There are 13 classifications of cost in the *Production Cost of Crops*. Other than the six agricultural materials, the table includes miscellaneous materials, water utilization, rent and charge, buildings and facilities for land improvement, depreciation of mature orchard, draught animals and labor.

The energy intensity of seeds and seedlings is equivalent to the en-

Table 2. Energy intensity of industrial products

(kJ/yen)

Column code		Title	Year 1970	1975	1980	1985	1990
0116[a]	0015[b]	Inedible field crops	81	29	23	11	32
2011[a]	3118[b]	Chemical fertilizers	45	27	72	68	86
2041[a]	3117[b]	Synthetic resins	36	17	5	21	12
2074[a]	3118[b]	Agricultural chemicals	45	27	12	9	4
3029[a]	3603[b]	Other special industrial machinery	21	6	4	2	2
5111[a]	5110[b]	Electric power for enterprise use	849	555	237	224	314

[a] Column code of industrial products in *1980-1985-1990 Linked Input-Output Tables.*

[b] Column code of industrial products in *1970-1975-1980 Linked Input-Output Tables.*

Data source: Table 1, Management and Coordination Agency (1985, 1995).

ergy intensity of inedible field crops, which includes the production of seeds and seedlings. The cost of fertilizers and manure consists of chemical fertilizers, soil conditioners, manure and compost. Since chemical fertilizers occupy a large amount of the cost, the energy intensity of fertilizers and manure is equivalent to the energy intensity of chemical fertilizers. The cost of agricultural chemicals, which consists of insecticides and herbicides, is equivalent to the energy intensity of agricultural chemicals calculated directly from the input-output analysis. The cost of agricultural implements consists of yearly payments and repayments for machines such as tractors, combines, power tillers and heaters. The energy intensity of agricultural materials is equivalent to the energy intensity in the production of agricultural machines and other specialized industrial machinery.

The accounting for of fuel, light, heat and power in the *Production Cost of Crops* usually consists of accounting for the petroleum and electric power for operating agricultural machines such as tractors and heating systems. Therefore, the energy intensity of petroleum refinery products is applied to the former, and the energy intensity of electric power for enterprise use is applied to the later. The energy intensities of field crops and greenhouse crops are estimated separately. The data for paddy rice is applied to the former, and the data of model greenhouses that were obtained from the author's field survey in Asahi City, Chiba Prefecture, is applied to the later. The results of the calculation are shown in Table 3. Both the

Table 3. Energy intensity of fuel and horticultural facilities, 1990

Title	Materials	Production cost	Percentage of production cost	Corresponded column code[a]	Energy intensity	Energy demand	Energy intensity
		(yen/10a)	(%)		(kJ/yen)	(MJ/10a)	(kJ/yen)
Fuel, light, heat and power	Petroleum	2,580	81	0711	811	2,092	
(Field crops)	Electric power	612	19	5111	314	192	
	Total	3,192	100			2,285	716
Fuel, light, heat and power	Petroleum	217,820	83	0711	811	176,660	
(Greenhouse crops)	Electric power	43,365	17	5111	314	13,619	
	Total	261,185	100			190,279	729
Horticultural facilities	Coating plastics	84,950	22	2041	12	1,052	
	Curtain plastics	40,750	11	2041	12	505	
	Heating systems	57,600	15	3029	2	94	
	Other materials	204,088	53	-	-	-	
	Total	387,388	100			1,651	4

[a] Column code of fossil fuel and industrial products in *1980-1985-1990 Linked Input-Output Tables.*

Data source: Tables 1 and 2, The Ministry of Agriculture, Forestry and Fisheries (1992c), author's field survey.

cost and energy used in greenhouse crops amount to about 82 times those used in the field crops. However, the energy intensity is determined by the percentages of petroleum and electric power used. Because the percentage of petroleum used in greenhouse crops is 83 percent, only two percent higher than that of field crops, the energy intensity of fuel for greenhouse crops (729kJ/yen) is slightly higher than that for field crops (716kJ/yen).

The cost of horticultural facilities can be broken down into payment and repayment for horticultural facilities such as plastics for mulching, heaters and irrigation systems. Coating and curtain plastics, and heating systems are counted as materials containing energy. The energy intensity of synthetic resins is applied to the former, and the energy intensity of other special industrial machinery is applied to the later. As well as this, the percentage of the cost is based on the model greenhouses. The result of calculation is shown as Table 3. Although the plastic materials amount to 33 percent of the total cost, they occupy 94 percent of all the energy demand of horticultural facilities.

Following the procedures described above, the energy intensity of agricultural materials for two decades is obtained as shown in Table 4. The percentage of production cost in fuel, light, heat and power, and horticultural facilities from 1970 to 1985 is substituted by the percentage for 1990. Fuel and power (fuel, light, heat and power), which gains energy input directly from fossil fuels, shows the highest energy intensity. Fertilizers

Table 4. Energy intensity of agricultural materials

(kJ/yen)

Year:	1970	1975	1980	1985	1990
Seeds and seedlings	81	29	23	11	32
Fertilizers and manure	45	27	72	68	86
Agricultural chemicals	45	27	12	9	4
Fuel, light, heat and power					
(Field crops)	2,706	1,043	502	456	716
(Greenhouse crops)	2,765	1,058	510	463	729
Horticultural facilities	15	6	2	7	4
Agricultural implements	21	6	4	2	2

Data source: Tables 1, 2 and 3.

and seeds, whose energy intensity amounts to 86 and 32kJ/yen in 1990 respectively, can be categorized as having the second largest energy intensity. However, the energy intensity is only one eighth to one twenty second the figure for the energy intensity of fuels. Other agricultural materials show small energy intensity (2-4kJ/yen in 1990). Therefore, it can be concluded that the production cost of fuel and power plays the most significant role in determining the input energy of crop production.

When considering the yearly transitions, the energy intensity of agricultural materials shows sharp fluctuations that are proportional to the energy intensity of fossil fuel. For example, the energy intensity of fuel and power for greenhouses in 1970 shows the highest energy intensity (2,765kJ/yen), with this figure having declined to a sixth of that amount by 1985. However, the yearly difference will not exert a great deal of influence on the input-output energy ratio of crop production when the inflation rate of agricultural materials is taken into account.

3.4 Input-output energy ratio of crop productions

3.4.1 Input-output energy ratio for 1990

The input energy of an agricultural material is obtained by multiplying production cost and energy intensity. Then, the total input energy of a crop's production is obtained by summing the input energy of agricultural materials. This method, called process analysis[2)], is available to estimate the input energy for industries that are not listed in input-output tables (Uchiyama, 1996).

The dada used in this section to calculate input fossil fuel energy is the *Production Cost of Crops* published every five year from 1970 to 1990 (The Ministry of Agriculture and Forestry, 1972a, b, c, d, 1976a, 1977a, b, c; The Ministry of Agriculture, Forestry and Fisheries, 1982a, b, c, d, 1987a, b, c, d, 1992a, b, c, d). The data for the output energy of crops is obtained from the *Standard Tables of Food Composition in Japan* (Science and Technology Agency, 1982). The cost of agricultural materials takes purchased expenses into account. Self-supplied agricultural materials are excluded from the calculation. Since this study uses the production cost listed in the *Production Cost of Crops*, detailed agricultural materials are neglected. Nonetheless, this simplified method is acceptable in a consistent calculation of many crops over many years.

The results of calculating the input-output energy ratio for 32 crops in 1990 are shown in Table 5. The values for the input-output energy ratio of crop production are shown in one decimal place, as many of former studies did. However, greenhouse vegetables, which values of input-output energy ratio are extreme small, are shown in two decimal places. The characteristics of crops and those values of input-output energy ratio are discussed here.

Potatoes, whose input-output energy ratio is of the order of 6.8 on

Table 5. Input-output energy ratio of crop production in Japan, 1990

Crops	Production cost	Input energy (MJ/10a)							Yield	Output energy	Input-output energy ratio
	(1,000yen/10a)	Seeds and seedlings	Fertilizer	Agricultural chemicals	Fuel, light, heat and power	Horticultural facilities	Agricultural implements	Total	(kg/10a)	(MJ/10a)	(output/input)
Paddy rice	61	74	691	29	2,285	-	69	3,147	533	7,830	2.5
Wheat	25	56	593	12	824	-	23	1,508	383	5,335	3.5
Six-row barley	24	70	720	7	878	-	21	1,695	258	3,658	2.2
Naked barley	35	73	604	11	1,192	-	38	1,919	313	4,467	2.3
Two-row barley	22	62	572	5	752	-	21	1,412	317	4,495	3.2
Av. (Grain)	33	67	636	13	1,186	-	34	1,936	361	5,157	2.7
Sweet potatoes	23	16	660	9	1,429	-	18	2,133	2,887	14,868	7.0
White potatoes	31	348	684	25	1,058	-	25	2,140	4,347	13,997	6.5
Av. (Potatoes)	27	182	672	17	1,243	-	22	2,137	3,617	14,433	6.8
Soy beans	23	56	361	16	1,255	-	21	1,709	207	3,612	2.1
Azuki red beans	25	56	677	15	721	-	19	1,488	249	3,531	2.4
Kidney beans	19	122	529	15	739	-	13	1,418	177	2,466	1.7
Av. (Beans)	22	78	522	15	905	-	18	1,538	211	3,203	2.1
Cucumbers	239	1,292	6,971	230	12,451	45	113	21,102	10,077	4,635	0.2
Tomatoes	234	452	4,810	78	6,400	465	65	12,269	6,093	4,082	0.3
Eggplants	262	328	8,433	267	10,466	92	94	19,681	9,641	7,231	0.4
Sweet peppers	117	1,204	3,985	28	6,175	34	76	11,501	5,786	5,092	0.4
Cabbages	64	259	1,654	29	1,611	-	57	3,610	4,839	4,839	1.3
Chinese cabbages	86	409	2,907	102	2,185	-	37	5,640	7,179	3,590	0.6
Welsh onions	109	221	2,692	81	5,855	-	79	8,929	3,126	3,532	0.4
Lettuces	61	95	2,154	45	1,703	25	26	4,048	1,997	999	0.2
Onions	56	359	1,717	47	1,696	1	35	3,854	6,254	9,131	2.4
Spinach	35	227	1,657	6	1,686	0	19	3,596	1,578	1,657	0.5
Japanese radishes	75	741	1,704	78	2,639	0	50	5,212	8,792	6,594	1.3
Carrots	93	205	2,446	71	2,713	29	57	5,521	5,117	6,857	1.2
Taros	53	62	1,641	40	1,812	2	34	3,590	1,852	4,649	1.3
Av. (Field vegetables)	114	450	3,290	85	4,415	53	57	8,350	5,564	4,837	0.6
Cucumbers (Greenhouse)	1,101	1,464	13,971	381	204,473	1,879	191	222,360	14,548	6,692	0.03
Tomatoes (Greenhouse)	631	925	6,942	216	110,723	1,159	114	120,079	9,569	6,411	0.05
Eggplants (Greenhouse)	1,019	777	11,540	392	152,487	1,978	177	167,349	11,812	8,859	0.05
Av. (Greenhouse vegetables)	917	1,055	10,818	330	155,894	1,672	161	169,929	11,976	7,321	0.04
Unshu mandarins	81	-	1,787	110	4,037	24	32	5,990	3,402	6,260	1.0
Natsudaidai	145	-	3,923	174	8,140	60	45	12,342	3,210	5,104	0.4
Apples	77	-	1,635	86	3,564	2	48	5,336	2,792	5,835	1.1
Japanese pears	122	-	2,809	132	4,363	38	64	7,407	2,542	4,245	0.6
Peaches	107	-	1,522	112	4,241	6	85	5,965	2,520	3,905	0.7
Grapes	116	-	1,944	103	4,388	112	55	6,602	1,606	3,757	0.6
Av. (Fruits)	108	-	2,270	120	4,789	40	55	7,274	2,678	4,851	0.7
Av. (All crops)	162	311	2,967	92	17,654	186	57	21,267	4,188	5,569	0.3

Data source: Table 4, The Ministry of Agriculture, Forestry and Fisheries (1992a, b, c, d), The Science and Technology Agency (1982).

average, are the most efficient crops. The reason of the efficient is the high amount of output food energy. Although the input fossil fuel energy of potatoes amounts to 2GJ/10a on average, the output food energy amounts to 14-15GJ/10a, whose values are two to fifteen time larger than those of other crops. Because potatoes are the most effecient crops from the point of view producing food energy, they were widely cultivated in the periods of starvation, e.g., crop failures in the Edo period. The aftermath of World War II, sweet potatoes were cultivated broadly for fodder and materials of starch industry.

Grain and beans show the second largest values of input-output energy ratio. The input-output energy ratio is respectively 2.7 and 2.1 on average. The input fossil fuel energy of these crops, except for paddy rice, amounts to 1.4-1.9GJ/10a on average. Here, most of the input energy is also supplied from fuel and power, and fertilizer. The input fossil fuel energy of paddy rice is 2GJ/10a, whose value is the highest among other grain. Paddy rice cultivation requires more frequent use of agricultural implements such as tractor, combine and planting machine than other grain cultivation because the cultivation methods are mechanized especially in the practice of plowing and leveling of paddy field, planting and harvesting.

In the production of field vegetables and fruits, the amount of input fossil fuel energy is usually larger than output energy. The average input-output energy ratio for these crops is 0.6 and 0.7 respectively. Their input energy amouts to 7-8GJ/10a on average, about three to four times larger than that of grain production. Most of the input fossil fuel energy is supplied from fuel and power (4 and 5GJ/10a) and fertilizer (2 and 3GJ/10a). The output energy of field vegetables amounts to 5GJ/10a on average, though this differs depending on the types of crops cultivated. Onions and eggplants have a large output energy (9 and 7GJ/10a), whereas lettuces and spinach have a relatively small output energy (1 and 2GJ/10a). Another reason for this low efficiency is the small output of food energy, when the weight of yield is taken account. For example, although the average weight of harvested crops in greenhouses amounts to 15 ton, which is about 22 times heavier than the weight of paddy rice, it results in a lower energy output. For instance, the calorific value of 100g of cucumber is no more than 46kJ since water occupies 96 percent of the mass.

Greenhouse vegetables are placed as the most inefficient crops, whose input-output energy ratio varies between 0.03 and 0.05. The production of greenhouse crops requires more fossil fuel energy fixed in plastics for covering facilities, pesticides and chemical fertilizers than other crops, however, the main reason of the inefficiency is due to the huge energy supplied from fuel and power (156GJ/10a). They require 90 times the fuel and power input as that used in paddy rice production. The energy converted from heavy oils and kerosene is used to control the temperature and humidity of greenhouses. For instance, the temperature of plastic greenhouses is kept at about 30°C even in winter by burning C heavy oil (Nihei, 1998).

3.4.2 Classification of crops based on energy efficiency

The results of calculating input-output energy ratio for 32 crops from 1970 to 1985 are shown in Table 6. Each crop doesn't show a large difference in the amount of input and output energy in two decades, though the energy intensity of agricultural materials varies to a greater extent as mentioned above. Considering the results of calculation from 1970 to 1990, the groups of crops are listed in order of the amount of input fossil fuel energy as: greenhouse vegetables (the average of input fossil fuel energy: 140-181MJ/10a), fruits and field vegetables (5-8MJ/10a), grain (2MJ/10a), potatoes and beans (1-2MJ/10a). As like this, the groups of crops are listed in order of the amount of output food energy as: potatoes (12-14MJ/10a), greenhouse vegetables (6-7MJ/10a), grain (5-6MJ), fruits and field vegetables (3-5MJ/10a), and beans (2-4MJ/10a). It is notable that the output food energy of greenhouse vegetables shows larger values than that of grains.

Then, the changes in input money of crop production are discussed here. Because of the inflation rate, it is difficult to compare the groups of crops through 1970 to 1990. In the case of 1990, groups of crops is listed in order of the amount of input money as: greenhouse vegetables (the av-

Table 6. Input-output energy ratio of crop production in Japan, 1970-1985

Year:	1970				1975				1980				1985			
Crops	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d
Paddy rice	15	2,788	7,154	2.6	30	2,506	7,712	3.1	53	2,678	7,183	2.7	105	2,941	7,742	2.6
Wheat	7	1,976	3,733	1.9	11	1,156	3,831	3.3	18	1,239	4,722	3.8	26	1,471	5,990	4.1
Six-row barley	6	2,329	4,864	2.1	9	1,192	5,275	4.4	18	1,620	5,388	3.3	24	1,549	4,467	2.9
Naked barley	8	1,621	3,268	2.0	16	1,462	4,081	2.8	28	1,677	4,723	2.8	36	1,688	5,451	3.2
Two-row barley	6	1,721	4,141	2.4	12	1,237	4,055	3.3	17	1,409	4,467	3.2	24	1,291	4,027	3.1
Av. (Grain)	8	2,087	4,632	2.2	16	1,511	4,991	3.3	27	1,725	5,297	3.1	43	1,788	5,535	3.1
Sweet potatoes	7	1,263	12,427	9.8	14	1,181	14,930	12.6	20	1,554	12,829	8.3	23	1,581	14,744	9.3
White potatoes	8	1,315	11,000	8.4	21	1,442	10,037	7.0	27	1,934	13,369	6.9	34	1,779	12,407	7.0
Av. (Potatoes)	8	1,289	11,713	9.1	17	1,312	12,483	9.5	24	1,744	13,099	7.5	28	1,680	13,576	8.1
Soy beans	4	609	2,844	4.7	12	956	3,316	3.5	19	1,325	3,228	2.4	28	1,339	4,677	3.5
Azuki red beans	5	706	2,425	3.4	12	981	2,226	2.3	21	1,385	1,446	1.0	26	1,335	3,261	2.4
Kidney beans	4	703	2,563	3.6	13	1,043	1,811	1.7	20	1,413	2,480	1.8	27	1,279	3,274	2.6
Av. (Beans)	4	673	2,611	3.9	12	993	2,451	2.5	20	1,374	2,385	1.7	27	1,318	3,737	2.8
Cucumbers	75	16,419	3,702	0.2	77	5,626	1,914	0.3	164	11,926	3,487	0.3	214	13,366	4,025	0.3
Tomatoes	75	11,788	4,288	0.4	126	10,787	5,454	0.5	142	9,634	5,649	0.6	187	10,776	4,904	0.5
Eggplants	64	9,041	5,795	0.6	108	8,092	7,583	0.9	154	9,445	5,106	0.5	174	10,558	5,818	0.6
Sweet peppers	44	9,430	2,369	0.3	74	6,916	3,259	0.5	115	9,549	4,504	0.5	129	7,918	4,146	0.5
Cabbages	18	3,871	4,046	1.0	33	2,720	4,538	1.7	50	3,324	4,481	1.3	56	3,024	5,525	1.8
Chinese cabbages	17	2,870	2,865	1.0	36	2,131	3,695	1.7	50	3,075	3,878	1.3	54	2,949	4,289	1.5
Welsh onions	24	5,611	4,180	0.7	41	3,659	4,353	1.2	70	5,589	3,627	0.6	94	6,743	3,312	0.5
Lettuces	39	3,802	781	0.2	48	4,786	1,247	0.3	66	3,269	1,296	0.4	73	3,992	1,264	0.3
Onions	17	3,248	5,919	1.8	29	2,389	6,890	2.9	45	3,244	7,610	2.3	52	2,991	8,350	2.8
Spinach	14	2,867	1,311	0.5	37	2,729	1,728	0.6	37	2,581	1,739	0.7	40	2,905	1,895	0.7
Japanese radishes	19	3,652	5,245	1.4	49	3,228	4,844	1.5	79	4,550	6,493	1.4	83	3,890	7,501	1.9
Carrots	32	5,765	4,383	0.8	53	4,645	4,540	1.0	66	3,999	5,513	1.4	83	3,996	5,919	1.5
Taros	21	4,331	3,416	0.8	26	2,214	4,930	2.2	41	3,525	4,450	1.3	49	3,248	4,287	1.3
Av. (Field vegetables)	35	6,361	3,715	0.6	57	4,609	4,229	0.9	83	5,670	4,449	0.8	99	5,873	4,710	0.8
Cucumbers (Greenhouse)	332	117,323	4,618	0.04	628	224,580	5,902	0.03	1,100	288,176	6,141	0.02	1,275	266,881	5,805	0.02
Tomatoes (Greenhouse)	198	87,574	5,841	0.07	350	103,061	6,342	0.06	558	93,336	7,223	0.08	725	119,286	5,850	0.05
Eggplants (Greenhouse)	344	216,317	6,477	0.03	551	163,638	9,218	0.06	974	162,023	9,059	0.06	1,049	138,806	8,996	0.06
Av. (Greenhouse vegetables)	291	140,405	5,645	0.04	510	163,760	7,154	0.04	877	181,178	7,474	0.04	1,016	174,991	6,884	0.04
Unshu mandarins	38	6,237	5,314	0.9	51	4,234	6,344	1.5	71	4,301	5,744	1.3	83	4,766	5,961	1.3
Natsudaidai	29	5,078	4,183	0.8	52	4,696	6,230	1.3	112	7,456	7,505	1.0	123	7,202	6,028	0.8
Apples	22	3,933	5,885	1.5	41	3,740	5,536	1.5	75	4,437	6,195	1.4	93	4,211	5,355	1.3
Japanese pears	30	4,971	6,725	1.4	62	4,425	6,638	1.5	77	4,239	6,055	1.4	109	5,423	5,147	0.9
Peaches	31	6,048	3,917	0.6	61	5,833	4,546	0.8	83	5,137	3,945	0.8	100	4,563	2,916	0.6
Grapes	40	16,808	2,910	0.2	91	22,727	3,398	0.1	80	4,381	3,292	0.8	107	4,180	3,363	0.8
Av. (Fruits)	32	7,179	4,822	0.7	60	7,609	5,449	0.7	83	4,992	5,456	1.1	103	5,058	4,795	0.9
Av. (All crops)	50	17,563	4,643	0.3	87	19,063	5,200	0.3	139	20,732	5,401	0.3	166	20,248	5,522	0.3

a: Production cost (1,000yen/10a), b: Input energy (MJ/10a), c: Output energy (MJ/10a), c: Input-output energy ratio (output/input)

Data source: Table 4, The Ministry of Agriculture and Forestry (1972a, b, c, d, 1976a, 1977a, b, c), The Ministry of Agriculture, Forestry and Fisheries (1982a, b, c, d, 1987a, b, c, d), Science and Technology Agency (1982).

erage of input money: 917 thousand yen/10a), field vegetables (114 thousand yen /10a), fruits (108 thousand yen/10a), grain (33 thousand yen/10a), potatoes (27 thousand yen/10a), and beans (22 thousand yen/10a). The average of all production cost increased from 50 to 162 (thousand yen/10a) in 1990, however, the average energy input for all crops increased from 18 to 21GJ/10a in two decades. The total production cost has increased by 3.2 times in the time period, whereas the input energy has only increased by 1.2 times. Energy is therefore useful as an index since it is not influenced to a great extent by monetary inflation rate.

There are few differences among the average of input-output energy ratio for the six groups of crops from 1970 to 1990. The average of input-output energy ratio for all crop production is 0.3 in all calculated years. Considering the results of calculation from 1970 to 1990, the groups of crops is listed in order of the amount of input fossil fuel energy as: potatoes (the average input-output energy ratio: 6.8-9.1), grain and beans (1.7-3.9), fruits and field vegetables (0.6-1.1), and greenhouse vegetables (0.04). From this classification, this study addresses potatoes as "high efficiency crops," grain and beans as "middle efficiency crops," fruits and field vegetables as "low efficiency crops," and greenhouse vegetables as "very low efficiency crops."

Taking account of these results, the regional input-output energy ratio of crop production is estimated like this. "If a region in which grain was only cultivated would indicate the values about the order of 1.7-3.9. If a region in which field vegetables were only cultivated would show the values about the order of 0.6-1.1." However, it needs to give some clear definitions of regional energy efficiency because more than one crop is usually cultivated in a region.

Chapter 4

Energy Efficiency and Agricultural Region

Considering the results of the calculation for crop production unit in the preceding chapter, regional input-output energy ratio and the energy efficiency (i.e., high to very low efficiency) will be estimated if a kind of crop is cultivated in a region. However, many crops that show different input-output energy ratio are usually produced in a region. It is difficult to grasp the kind of crops cultivated in a region and to tell the regional energy efficiency depending on the values of regional input-output energy ratio. In this chapter, the author should like to attempt to define the efficiency of regional input-output energy ratio through examining some typical combination of crops.

4.1 Regional input-output energy ratio

Regional input-output energy ratio is calculated by whole fossil fuel energy and food energy used for all crops cultivated in a region. It is defined by Nihei (2000) as

$$Q = \frac{\sum_{i=1}^{n} \varepsilon_i S_i}{\sum_{i=1}^{n} \varepsilon'_i S_i} \qquad (4)$$

where Q is regional input-output energy ratio, ε_i is the output energy of crop i (J/m^2), ε'_i is the input energy of crop i (J/m^2), S_i is the planted area of crop i (m^2), n is the number of crops produced in the region. The variable S_i can be substituted for the percentage of the planted area of crop i (percentage). In order to apply the equations to real regions, the following assumptions are used:

(1) The energy intensity of agricultural materials is uniform in all crop productions. For instance, the agricultural chemical sector is subdivided into ammonia fertilizer, ammonium sulfate, urea, phosphorus acid nitrogen fertilizer, etc. However, this method assumes those materials have the same energy intensity. To improve the accuracy, it is necessary to use *Input-output Tables* with a more detailed classification for the subdivisions.

(2) If the same crops are grown, the amount of input and output energy is uniform in all places. The amount of input-output energy is calculated not by each region but for the average in Japan. To improve the accuracy, it is necessary to use the *Production Cost of Crops* for each place.

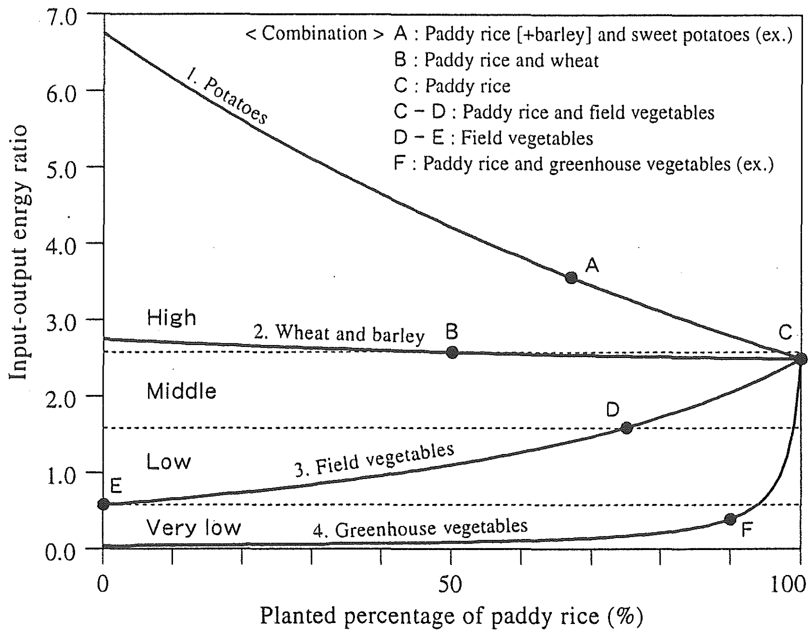
The changing pattern of regional input-output energy ratio are examined at first in accordance with the changes in the planted area of crops. Paddy rice, which they cultivate in the widest area in Japan, is selected as a standard crop for the examination. Assuming that a region in which paddy rice and another group of crops are cultivated, an investigation is made into the changes of the regional input-output energy ratio with the transition of the planted area of paddy rice. When S_r and S_o respectively denote the variables for the planted percentage of paddy rice and another group of crops, the equation (4) is converted into

$$Q_{ro} = \frac{\varepsilon_o(1-S_r)+\varepsilon_r S_r}{\varepsilon'_o(1-S_r)+\varepsilon'_r S_r} \qquad (5).$$

The another group takes account of a major group from high to very low efficiency, i.e., potatoes, wheat and barley, field vegetables and greenhouse vegetables. When the equation (5) is accompanied by the values of input and output energy in 1990, the solution is described as the curves 1 to 4 in Figure 2a.

In the combination of paddy rice and high efficiency crops (i.e., potatoes), the values of regional input-output energy ratio declines with the increase of the planted percentage of paddy rice (curve 1, Figure 2a). In the combination of paddy rice and middle efficiency crops (i.e., wheat and barley), the values show less fluctuations with the increase of the planted percentage of paddy rice (curve 2). In the combination of paddy rice and low efficiency crops (i.e., field vegetables), the values become larger with the increase of the planted percentage of paddy rice (curve 3). Furthermore, in the combination of paddy rice and very low efficiency crops (i.e.,

a. Graph



b. Classification

Energy efficiency	Input-output energy ratio[a]	Typical crops (assumed)				
		Potatoes	Wheat, barley	Paddy rice, beans	Field vegetables, fruits	Greenhouse vegetables
High	2.7 -	○	○	○		
Middle	1.6 - 2.6		○	○		
Low	0.6 - 1.5			○	○	
Very low	- 0.5				○	○

[a] Values are calculated by the data of 1990.

Figure 2. Planted percentage of selected crops and regional energy efficiency

Data source: Table 5.

greenhouse vegetables), the values increases drastically when the planted percentage of paddy rice reached more than about 90 percent (curve 4). Namely, a little increase in the planted area of greenhouse vegetables results in a great decrease in regional input-output energy ratio.

4.2 Classification of agricultural regions based on energy efficiency

Through the examination of typical crop combination, a way of thinking about the definition of regional energy efficiency is presented in this section. Two types of crop combination is taken into account at first, i.e., the single-crop farming region of paddy rice, and the double-crop farming region of paddy rice and wheat (and barley). In the single-crop farming region of paddy rice, it can be assumed that 100 percent of the cropland consists of rice paddies, and the regional input-output energy ratio will be indicated at the order of 2.5 (point C, Figure 2a). In the double-crop farming region of paddy rice and wheat, it can be assumed that 50 percent of the cropland consists of rice paddies, and the regional input-output energy ratio will be indicated at the order of 2.6 (point B). This study defines larger values than the single-crop farming region and the double-crop farming region as "high efficiency region" (regional input-output energy ratio: more than 2.7). It is expected that paddy rice, wheat and barley, and potatoes are the typical crops of high efficiency region. For example, assuming that a traditional "rice-wheat-potato producing region," in which they cultivate paddy rice, wheat and sweet potatoes with one third of the planted area to each, the regional input-output energy ratio will be indicated at the order of 3.6 (point A) under a presumption that paddy rice and wheat have same value in energy balance.

Following high efficiency region, the combination of paddy rice and field vegetables is taken into account. However, since the kinds of field vegetables are in great numbers, it is difficult to define a proper proportion of planted percentages for paddy rice and field vegetables. As in the reason for this, this study empirically considers that paddy rice becomes a primary crop over 75 percent in planted area, and gives the range an appellation "paddy rice and field vegetable region" (i.e., point C to D, Figure 2a). The reason of this division is that leading municipalities in field vegetable production in the Kanto Region indicate fewer values of input-output energy ratio than the paddy rice and field vegetable region. They are namely, the production of cabbages at Tsumagoi Village in Gunma Prefecture, watermelons, Japanese radishes, cabbages at Miura City in Kanagawa Prefecture, Chinese cabbages at Yachiyo Town in Ibaraki prefecture (q.v., Maruyama, 1991: Saito, et al., 1985: Morimoto, et al., 1990). This study defines the values of the paddy rice and field vegetable region as "middle efficiency region" (regional input-output energy ratio: 1.6-2.6). It is expected that paddy rice, wheat and barely will be the typical crops of middle efficiency region.

This study expediently gives an appellation "field vegetable region" to the region whose regional input-output energy ratio indecates smaller values than that of the paddy rice and field vegetable region. In proportion as the planted percentage of field vegetables increases, the regional input-output energy ratio of the field vegetable region declines, and it becomes the order of 0.6 when field vegetables occupy all of the cropland (point E, Figure 2a). This study defines the values of the field vegetable region as "low efficiency region" (regional input-output energy ratio: 0.6-1.5). It is expected that not only vegetables but also grain and other crops are planted in various percentages in low efficiency region.

The combination of paddy rice and greenhouse vegetables generally indicates the lowest values of regional input-output energy ratio. Because a huge amount of fossil fuel energy is used in the production of greenhouse vegetables, a small increase of the planted area of greenhouse vegetables makes regional input-output energy ratio decline largely. For example, if the planted percentage of greenhouse vegetables becomes 10 percent in a single-crop farming region of paddy rice, the regional input-output energy ratio will decline to the order of 0.4 (point F, Figure 2a). If the planted percentage of greenhouse vegetables becomes 10 percent in the rice-wheat-potato producing region, the regional input-output energy ratio will decline to the order of 0.5. This study defines the lower values than those of field vegetable region as "very low efficiency region" (regional input-output energy ratio: under 0.5). This is a category that will be characterized by the production of greenhouse and field vegetables.

As the above-mentioned crop combination, which is based on the planted percentage of paddy rice, this study classifies regional energy efficiency into four levels from high to very low as shown in Figure 2b. Although beans and fruits are excluded from the examination, they will be substituted by the values of grain and field vegetables respectively. For example, if paddy rice and fruits are cultivated in a region with 50 percent planted area to each, the regional input-output energy ratio will be classified into low efficiency.

The results of the calculation of regional energy efficiency from 1970 to 1990 are shown in Table 7. Besides the results in 1990, the regional energy efficiency of 1970 is defined by the values of input-output energy ratio more than 2.7 as high efficiency, from 2.6 to 1.7 as middle efficiency, from 1.6 to 0.6 as low efficiency and under 0.5 as very low efficiency. The regional energy efficiency of 1975 is defined by the values of input-output energy ratio more than 3.3 as high efficiency, from 3.2 to 2.3 as middle efficiency, from 2.2 to 0.9 as low efficiency and under 0.8 very low efficiency. The regional energy efficiency of 1980 and 1985 is defined by the values of input-output energy ratio more than 3.0 as high efficiency, from 2.9 to 1.9 as middle efficiency, from 1.8 to 0.8 as low efficiency and under 0.7 as very low efficiency. The values that divide middle efficiency from

Table 7. Input-output energy ratio and regional energy efficiency, 1970-1990

Regional energy efficiency	Year				
	1970	1975	1980	1985	1990
High	2.7 -	3.3 -	3.0 -	3.0 -	2.7 -
Middle	1.7 - 2.6	2.3 - 3.2	1.9 - 2.9	1.9 - 2.9	1.6 - 2.6
Low	0.6 - 1.6	0.9 - 2.2	0.8 - 1.8	0.8 - 1.8	0.6 - 1.5
Very low	- 0.5	- 0.8	- 0.7	- 0.7	- 0.5

Data source: Tables 5 and 6.

high and low efficiency fluctuate because of the yearly fluctuation of the input-output energy ratio of the standard crops, i.e., paddy rice, wheat and barley. However, the values that divide low and very low efficiency show a little fluctuation because they are defined from the average of many crops. Although the average of the input-output energy ratio of crop production shows less fluctuation than the price of fossil fuel energy, input-output energy ratio for each crop production unit varies in according with the amount of harvest and input fossil fuel energy.

4.3 Limitation of regional energy efficiency

Since farmers produce many kinds of crops with various planted percentages in a region, the values of regional input-output energy ratio cannot give a precise explanation for the kinds of crops and thier planted percentage. Actually, even in traditional rice-wheat-potato producing regions, the regional input-output energy ratio never exceeds the order of 4.0, and seldom exceeds the order of 3.0. This is because they cultivate low efficiency crops such as field vegetables besides grain and sweet potatoes. Furthermore, if field vegetables are only cultivated in a region, the regional energy efficiency might be classified as very low, when they produce the vegetables such as lettuces, sweet peppers and Welsh onions whose input-output energy ratio indicates lower values than the average of field vegetables.

Even if the planted percentage of a crop never changes, the values of regional input-output energy ratio vary widely. This is another reason of the difficulty for elucidating the characteristics of regional crop production by examining regional input-output energy ratio. Namely, when the planted percentage of paddy rice changes, the curves 1 and 4 in Figure 2a indicate the marginal values of regional input-output energy ratio. In other words, the input-output energy ratio constantly takes some values between the two curves representing the combination of paddy rice with potatoes and greenhouse vegetables. For example, when regional input-output energy ratio takes the order of 0.5, the range of the planted percentage of paddy rice varies from zero to 93 percent. Although the regional input-output energy ratio is categorized in very low efficiency, there is a possibility that middle efficiency crop such as paddy rice might occupy almost all of the cropland.

The classification of the regional energy efficiency presented in this chapter can be used as an index that explains the characteristics of regional crop production. However, since many kinds of crops are cultivated in a region, it needs detailed explanations for the kinds of crops besides the values of regional input-output energy ratio. Still more, since the energy efficiency is calculated based on the planted area of typical crops in Japan (i.e., paddy rice, wheat and barley, and field vegetables), the classification will not be applied to the foreign countries or the regions in which other kinds of crops in terms of energy balance occupy a large part of the cropland. It needs to select other standard crops to examine the energy efficiency for the regions.

Chapter 5

Temporal and Spatial Changes of Agricultural Regions

5.1 Japan

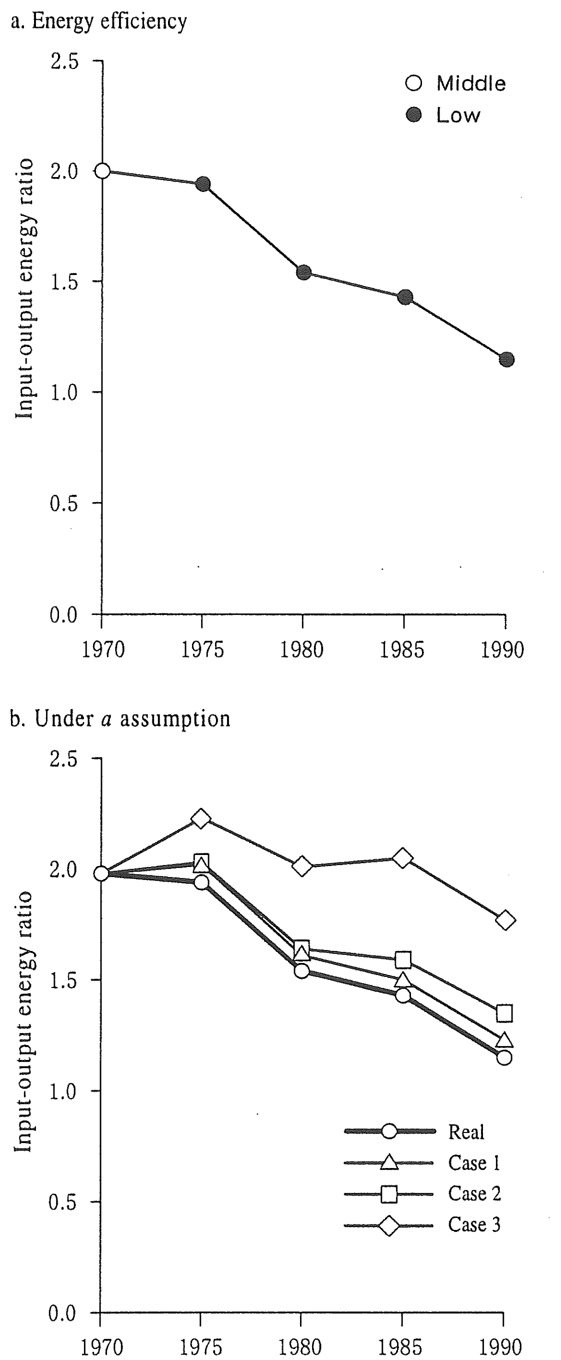
5.1.1 Temporal change

The equation (4) can be applied at various scales of regions. The calculation of country level is performed at first in this section. The data for the planted area of crops is obtained from the *World Census of Agriculture and Forestry* and the *Census of Agriculture* (The Ministry of Agriculture and Forestry, 1971, 1976b: The Ministry of Agriculture, Forestry and Fisheries 1981, 1986, 1991). Input and output energy for several crops in the data are substituted; (1) the average of grain for upland rice and miscellaneous cereals, (2) six-row barley for barley and naked barley, (3) the average of beans for other beans, chestnuts and Japanese apricots, (4) the average of open-field vegetables for water melons, strawberries and other open-field vegetables, (5) the average of greenhouse vegetables for greenhouse vegetables and greenhouse fruits, (6) the average of fruits for persimmons and other fruits. The area of greenhouse facility substitutes for the planted area of greenhouse crops, because it is difficult to grasp actual crop rotation systems in greenhouse facilities. According to this substitution, for example, when a greenhouse facility takes a rotation of winter cucumber and summer tomato, the winter cucumber production that requires more input fossil fuel energy represents the energy use of the greenhouse facility.

Figure 3a shows the changes in the input-output energy ratio of crop production in Japan. The values of the input-output energy ratio changed from 2.0 in 1970 to 1.2 in 1990. In other words, the energy efficiency of Japanese crop production degraded by 40 percent over two decades. The values of regional input-output energy ratio corresponded with middle efficiency in 1970 and low efficiency from 1975 to 1990. The degradation of energy efficiency could be attributed to a change of the planted area of crops since the input-output energy ratio of crop production unit didn't change by a great extent.

The whole cropland of Japan decreased from 4.5 to 3.1 million hectares over the twenty years. The crops whose planted area changed by a greater extent are paddy rice, potatoes and greenhouse crops (Table 8). The planted area of paddy rice has decreased from 2.9 to 1.8 million hectares, and the planted area of potatoes decreased from 248 to 125 thousand hectares. The planted area of greenhouse crops increased from 9.2 to 49 thousand hectares.

In order to comprehend the cause of the degradation, an assumption is used here. The planted area of a crop is fixed at the 1970 level, and a calculation of the input-output energy ratio for two decades is performed.



Case 1: the planted area of potatoes is fixed at 1970 level
Case 2: the planted area of paddy rice is fixed at 1970 level
Case 3: the planted area of greenhouse is fixed at 1970 level

Figure 3. Changes in energy efficiency of crop production in Japan

Data source: The Ministry of Agriculture, Forestry and Fisheries (1971, 1976b), The Ministry of Agriculture, Forestry and Fisheries (1981, 1986, 1991).

Table 8. Changes in planted area of crops in Japan

(1,000ha)

Year:	1970	1975	1980	1985	1990
Paddy rice	2,896	2,471	2,309	2,061	1,849
Wheat, barley, other grain	564	211	284	327	375
Potatoes	248	157	142	142	123
Beans	131	141	145	127	125
Field vegetables	360	338	340	312	318
Greenhouse crops	9	20	30	38	49
Fruits	312	322	307	270	242
Total	4,520	3,660	3,556	3,277	3,081

Data source: The Ministry of Agriculture and Forestry (1971, 1976b), The Ministry of Agriculture, Forestry and Fisheries (1981, 1986, 1991).

According to this assumption, the crop that shows the highest values in 1990 can be attributed to a primary factor of the decline. The assumption applies to paddy rice, potatoes and greenhouse crops, and Figure 3b shows the results. If the planted area of paddy rice is fixed at the 1970 level (i.e., 2.9 million hectares), the input-output energy ratio becomes the order of 1.4 in 1990. If the planted area of potatoes is fixed at the 1970 level (i.e., 248 thousand hectares), the input-output energy ratio becomes the order of 1.3 in 1990. In the same way, if the planted area of greenhouse crops were not changed (i.e., 9.2 thousand hectares), the input-output energy ratio would become the order of 1.8. Therefore, the main cause of the degradation of energy efficiency can be attributed to the increase in the planted area of greenhouse crops.

Although the planted area of greenhouse crops in 1990 occupied only 1.6 percent of all crops, it had a great influence on the degradation of input-output energy ratio because of the huge amount of input energy per production unit. From the results of the calculation in this study, we see that the whole input energy of greenhouse vegetables in 1990 amounts to 0.8PJ, about 44 percent of all the input energy of crop production.

5.1.2 Prefectural change

Besides the sequential changes in the energy efficiency of Japan, the spatial changes in the energy efficiency of prefectures are discussed in this section through the maps 1970 and 1990. The two years' analysis will present a distinctive figure of dramatic changes in the energy efficiency of Japanese agriculture, because horticultural sector (i.e., low and very low efficiency crops) was developed by the subsidies of Japanese Government, whereas the planted area of paddy rice (i.e., middle efficiency crops) was reduced by the set aside program from the 1970s. The latest calculation is performed to the year of 1990, because it is the newest data in the latest *Linked Input-output Tables* published in 1995.

The input-output energy ratio of prefectures in 1970 ranged from 3.1 at Kagoshima Prefecture to 1.0 at Kochi Prefecture. The regional energy efficiency of crop production was classified into three categories from high to low efficiency. The groups of crops produced in all prefectures were listed in order of average planted percentage as: paddy rice (63%), wheat and barley (11%), field vegetables (9.3%), fruits (9.0%), potatoes (5%), beans (2%) and greenhouse crops (0.3%).

The prefectures classified into high efficiency in 1970 were namely Kagoshima Prefecture and Hokkaido (Figure 4a). The groups of crops in the high efficiency prefectures were listed in order of average planted percentage as: paddy rice (46%), potatoes (22%), wheat and barley (13%), beans (10%), field vegetables (5%), fruits (3%) and greenhouse crops (0.1%). Although paddy rice, potatoes, wheat and barley showed high values in planted percentage, those of potatoes were four times larger than

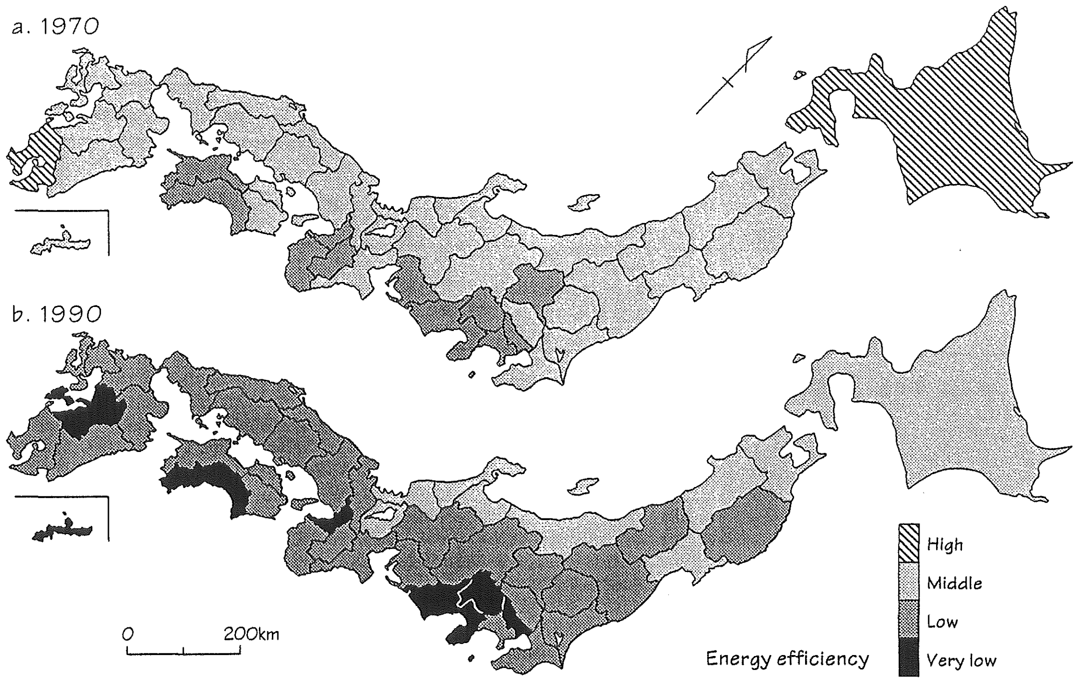


Figure 4. Energy efficiency of crop production at prefectures in Japan, 1970-1990
Data source: Tables 5 and 6, The Ministry of Agriculture and Forestry (1971), The Ministry of Agriculture, Forestry and Fisheries (1991).

the country's average (Table 9). The planted area of sweet potatoes in Kagoshima Prefecture (43 thousand hectares), and the planted area of white potatoes in Hokkaido (68 thousand hectares) was the largest in Japan.

Middle efficiency region consisted of the 34 prefectures located mainly in the Tohoku, Hokuriku, Cyubu, Cyugoku and Kyusyu Regions. The groups of crops in the middle efficiency prefectures were listed in order of average planted percentage as: paddy rice (69%), wheat and barley (11%), field vegetables (8%), fruits (7%), potatoes (4%), beans (2%) and greenhouse crops (0.3%). The values were almost consistent with the country's average, though the values of paddy rice were a little higher. The middle efficiency region included four of the top five prefectures in the production of paddy rice (i.e., Hokkaido 249 thousand hectares, Nigata 169, Akita 112, Miyagi 110, Fukushima 107 and Ibaraki 103: underlines represent the prefectures mentioned in the sentence), four of the top five prefectures in the production of beans (i.e., Hokkaido 90, Iwate 10, Fukushima 7, Nagano 5 and Aomori 5), four of the top five prefectures in the production of wheat and barley (i.e., Ibaraki 73, Hokkaido 47, Tochigi 41, Kumamoto 37 and Chiba 30), and three of the top five prefectures in the production of field vegetables (i.e., Chiba 27, Aichi 23, Hokkaido 22, Ibaraki 21 and Saitama 20).

Low efficiency region consisted of the 11 prefectures located mainly in the Kanto, Tokai, Kinki and Shikoku Regions. The groups of crops in

Table 9. Energy efficiency of prefectures and average planted area of crops in Japan

Year	Energy efficiency	Input-output energy ratio	Number of prefectures	Average planted area (%)						
				Potatoes	Paddy rice	Wheat, barley, other grain	Beans	Fruits	Field vegetables	Greenhouse crops
1970	High	2.7 -	2	22	46	13	10	3	5	0.1
	Middle	1.7 - 2.6	34	4	69	11	2	7	8	0.1
	Low	0.6 - 1.6	11	5	51	11	2	16	16	0.7
	Very low	- 0.5	-	-	-	-	-	-	-	-
	Total		47	5	63	11	2	9	9	0.3
1990	High	2.7 -	-	-	-	-	-	-	-	-
	Middle	1.6 - 2.6	9	2	73	9	6	3	6	0.4
	Low	0.6 - 1.5	31	3	58	9	4	12	12	1.9
	Very low	- 0.5	7	3	38	4	2	25	22	6.6
	Total		47	3	58	8	4	12	13	2.3

Data source: Tables 5 and 6, The Ministry of Agriculture and Forestry (1971), The Ministry of Agriculture, Forestry and Fisheries (1991).

the low efficiency prefectures were listed in order of average planted percentage as: paddy rice (51%), fruits (16.0%), field vegetables (15.5%), wheat and barley (11%), potatoes (5%), beans (2%) and greenhouse crops (0.7%). In these percentages, paddy rice, potatoes, wheat and barley indicated high values, about two times larger than those of the country's average. The middle efficiency region included three of the top five prefectures in the production of fruits (i.e., Ehime 37 thousand hectares, Aomori 17, Wakayama 17, Kumamoto 16, and Shizuoka 16), and three of the top five prefectures in the production of greenhouse crops (i.e., Kochi 1.1, Shizuoka 0.9, Aichi 0.6, Ibaraki 0.5 and Chiba 0.5).

In 1990, the input-output energy ratio of prefectures ranged from 2.3 at Hokkaido to 0.2 at Okinawa Prefecture. The regional energy efficiency of crop production was classified into three categories from middle to very low efficiency. The emergence of very low efficiency and the disappearance of high efficiency prefectures were the distinctive feature of the 1990's map (Figure 4b). The groups of crops produced in all prefectures were listed in order of average planted percentage as: paddy rice (58%), field vegetables (13%), fruits (12%), wheat and barley (8%), beans (6%), potatoes (3%) and greenhouse crops (2.3%). As compared with the average of 1970, the percentages of field vegetables, fruits, beans and greenhouse crops increased, and the percentages of paddy rice, potatoes, wheat and barley decreased.

Very low efficiency region in 1990 included seven prefectures, namely, Tokyo (input-output energy ratio: 0.5), and Yamanashi (0.5), Shizuoka (0.5), Osaka (0.5), Kochi (0.3), Kumamoto (0.4) and Okinawa (0.2) Prefectures. The groups of crops in the very low efficiency prefectures were listed in order of average planted percentage as: paddy rice (38%), fruits (25%), field vegetables (22%), greenhouse crops (6.6%), wheat and barley (4%), potatoes (3%) and beans (2%). As compared with the country's average, the percentage of greenhouse crops indicated three times larger values, and the percentage of fruits and field vegetables indicated two times larger values. The very low efficiency region included three of the top five prefectures in the production of greenhouse crops (i.e., Kumamoto 6.6 thousand hectares, Ibaraki 3.2, Aichi 2.5, Shizuoka 2.3 and Kochi 2.3).

Low efficiency prefectures increased from 11 in 1970 to 31 in 1990. As they surrounded the very low efficiency region, the prefectures were located mainly in the Kanto, Cyubu, Kinki, Cyugoku, Shikoku and Kyusyu Regions. The groups of crops in the low efficiency prefectures were listed in order of average planted percentage as: paddy rice (58%), field vegetables (12.4%), fruits (11.5%), wheat and barley (9%), beans (4%), potatoes (3%) and greenhouse crops (2.3%). As compared with the average of low efficiency prefectures in 1970, fruits and field vegetables decreased in four percent respectively, and paddy rice increased in seven percent. The low efficiency region included four of the top five prefectures in the production of wheat and barley (i.e., Hokkaido 143 thousand hectares, Tochigi 28, Saga 28, Fukuoka 23 and Ibaraki 21), four of the top five prefectures in the production of potatoes (i.e., Hokkaido 63, Kagoshima 17, Ibaraki 7, Chiba 5 and Nagasaki 5), three of top five prefectures in the production of fruits (i.e., Ehime 25; Aomori 21, Wakayama 17, Nagano 16 and Kumamoto 13), and three of the top five prefectures in the production of field vegetables (i.e., Hokkaido, 49, Chiba 22, Ibaraki 18, Nagano 17 and Aomori 14).

Middle efficiency prefectures decreased from 34 in 1970 to nine in 1990. They were located mainly in the prefectures along the shore of the Japan Sea from Hokkaido to the middle part of Japan. The groups of crops in the middle efficiency prefectures were listed in order of average planted percentage as: paddy rice (73%), wheat and barley (9%), beans (6.2%), field vegetables (6.2%), fruits (3%), potatoes (2%) and greenhouse crops (0.4%). The values of paddy rice indicated 15 percent higher than those of the country's average in 1990, and became four percent higher than that of middle efficiency prefectures' average in 1970. The middle efficiency region included four of the top five prefectures in the production of paddy rice (i.e., Hokkaido 143 thousand hectares, Nigata 126, Akita 103, Miyagi 92 and Fukushima 87), and three of the top five prefectures in the production of beans (i.e., Hokkaido 72, Akita 9, Chiba 7, Tochigi 6 and Toyama 8).

Here these figures bring a brief summary about the characteristics of energy efficiency and the average planted percentage of crops. High efficiency prefectures went for Kagoshima Prefecture and Hokkaido in 1970. The average planted percentage of crops in the high efficiency prefectures indicated high values in paddy rice, potatoes, wheat and barley. Although middle efficiency prefectures ranged over almost all the Regions in 1970, they remained mainly in the coastal prefectures of the Japan Sea, such as Hokkaido, the Tohoku and Hokuriku Regions in 1990. The average planted percentage of crops in the middle efficiency prefectures indicated high values in paddy rice. Low efficiency prefectures distributed in the coastal prefectures of the Pacific Ocean from the Kanto to Shikoku Regions in 1970. They expanded to almost all regions in 1990. The average planted percentage of crops in low efficiency prefectures indicated high values in paddy rice, fruits and field vegetables. Very low efficiency prefectures appeared in the southeastern part of Japan in 1990. The average planted percentage in the very low efficiency prefectures indicated high values in fruits, field vegetables and greenhouse crops.

However, since the planted percentage of crops influences the values of regional input-output energy ratio, the prefectures in low and very low efficiency were not always consistent with the leading production centers of low and very low efficiency crops. For example, the planted area of fruits reached 27 percent in Yamanashi Prefecture, whose input-output energy ratio was the lowest in 1970. However, though the values were three times larger than that of the country's average, the planted area of fruits (eight thousand hectares) was ranked in twelfth position of all prefectures in 1970. In Okinawa Prefecture, whose input-output energy ratio was the lowest in 1990, the planted area of greenhouse crops indicated 11 percent, and the planted area of fruits reached 42 percent. These values respectively showed six and three times larger than those of the country's average. However, the area of greenhouse facilities (545 hectares) and the planted area of fruits (five thousand hectares) were ranked in thirty second and thirty fourth position of all prefectures in 1990[3)]. Since the planted area of middle and high efficiency crops such as paddy rice and potatoes were relatively small in the two prefectures, they consequently gained high values in the planted percentage of low and very low efficiency crops.

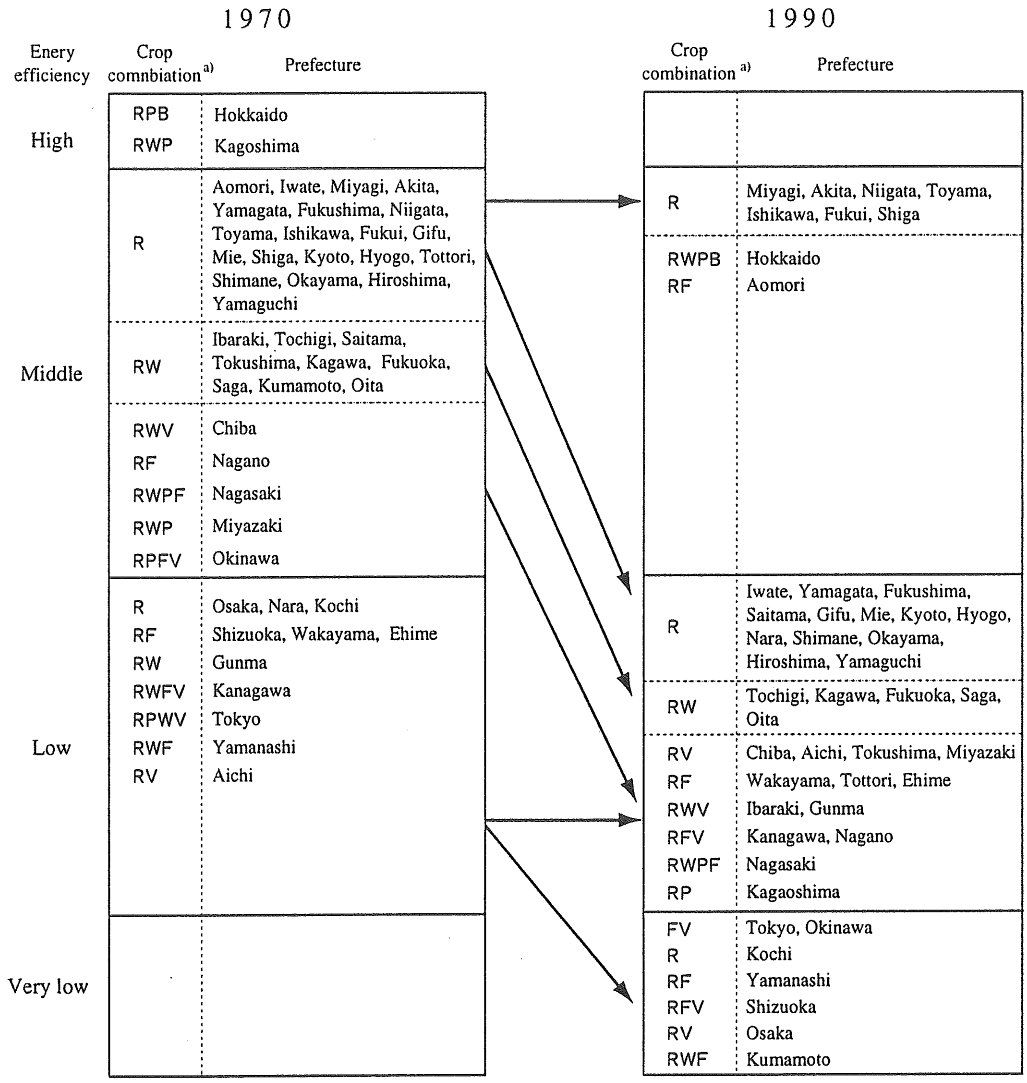
5.1.3 Regional energy efficiency and planted area of crops

Analyzing the four categories of energy efficiency based only on the average percentages of planted area couldn't comprehend the relationship between energy efficiency and crop production, because the kinds of crops often differed in the prefectures categorized in same energy efficiency. It needs to take a detailed examination of the changes in the energy efficiency of prefectures and the kinds of crops produced. Calculating the types of crop combination by Weaver's method is one of appropriate ways to examine the characteristics of regional crop production (Weaver, 1954a). This study applies a modified Weaver's method by Doi (1954) to calculate the types of crop combination, and scrutinizes the changes in the prefectural energy efficiency. The modified Weaver's method can specify the types of crop combination in any case of planted percentages. This is a merit of the Doi's modified method[4].

The modified Weaver's method is applied to the seven groups of crops classified in the *World Census of Agriculture and Forestry*, i.e., potatoes, paddy rice, wheat and barley (and other grain), beans, field vegetables, fruits and greenhouse crops. Letter symbols stand for major crops in the types of crop combination, namely; "P" represents potatoes, "R" represents paddy rice, "W" represents wheat and barley, "B" represents beans, "F" represents fruits, and "V" represents field vegetables. The calculation of prefectures in 1970 worked out at 12 types of crop combination, i.e., R (the number of prefecture: 23), RW (10), RF (4), RWP (2), RV (1), RWF (1), RPB (1), RWV (1), RPWV (1), RWPF (1), RPFV (1) and RWFV (1). Then, the calculation of prefectures in 1990 worked out at 11 types of crop combination, i.e., R (21), RW (5), RF (5), RV (5), RFV (3), FV (2), RWV (2), RP (1), RWF (1), RWPB (1) and RPWF (1). Although all the combination types included R in 1970, one of the types (i.e., FV) didn't contain R in 1990.

The crop combination of high efficiency prefectures, Kagoshima Prefecture and Hokkaido, was described as RWP and RPB types in 1970 (Figure 5). Kagoshima Prefecture changed into low efficiency's RP type, and Hokkaido changed into middle efficiency's RWPB type in 1990. The planted percentage of crops in Kagoshima Prefecture decreased from 17 to seven percent in wheat and barley, and increased from 41 to 61 percent in paddy rice, 31 to 41 percent in potatoes, five to 17 percent in field vegetables, five to nine percent in fruits, one to two percent in beans, and 0.1 to 2.7 percent in greenhouse crops. The planted percentage of crops in Hokkaido decreased from 52 to 35 percent in paddy rice, 19 to 17 percent in beans and 1.0 to 0.7 percent in fruits, and increased from 10 to 35 percent in wheat and barley, 14 to 15 percent in potatoes, five to 12 percent in field vegetables, and 0.02 to 0.4 percent in greenhouse crops.

The types of crop combination in middle efficiency prefectures in 1970 were R (number of prefectures: 20), RW (9), RWV (1), RF (1), RWPF (1), RWP (1) and RPFV (1). Among the 20 prefectures of R type, 11 prefectures changed into low efficiency's R type, and the seven prefectures remained unchanged in 1990. Among the nine prefectures of RW type, five prefectures changed into low efficiency's RW type. In the R type prefectures whose energy efficiency declined from middle to low, the planted percentage of crops changed from 77 to 75 percent in paddy rice, seven to four percent in wheat and barley, seven to eight percent in field vegetables, five to six percent in fruits, three to five percent in beans, two to one per-



Arrows represnt more than 4 prefectures.

a) Crop-combinations are calculated by Modified Weaver Method.
Each letter represents: P- potatoes, R- paddy rice, W- wheat, barley and other grain, B- beans, F- fruits, V- field vegetables.

Figure 5. Changes in energy efficiency and crop-combination types at prefectures in Japan

Data source: Figure 4, The Ministry of Agriculture and Forestry (1971), The Ministry of Agriculture, Forestry and Fisheries (1991).

cent in potatoes, and 0.1 to 1.2 percent in greenhouse crops. In the RW type prefectures whose energy efficiency declined from middle to low, the planted percentage of crops changed from 59 to 54 percent in paddy rice, 22 to 24 percent in wheat and barley, 10 to nine percent in fruits, five to seven percent in field vegetables, two to one percent in potatoes, one to five in beans, and 0.1 to 1.6 percent in greenhouse crops. Both of the cases show a considerable increase in the planted percentage of greenhouse crops. Other types of crop combination including R in the middle efficiency prefectures changed into low efficiency's crop combination with the exclusion of the middle efficiency crop's W, (i.e., Chiba, Miyazaki and Okinawa Prefectures), and with the inclusion of the low efficiency crop's V (i.e., Nagano Prefecture).

The 11 prefectures of low efficiency in 1970 varied considerably in the types of crop combination. The crop combination of the low efficiency prefectures consisted of middle efficiency crops (e.g., R and RW), and middle and low efficiency crops (e.g., RF and RV). Five of the prefectures changed into very low efficiency, and six of the prefectures remained being low efficiency in 1990. In the prefectures whose energy efficiency declined from low to very low, the planted percentage of crops changed from 51 to 42 percent in paddy rice, 17 to 25 percent in field vegetables, 14 to 24 percent in fruits, nine to two percent in wheat and barley, six to three percent in potatoes, two to one percent in beans, and 1.1 to 5.9 percent in greenhouse crops. These changes also indicate a great increase in the planted percentage of greenhouse crops. Middle and high efficiency crop disappeared in the crop combination of Tokyo (i.e., from RPWV to FV) and Yamanashi Prefecture (i.e., from RWF to RF), and low efficiency crop appeared in the crop combination of Shizuoka (i.e., from RF to RFV) and Osaka Prefectures (i.e., from R to RV). These changes show an increase in the planted percentage of field vegetables and fruits.

Here these figures bring a brief summary. The changing patterns of crop combination types and prefectural energy efficiency are summarized as thus; (a) from middle efficiency's R to middle efficiency's R type, (b) from middle efficiency's R to low efficiency's R type, (c) from middle efficiency's RW to low efficiency's RW type, (d) from middle efficiency's R-complex (e.g., RWV, RWPF) to low efficiency's R-complex types, (e) from low efficiency's R-complex to low efficiency's R-complex types, and (f) from low efficiency's R-complex to very low efficiency's complex types (i.e., the combination types that include R, V and F). It is considered that the changes of (b), (c), (d) and (f) exert a great influenced on the degradation of energy efficiency in Japanese agriculture. Still more, though it didn't appear in the combination of the modified Weaver's method, it is considered that the increase of the planted percentage of greenhouse crops also influenced the decline. As mentioned in the previous chapter, a small increase of greenhouse crops leads to the great reduction of the regional input-output energy ratio.

5.2 The Kanto Region

Following the examinations of Japan, this section presents a detailed explanation for the spatial-temporal changes of energy efficiency focusing on municipalities in the Kanto Region, which includes several prefectures whose energy efficiency of crop production declined in the two decades. As the partial remarks on prefectures in the former section, the Kanto Region includes four prefectures that changed from middle to low efficiency (i.e., Ibaraki, Tochigi, Saitama and Chiba Prefectures), two prefectures that remained low efficiency (i.e., Gunma and Kanagawa Prefectures), and the change from low to very low efficiency appeared in Tokyo. The examination of municipalities in the Kanto Region will be able to comprehend the spatial distribution of regional crop production centers, e.g., the regions active in the production of greenhouse vegetables, because farmer's organizations such as agricultural cooperatives are often established as a unit at municipality level. In this examination of the Kanto Region, the appellation of "greenhouse vegetables" substitutes for "greenhouse crops," since vegetables are prevalent as greenhouse crops in the region.

5.2.1 Municipalities in 1970

The input-output energy ratio of municipalities in the Kanto Region in 1970 ranged from 3.0 of Nakaminato City (i.e., the present Hitachinaka City) in Ibaraki Prefecture to 0.5 of Toyosato Village (i.e., the present Fukaya City) in Saitama Prefecture. The regional energy efficiency of crop production was classified into four categories from high to very low. The groups of crops in all municipalities were listed in order of average planted percentage as: paddy rice (46%), wheat and barley (25%), field vegetables (16%), potatoes (6%), fruits (4%), beans (3%) and greenhouse vegetables (0.3%). As compared with the average of Japan in 1970, the planted percentage of crops indicated higher values in wheat and barley, field vegetables, potatoes and beans, almost same values in greenhouse vegetables, and smaller values in paddy rice and fruits.

Six municipalities were classified into high efficiency in 1970, namely, Nakaminato City, Oarai Town and Dejima Village (i.e., the present Kasumigaura Town) in Ibaraki Prefecture, Tonosho Town in Chiba Prefecture, Higashimurayama City and Hinohara Village in Tokyo (Figure 6). The groups of crops in the high efficiency municipalities were listed in order of average planted percentage as: wheat and barley (32%), paddy rice (28%), potatoes (24%), field vegetables (9%), fruits (5%), beans (3%) and greenhouse vegetables (0.1%). Although the percentages in wheat and barley, paddy rice and potatoes indicated high values, the percentage of potatoes was four times larger than that of the average of the Kanto Region (Table 10). The double-crop farming of sweet potatoes and barley occu-

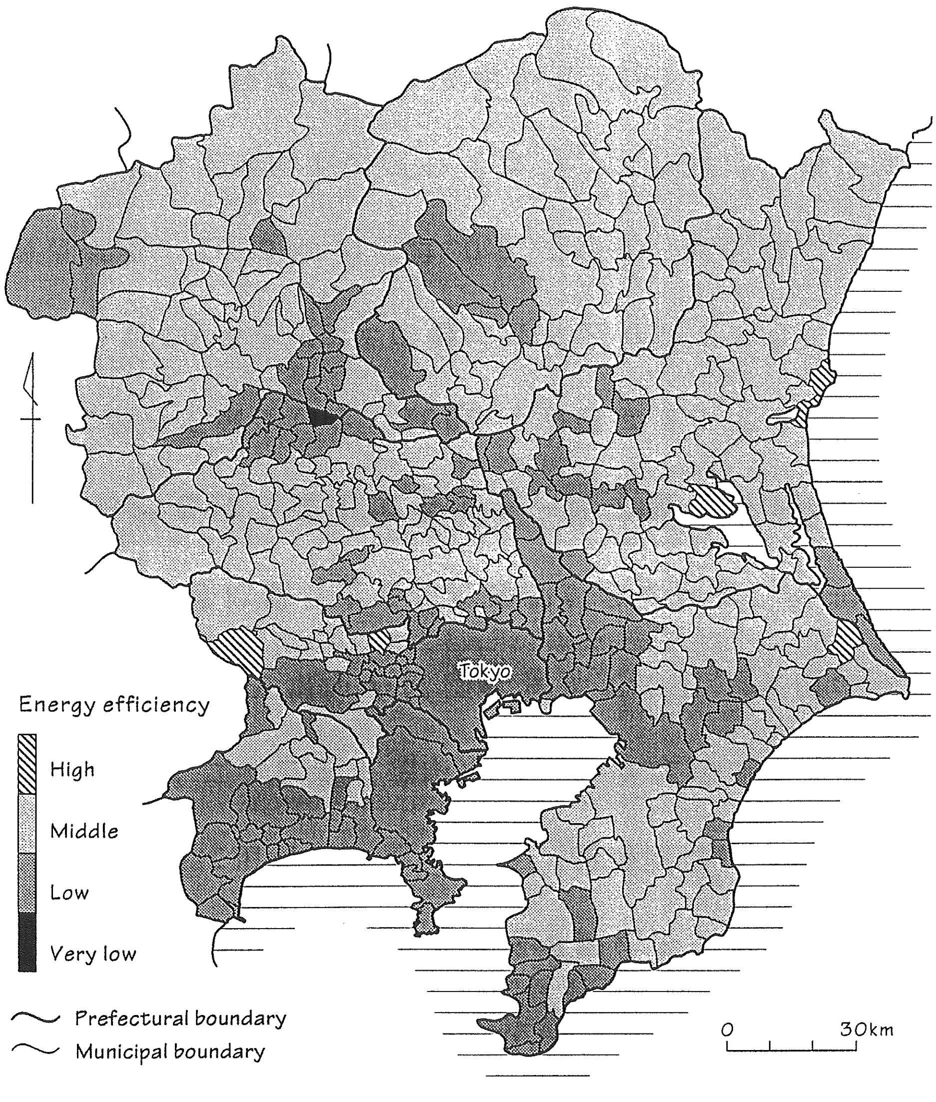


Figure 6. Energy efficiency of crop production at municipalities in the Kanto Region, 1970
Data source: Table 6, The Ministry of Agriculture and Forestry (1971).

Table 10. Energy efficiency of municipalities and average planted area of crops in the Kanto Region

Year	Energy efficiency	Input-output energy ratio	Number of municipalities	Average planted area (%)						
				Potatoes	Paddy rice	Wheat, barley, other grain	Beans	Fruits	Field vegetables	Greenhouse vegetables
1970	High	2.7 -	6	24	28	32	3	5	9	0.1
	Middle	1.7 - 2.6	316	5	50	28	3	3	10	0.1
	Low	0.6 - 1.6	143	5	38	18	3	7	29	0.6
	Very low	- 0.5	1	1	6	1	0	1	90	1.5
	Total		466	6	46	25	3	4	16	0.3
1990	High	2.7 -	4	39	36	14	2	0	8	0.3
	Middle	1.6 - 2.6	126	2	66	16	7	1	7	0.4
	Low	0.6 - 1.5	253	4	40	12	10	6	27	1.7
	Very low	- 0.5	54	5	33	6	6	3	38	7.9
	Total		437	4	47	13	8	4	22	2.0

Data source: Tables 5 and 6, The Ministry of Agriculture and Forestry (1971), The Ministry of Agriculture, Forestry and Fisheries (1991).

pied a large area of cropland on the diluvial uplands in Nakaminato City, Oarai Town, Dejima and Tonosho Villages.

Middle efficiency region consisted of 316 municipalities. They occupied a large part of Ibaraki, Tochigi, Gunma, Saitama and Chiba Prefectures. The groups of crops in the middle efficiency prefectures were listed in order of average planted percentage as: paddy rice (50%), wheat and barley (28%), field vegetables (10%), potatoes (5%), beans (3.5%), fruits (2.9%) and greenhouse vegetables (0.1%). These values were almost consistent with the average of the Kanto Region, though the values of paddy rice, wheat and barley were a little higher. These municipalities corresponded with the single-crop farming region of paddy rice, and the regions active in the production of paddy rice, wheat and barley. In fact, the central part of Gunma Prefecture and the southern part of Tochigi Prefecture have been known as the double-crop farming region of paddy rice and wheat (Horiuchi, 1995: Saito, 1996).

Low efficiency region in 1970 consisted of 143 municipalities. They were located continuously in urban and suburban area such as Chiba, Kawasaki and Yokohama Cities, and the 23 Wards of Tokyo. Besides these cities, low efficiency municipalities dispersed at the production centers of field vegetables in the outer suburbs, e.g., the production of Chinese cabbages and cabbages at Yachiyo and Sowa Towns in Ibaraki Prefecture (Morimoto et al., 1990), sweet peppers and eggplants at the Rokko District in Ibaraki Prefecture (Tabayashi et al., 1998), strawberries at Kanuma City in Tochigi Prefecture, cucumbers and eggplants at Tatebayashi City, cabbages at Tsumagoi Village in Gunma Prefecture, Japanese radishes at Miura City in Kanagawa Prefecture. Low efficiency municipalities also extended to the fruits production centers in the outer suburbs, e.g., the production of Japanese pears at Sekijo Town in Ibaraki Prefecture, and at Ichikawa City in Chiba Prefecture (Harada, 1976), Unshu mandarin at Odawara City and Yugawara Town in Kanagawa Prefecture. Tsumagoi Village is known as a track farming center in high land, whose cropland is located in 940 to 1,447 meters' altitude, and they cultivate summer vegetables having under control the cool temperature of summer. The production of field vegetables in the Miura Peninsula has the property of track farming region and suburban agriculture. They adopted triple-crop farming of water melons, Japanese radishes and cabbages with harnessing the warm temperature of winter (Saito et al., 1985). The groups of crops in the low efficiency municipalities were listed in order of average planted percentage as: paddy rice (38%), field vegetables (29%), wheat and barley (18%), fruits (7%), potatoes (5%), beans (3%) and greenhouse vegetables (0.6%). Although the percentage of paddy rice and field vegetables indicated high values, in particular, the latter were two times larger than that of the average in the Kanto Region.

Very low efficiency region was applied only to Toyosato Village, Saitama Prefecture. The groups of crops in the village were listed in order of average planted percentage as: field vegetables (90%), paddy rice (6%), greenhouse vegetables (1.5%), fruits (0.9%), potatoes (0.7%), wheat and barley (0.7%) and beans (0.1%). Although the percentage of field vegetables indicated extreme high values, the percentage of greenhouse vegetables also was five times larger than that of the average of the Kanto Region. In Toyosato Village, they adopted triple-crop farming of Welsh onions, spinach and spring vegetables at the open-field with deep top soil on the natural levees of the Tone River. Double-crop farming of cucumbers in greenhouse facilities could be also seen in the village (Yamamoto et al., 1988).

The figures mentioned above bring a brief summary of the municipalities in the Kanto Region in 1970. The spatial pattern based on energy efficiency was characterized by; (a) low efficiency municipalities in urban and suburban, (b) middle efficiency municipalities extending in the outer suburbs, and (c) low efficiency region dispersing in the outer suburbs. The crops produced in the municipalities were characterized based on the planted percentage by; (d) the production of paddy rice, wheat and barley in middle efficiency municipalities, and (e) the production of paddy rice and field vegetables in low efficiency municipalities. In particular, the low efficiency municipalities located in the outer suburbs were consistent with the crop production centers practicing the intensive production of field vegetables and fruits.

5.2.2 Municipalities in 1990

The input-output energy ratio of the municipalities in the Kanto Region in 1990 ranged from 3.2 of Nakaminato City (i.e., the present Hitachinaka City) in Ibaraki Prefecture to 0.1 of Hasaki Town in Ibaraki Prefecture. The regional energy efficiency of crop production was classified into four categories from high to very low. The groups of crops in all municipalities were listed in order of average planted percentage as: paddy rice (47%), field vegetables (22%), wheat and barley (13%), beans (8%), potatoes (3.9%), fruits (3.9%) and greenhouse vegetables (2.0%). As compared with the average of Japan in 1990, the planted percentage indicated higher values in field vegetables, wheat and barley, beans and potatoes, and smaller values in paddy rice, fruits and greenhouse vegetables. As compared with the average of the Kanto Region in 1970, the planted percentage indicated higher values in paddy rice, beans, field and greenhouse vegetables, almost same values in fruits, and smaller values in potatoes, wheat and barley. The 12 municipalities whose cropland decreased under 10 hectares in 1990 are excluded from this examination because there appears considerable number of statistical concealment.

The appearance of 54 municipalities of very low efficiency attributed a prominent characteristic to 1990's map (Figure 7). Among them, 40

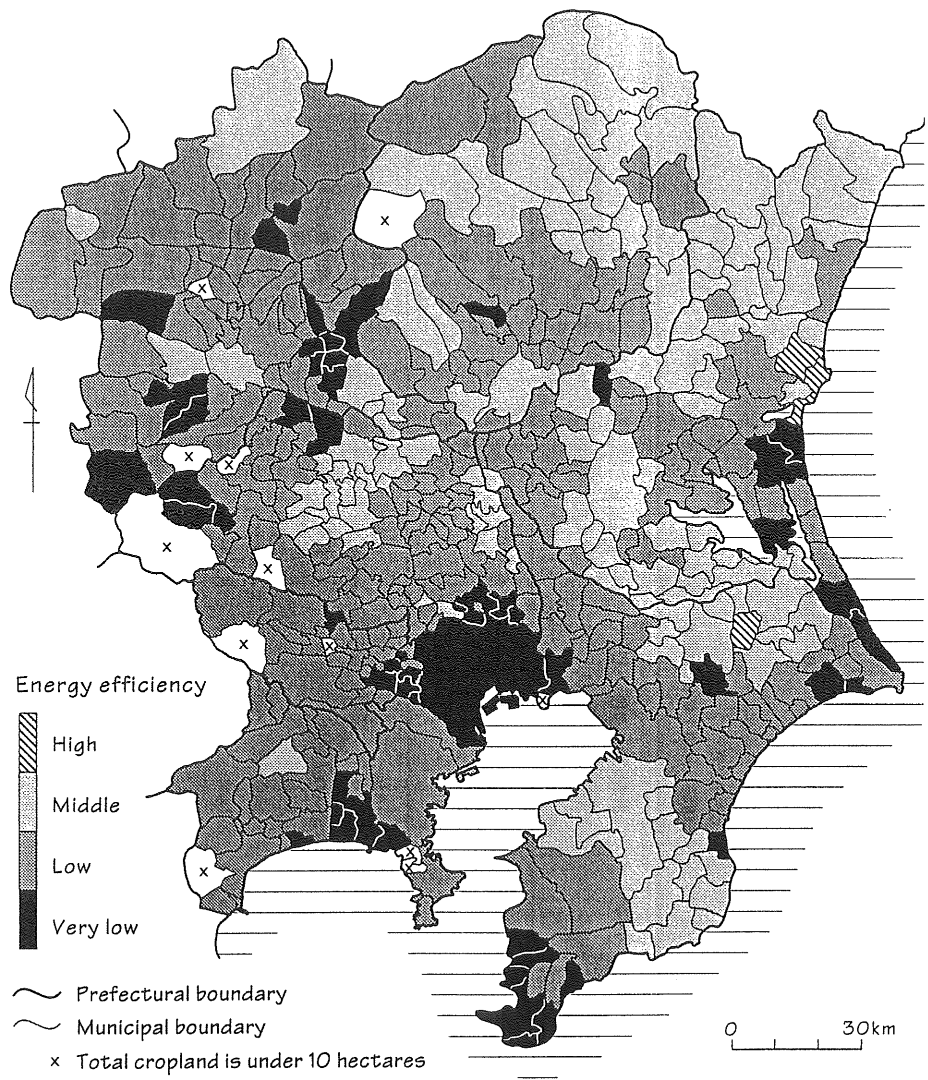


Figure 7. Energy efficiency of crop production at municipalities in the Kanto Region, 1990

Data source: Table 5, The Ministry of Agriculture, Forestry and Fisheries (1991).

municipalities had been low and very low efficiency, and 14 municipalities had been middle efficiency in 1970. The very low efficiency municipalities were distributed continuously in urban and suburban, and also dispersed in the outer suburbs about 30 to 100 km from Tokyo metropolitan area. The groups of crops in the very low efficiency municipalities were listed in order of average planted percentage as: field vegetables (38%), paddy rice (33%), greenhouse vegetables (7.9%), wheat and barley (6.4%), beans (5.6%), potatoes (5.3%) and fruits (3%). Although field vegetables indicated the highest values, the percentage of greenhouse vegetables showed four times larger values than the average of the Kanto Region (Table 10). Greenhouse facilities occupied no less than 35 percent of all cropland in Hasaki Town, whose input-output energy ratio was the lowest. Besides the municipality active in the production of sweet peppers, many of the very low efficiency's municipalities located in the outer suburbs retained more than 50 hectares of greenhouse facilities for vegetables, e.g., the production of melons at Asahi Village and Hokota Town (Tabayashi et al., 1984: Kitamura, 1995), strawberries at Aso Town, tomatoes at Kyowa Town in Ibaraki Prefecture (Tabayashi, 1993), strawberries at Nishikata Town in Tochigi Prefecture, cucumbers and eggplants at Akabori, Kasagake and Yabutsukahonmachi Towns, Gunma Prefecture, cucumbers and tomatoes at Fukaya and Honjo City in Saitama Prefecture, cucumbers, tomatoes and strawberries at Asahi City, strawberries at Tateyama City in Chiba Prefecture. Except for these production centers of greenhouse vegetables, at the very low efficiency's municipalities located in mountainous regions in Gunma and Saitama Prefectures, the percentage of greenhouse facilities became higher as the consequence of decrease in other crops' production. About 60 to 91 percent of cropland decreased during two decades at Tomioka City, Kanra Town, Nizato and Ueno Villages in Gunma Prefecture, and at Onogami and Ryokami Villages in Saitama Prefecture.

The number of low efficiency municipalities increased from 143 to 253. Among them, three municipalities had been high efficiency, 153 municipalities had been middle efficiency, and 97 municipalities had been low efficiency in 1970. Since a great number of municipalities changed from middle to low efficiency in Gunma and Saitama Prefectures, the low efficiency region came to occupy a large area in the eastern part of the Kanto Region. The groups of crops in the low efficiency municipalities were listed in order of average planted percentage as: paddy rice (40%), field vegetables (27%), wheat and barley (12%), beans (10%), fruits (6%), potatoes (4%) and greenhouse vegetables (1.7%). As compared with the average of low efficiency municipalities in 1970, the planted percentage indicated higher values in paddy rice, beans and greenhouse vegetables, and smaller values in field vegetables, wheat and barley, potatoes and fruits. The notable difference was the increase of greenhouse vegetables. According to the set-aside program for paddy rice, the expansion of the soybeans cultivated in paddy field resulted in the increase of the planted percentage of beans. Although the percentage of paddy rice and field vegetables still indicated high values, the low efficiency municipalities in 1990 were not always accordance with the production centers of fruits and field vegetables.

Middle efficiency municipalities decreased from 316 to 126. Among them, 125 municipalities had been middle efficiency in 1970. These municipalities remained in the Yamizo Mountains and the Abukuma Highlands in the northern part of Ibaraki and in the northeastern part of Tochigi Prefectures, the Tone Valley in the southern part of Ibaraki Prefecture, the Omiya Uplands in Saitama Prefecture, the Joso Uplands and the Boso Hills in Chiba Prefecture. The area was consistent with the region active in paddy rice, wheat and barley production. The groups of crops in the middle efficiency municipalities were listed in order of average planted percentage as: paddy rice (66%), wheat and barley (16%), beans (7.0%), field vegetables (6.9%), potatoes (2%), fruits (1%) and greenhouse vegetables (0.4%). As compared with the average of middle efficiency municipalities in 1970, the planted percentage indicated higher values in paddy rice, beans and greenhouse vegetables, and smaller values in wheat and barley, field vegetables, fruits and potatoes. A prominent characteristic of the fluctuation is the increase of paddy rice and the decrease of wheat and barley.

Four municipalities were classified into high efficiency in 1990, namely, Nakaminato and Katsuta Cities (i.e., the present Hitachinaka City) and Oarai Town in Ibaraki Prefecture, and Taiei Town in Chiba Prefecture. Nakaminato City and Oarai Town had been classified into high efficiency in 1970. The groups of crops in the high efficiency municipalities were listed in order of average planted percentage as: potatoes (39%), paddy rice (36%), wheat and barley (14%), field vegetables (8%), beans (2%), greenhouse vegetables (0.3%) and fruits (0.1%). As compared with the average of high efficiency municipalities in 1970, the planted percentage indicated higher values in potatoes, paddy rice and greenhouse vegetables, and smaller values in wheat and barley, field vegetables, beans and fruits. A prominent characteristic of this change was the increase of potatoes, whose values became 10 times larger than that of the average of the Kanto Region in 1990. Since the production of *Hoshiimo* (i.e., dried sweet potatoes) is flourishing in and around Hitachinaka City, the double-crop farming of barley and sweet potatoes for processing occupies a large area of the upland field (Nihei et al., 2000). Being resemblance to the landscape of the municipality, sweet potatoes for raw shipment that have red stems are seen widely in the upland field in the summer of Taiei Town, which is located near the Narita Airport.

The figures mentioned above bring a brief summary of the municipalities in Kanto Region in 1990. The spatial pattern was characterized by; (a) very low and low efficiency municipalities in urban and suburban, (b) middle and low efficiency municipalities extending in the outer suburbs, and (c) very low efficiency region dispersing in the outer suburbs. The crops produced in the municipalities were characterized based on the planted percentage by; (d) the production of paddy rice, wheat and barley in middle efficiency municipalities, (e) the production of paddy rice and field vegetables in low efficiency municipalities, and (f) the production of field and greenhouse vegetables in very low efficiency municipalities. The very low efficiency municipalities in the outer suburbs were consistent with the crop production centers of greenhouse vegetables and the mountainous region whose cropland decreased.

5.2.3 Energy efficiency and planted area of crops

(1) Energy efficiency and crop combination

Analyzing the four categories of energy efficiency based only on the average percentage of planted area won't comprehend the relationships between energy efficiency and crop production. It need make a mention of the kinds of crops that are often differs in the municipalities categorized in same energy efficiency. In this section, the author also applies Doi's modified Weaver's method to the calculation of crop combination types in the Kanto Region, and scrutinizes the changes in the municipality's energy efficiency.

The calculation of municipality's crop combination in 1970 worked out at 31 types. The double-crop combination of paddy rice and wheat (and barley) was the largest number, and the single-crop combination of paddy rice was the second largest number, i.e., RW (the number of municipalities: 160), R (120), RWV (53), RV (27), WPV (13), WV (11), V (10), RWF (10), W (6), RF (6), RWPV (5), WPBV (4), RWBV (4), WPFV (4), WBV (3), RFV (3), RWB (3), RWFV (3), RWPBV (3), WFV (2), F (2), RB (2), PV (2), RWP (2), RBV (2), BV (1), FV (1), RPV (1), RWPB (1), RWPF (1) and RWPFV (1).

The high efficiency municipalities in 1970 indicated high values of planted percentage in the production of paddy rice, potatoes, wheat and barley. The types of crop combination for the municipalities were RWP at Nakaminato City (i.e., the present Hitachinaka City), RW at Oarai Town and RWPF at Dejima Town (i.e., the present Kasumigaura Town) in Ibaraki Prefecture, R at Tonosho Town in Chiba Prefecture, WPV at Higashimurayama City and WPBV at Hinohara Village in Tokyo (Figures 6 and 8). Many of the municipalities in high efficiency included high and middle efficiency crops such as potatoes, wheat and barely in the combination, however, the combination composed of paddy rice, potatoes, wheat and barley was only appeared in Nakaminato City.

The middle efficiency municipalities in 1970 indicated high planted percentage in paddy rice, wheat and barley production. The number of RW type was the largest among the municipalities. The RW type municipalities occupied the northern and middle part of Ibaraki Prefecture, the south-

Figure 8. Crop-combination types by a modified Weaver's method in the Kanto Region, 1970

Data source: The Ministry of Agriculture and Forestry (1971).

ern part of Tochigi Prefecture, the middle and the southern part of Gunma Prefecture, the Omiya Uplands in Saitama Prefecture, the Joso Uplands and the northern part of the Kujukuri Coastal Plains in Chiba Prefecture. The R type municipalities of middle efficiency occupied the Abukuma Highlands in the northern part of Ibaraki Prefecture, the Nasunohara Uplands in the northeastern part of Tochigi Prefecture, the Tone and the Naka Valleys in the eastern part of Saitama Prefecture, the Boso Peninsula and the Joso Uplands in Chiba Prefecture. Various types of crop combination that included paddy rice, wheat and barley, beans, fruits and field vegetables were seen in the municipalities of middle efficiency in the western part of Gunma and Saitama Prefectures, Tokyo metropolitan area, and the northern part of Kanagawa Prefecture.

The municipalities of low and very low efficiency in 1970 indicated high values in the planted percentage of field vegetables and paddy rice. The crop combination included middle and low efficiency crops such as paddy rice, wheat and barley, field vegetables and fruits. The RV type municipalities of low efficiency existed mainly in urban and suburban, and the other various types such as RWV, R, RW, RB and RF were located in the outer suburbs. However, the V type of low and very low efficiency was accordance with the production center of field vegetables, i.e., Tsumagoi Village in Gunma Prefecture, Toyosato Village in Saitama Prefecture, Miura City in Kanagawa Prefecture.

The calculation of municipality's crop combination in 1990 also worked out at 31 types, however, the kinds of types were not always same as those of 1970. The single-crop combination of paddy rice was the largest in number, and the double-crop combination of paddy rice and wheat (and barley) was the second largest. The distinctive feature of crop combination in 1990 was the decrease of the types including W, and the emergence of the types including G (i.e., greenhouse vegetables). The 31 types of the combination were, namely; R (the number of municipalities: 123), RW (80), RV (60), V (34), RWV (26), FV (18), RFV (16), RF (15), RWFV (14), RPV (10), F (4), RWF (4), BV (3), RWP (3), WFV (3), RB (2), VG (2), RG (2), RBV (2), PFV (2), RWPV (2), RWBV (2), WPFV (2), RP (1), PV (1), PBV (1), PVG (1), RVG (1), RPFV (1), RBFV (1) and WBFV (1). The combination that emerged only in 1970 was the types of WPV, WV, W, WPBV, WBV, RWB, RWPBV, PV, RWPB, RWPF and RWPFV, and the combination that emerged only in 1990 was the types of VG, RG, PFV, RP, PV, PBV, PVG, RVG, RPFV, RBFV and WBFV.

Among the very low efficiency municipalities in 1990, the combination including V and single-crop combination of V were seen especially in urban and suburban, and the combination including G existed in the outer suburbs (Figures 7 and 9). The later types were RVG of Asahi Village, RG of Aso and Hasaki Towns in Ibaraki Prefecture, VG of Yabutsukahonmachi and Kasakake Towns in Gunma Prefecture, and RVG of Shirahama Town

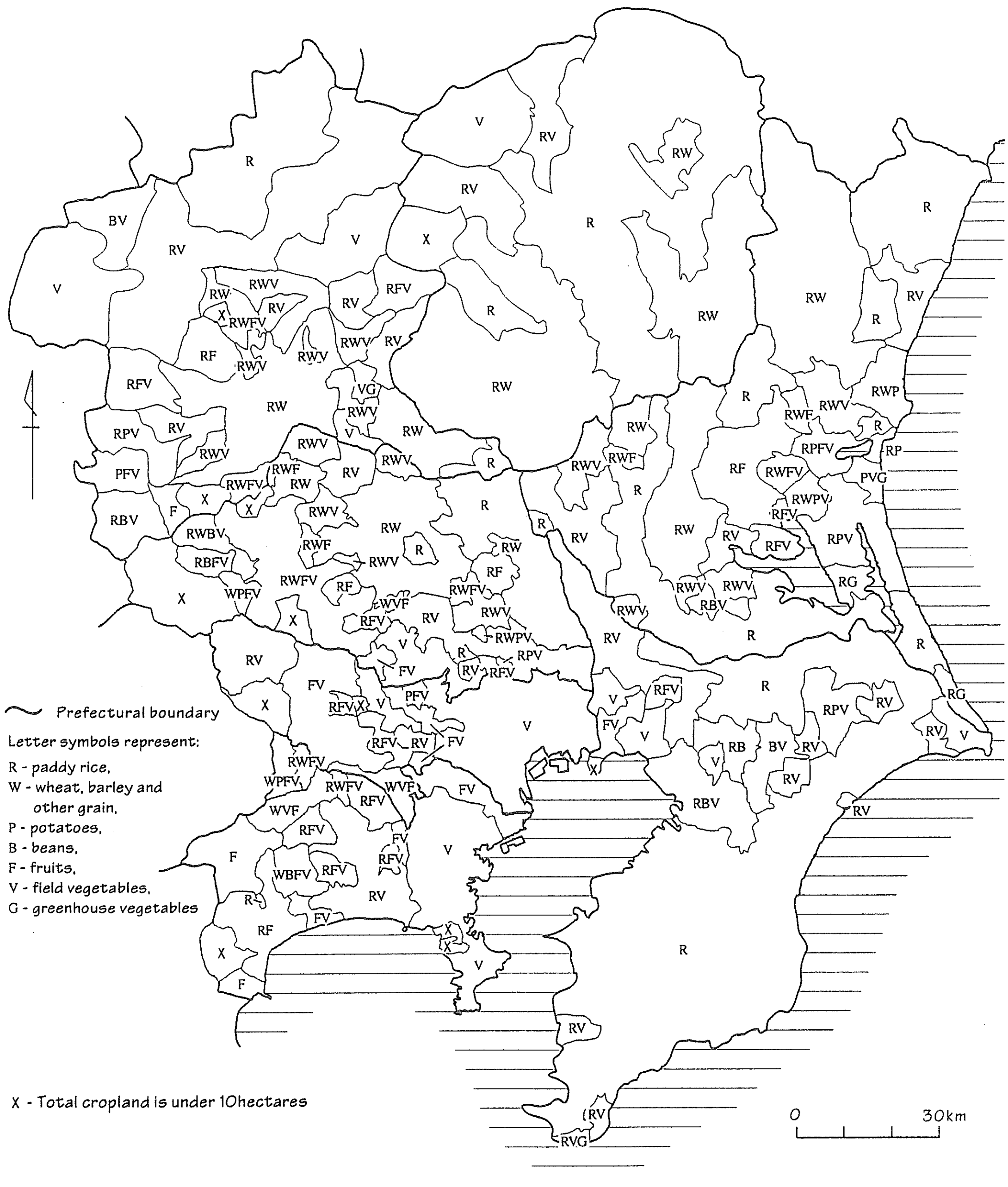


Figure 9. Crop-combination types by a modified Weaver's method in the Kanto Region, 1990

Data source: The Ministry of Agriculture, Forestry and Fisheries (1991).

in Chiba Prefecture. Other municipalities of very low efficiency in the outer suburbs had the combination composed of middle and high efficiency crops such as R, W, B and P. The municipalities of very low efficiency whose combination was composed only by middle efficiency crops were Kyowa and Kamisu Towns (combination: R) in Ibaraki Prefecture, Nishikata Town (RW) in Tochigi Prefecture, Asahi and Tateyama Cities, Ichinomiya, Tomiyama, Wada and Tomiura Towns (R) in Chiba Prefecture. The average percentage of greenhouse vegetables in these municipalities was nine, and the largest was 14 percent in Tomiura Town and the smallest was seven percent in Nishikata Town.

The low efficiency municipalities in 1990 indicated high values of planted percentage in field vegetables and paddy rice. The types of crop combination mainly included middle and low efficiency crops such as paddy rice, wheat, barley, field vegetables and fruits. Although these types of combination were similar to 1970, the difference was the increase of R and RW types. The R type municipalities of low efficiency existed in the Kujukuri Coastal Plains and the Awa District in Chiba Prefecture, and the RW type municipalities of low efficiency were located from the southern part of Tochigi Prefecture and to the middle part of Gunma Prefecture. Single-crop combination of V and the complex types including V were appeared in the low efficiency municipalities in urban and suburban, and the production centers of field vegetables in the outer suburbs. However, many low efficiency's municipalities in the western part of Kanagawa Prefecture were indicated by single-crop combination of F and the complex types including F.

Most of the middle efficiency municipalities in 1990 came under the single-crop combination of R and the double-crop combination of RW (i.e., 111 municipalities out of 126). The RW type municipalities of middle efficiency were located mainly in the Yamizo Mountains, which comprise the northern part of Ibaraki Prefecture and the northeastern part of Tochigi Prefecture, and the middle part of Saitama Prefecture. The R type municipalities of middle efficiency existed especially in the Abukuma Highlands in the northeastern part of Ibaraki Prefecture, the Kinu and the Tone Valleys in the western and the southern part of Ibaraki Prefecture, the Echigo Mountains in the northern part of Gunma Prefecture, the middle part of the Boso Peninsula, and the Joso Uplands in Chiba Prefecture.

Crop combination types for high efficiency municipalities in 1990 were RWP at Nakaminato and Katsuta Cities, RP at Oarai Town in Ibaraki Prefecture, and RPV at Taiei Town in Chiba Prefecture. These combinations included high and middle efficiency crops such as potatoes and paddy rice. In particular, the planted percentages of potatoes in Nakaminato City and Taiei Town went up to 43 and 44 percent in 1990 respectively.

A short summary of the relationship between energy efficiency and crop combination is presented here. The crop combination of high efficiency municipalities had included R, W and P in 1970, and it changed to R and P in 1990. The crop combination of middle efficiency municipalities was distinguished in R and RW types both in 1970 and 1990. Although the crop combination of low efficiency municipalities had been various in 1970, R and RW types became a great number in 1990. The crop combination of very low efficiency municipalities that appeared in 1990, included V in urban and suburban, and various crops such as R, W, B and G in the outer suburbs.

(2) Changing patterns of crop combination

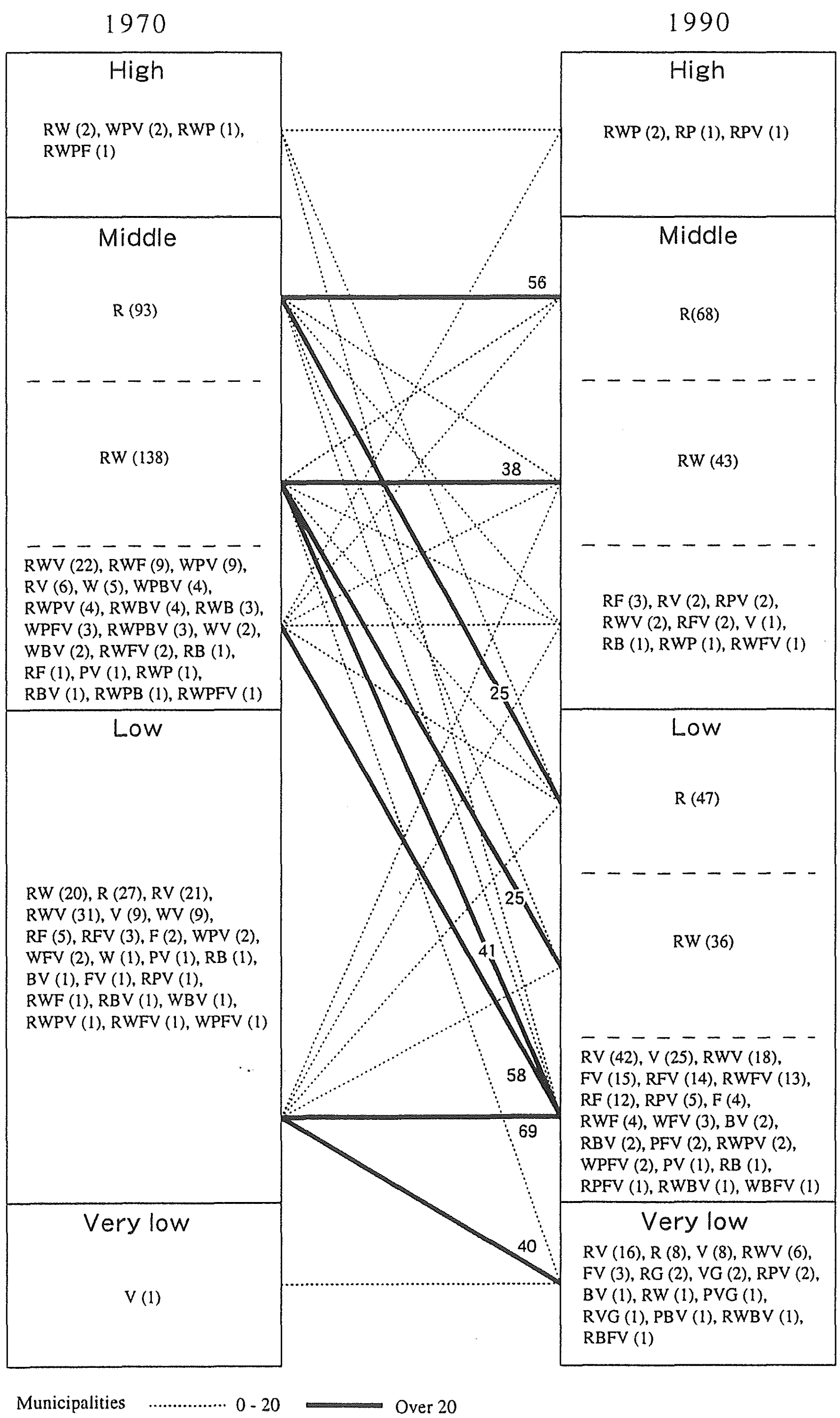
Following the distribution of crop combination types, a study of the changing patterns of crop combination types and municipality's energy efficiency is presented. The number of the survey unit was 466 in 1970 and 448 in 1990 will be adequate for seizing typical patterns of the change.

The number of high efficiency municipalities was six in 1970. Two of them remained being high efficiency in 1990, i.e., Nakaminato City and Oarai Town. Three of them changed into low efficiency in 1990, i.e., Dejima and Tonosho Towns, and Higashimurayama City. Besides these municipalities, the calculation of crop combination avoided Hinohara Town in 1990 because the cropland decreased to five hectares.

The number of middle efficiency municipalities was 316 in 1970. Among these municipalities, the number of RW type was 138, R type was

93, and complex types of middle efficiency crops such as R and W were 79 (Figure 10). Among the RW type, 38 municipalities remained being middle efficiency's RW, 25 municipalities changed into low efficiency's RW, and 41 municipalities changed into low efficiency's complex types in 1990. Among the R type, 56 municipalities remained being middle efficiency's R, 25 municipalities changed into low efficiency's R. Among the complex types, 58 municipalities changed into low efficiency's complex types, which included low efficiency crops such as V and F in the combination.

In the 25 municipalities that changed from middle efficiency's RW to low efficiency's RW, the average planted area of crops shifted from 49 to 50 percent in paddy rice, 40 to 35 percent in wheat and barley, 6.0 to 6.3 percent in field vegetables, two to one percent in potatoes, one to five percent in beans, one to two percent in fruits, and 0.2 to 1.7 percent in greenhouse vegetables. In the 25 municipalities that changed from middle efficiency's R to low efficiency's R, the average planted area of crops shifted from 75 to 78 percent in paddy rice, 11 to four percent in wheat and barley, eight to 10 percent in field vegetables, three to one percent in potatoes, one to four percent in beans, 1.1 to 0.8 percent in fruits, and 0.3 to 1.7 percent in greenhouse vegetables. In the 58 municipalities that changed from middle efficiency's complex types to low efficiency's complex types, the average planted area of crops shifted from 31 to nine percent in wheat



Figures in parentheses show the number of municipalities

Crop-combinations are calculated by Modified Weaver Method. Each letter represents: P- potatoes, R- paddy rice, W- wheat, barley and other grain, B- beans, F- fruits, V- field vegetables.

Figure 10. Changes in energy efficiency and crop-combination types at municipalities in the Kanto Region

Data source: Figures 6, 7, 8 and 9.

and barley, 25 to 24 percent in paddy rice, 19 to 36 percent in field vegetables, 11 to seven percent in potatoes, seven to 18 percent in beans, seven to five percent in fruits, and 0.1 to 1.4 percent in greenhouse vegetables. Namely, the distinctive characteristics were; (a) the increase of the greenhouse vegetables in the R and RW municipalities, (b) the increase of field and greenhouse vegetables, and the decrease of wheat and barley in the complex type's municipalities.

Among the 143 municipalities that had been classified into low efficiency in 1970, 69 municipalities remained being low efficiency's complex types, and 40 municipalities changed into very low efficiency's complex types. In the latter municipalities, the average planted area of crops shifted from 40 to 35 percent in paddy rice, 31 to 40 percent in field vegetables, 15 to six percent in wheat and barley, five to three percent in potatoes, three to five percent in beans, 3.7 to 3.9 percent in fruits, and 1.0 to 7.8 percent in greenhouse vegetables. A remarkable change was the increase of the planted percentage of greenhouse vegetables, whose values became eight times larger than that of 1970. Besides these municipalities, Toyosato Village that had been classified into very low efficiency in 1970 was consolidated into Fukaya City in 1973. As a result, the planted percentage of crops in the municipality declined in the production of field vegetables and increased in the production of greenhouse vegetables. The groups of crops in Fukaya City were listed in order of average planted percentage in 1990 as: field vegetables (54%), paddy rice (25%), wheat and barley (14%), greenhouse vegetables (6.5%), potatoes (1%), beans (0.3%) and fruits (0%).

Here the figures above-mentioned bring a brief summary about the characteristics of changing patterns of the energy efficiency and crop combination as thus; (a) from middle efficiency's R to middle efficiency's R, (b) from middle efficiency's R to low efficiency's R, (c) from middle efficiency's RW to middle efficiency's RW, (d) from middle efficiency's RW to low efficiency's RW, (e) from middle efficiency's RW to low efficiency's complex types, (f) from middle efficiency complex types to low efficiency's complex types, (g) from low efficiency's complex types to low efficiency's complex types, and (h) from low efficiency's complex types to very low efficiency's complex types. It can be considered that the changing patterns of (b), (d), (e), (f) and (h) influenced on the degradation of energy efficiency in the Kanto Region. In particular, the causes of the changes in (b), (d) and (h) could be attributed to the increase of the planted percentage of greenhouse vegetables, and the causes of the changes in (e) and (f) could be attributed to the increase of the planted percentage of field and greenhouse vegetables, and decrease of the planted percentage of wheat and barley.

Considering the relationship between these changing patterns and their spatial distribution, the pattern (b) was seen in Ibaraki (the number of municipalities: 2), Tochigi (12), Gunma (7) and Saitama (4) Prefectures, the pattern (d) was seen in Tochigi (2), Saitama (7) and Chiba (16) Prefectures, the pattern (e) was seen in Ibaraki (13), Gunma (14), Saitama (8), Chiba (3) and Kanagawa (3) Prefectures, the pattern (f) appeared in Ibaraki (8), Tochigi (2), Gunma (14), Saitama (14), Chiba (2), Kanagawa (5) Prefectures and Tokyo (13), and the pattern (f) appeared in Ibaraki (3), Tochigi (1), Gunma (7), Saitama (5), Chiba (11), Kanagawa (6) Prefectures and Tokyo (7). That is to say, the main causes of the decline in the energy efficiency of the Kanto Region could be ascribed to the decrease of paddy rice, wheat and barley in the outer suburbs, and the increase of field and greenhouse vegetables in urban and suburban, and greenhouse vegetables in the outer suburbs.

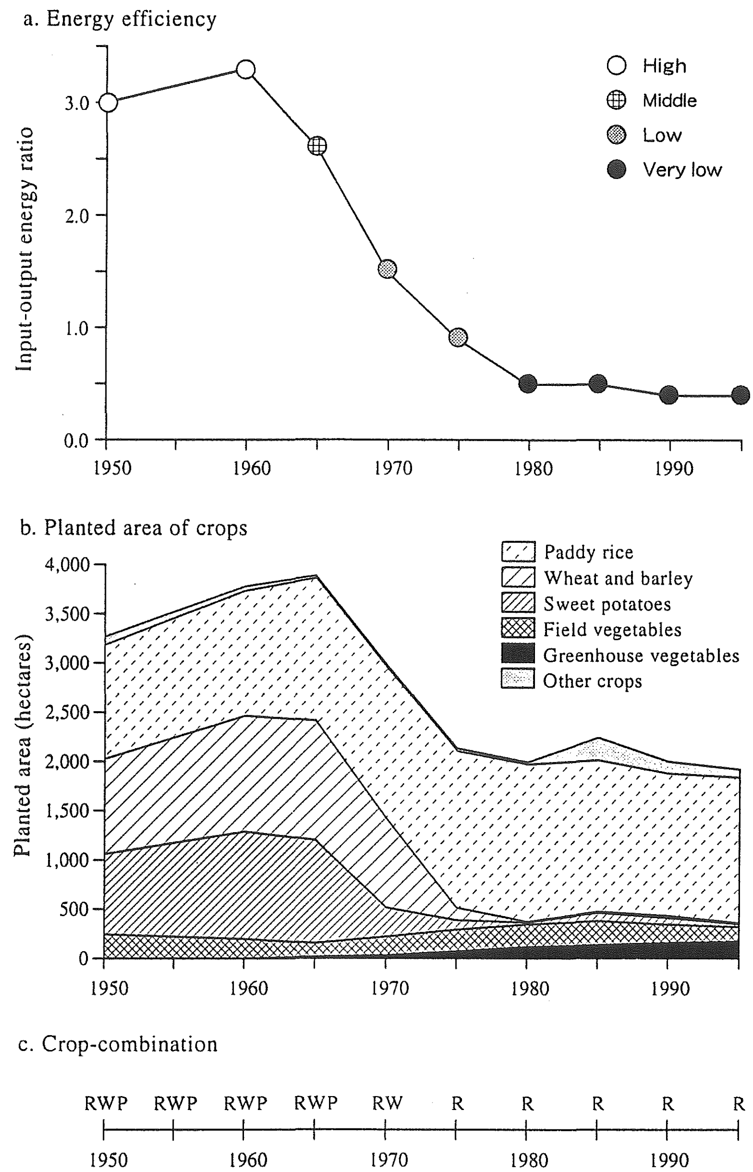
5.3 A decline in energy efficiency with the development of greenhouse horticulture: a case of Asahi City

As mentioned in the former section, Asahi City in the north end of the Kujukuri Coastal Plains was classified into one of the very low efficiency municipalities in the outer suburbs. The input-output energy ratio of Asahi City declined in accordance with the development of greenhouse horticulture. In this section the author examines the declining process of energy efficiency in Asahi City with reference to the development stages of greenhouse horticulture (Nihei, 1998). The values of input and output energy in 1970 substitute for the crop production before 1970, and those of 1990 substitute for the crop production in 1995.

The input-output energy ratio of Asahi City was 3.0 in 1950 and 3.3 in 1960. These values were classified into high efficiency region (Figure 11). According to the development stages, these years were consistent with "the period of rice-wheat-potato production." In other words, the main crops in the municipal were paddy rice, wheat, barley and sweet potatoes in the period. They cultivated the crops about 1,000 hectares each. The crop combination type of Asahi City was RWP by the modified Weaver's method.

In the period of rice-wheat-potato production, the crop production on the upland field was prominent in the double-crop farming, i.e., wheat and barley in winter and sweet potatoes in summer. The sweet potatoes for process was the main crop for merchandise. Sweet potatoes were shipped to the starch factories, which used to exist a large number in the Kujukuri Coastal Plains. Besides these crops, though the planted area was only about 200 hectares, they cultivated many kinds of field vegetables, especially Japanese radishes and Welsh onions. The lots of dry field in Asahi City usually were diminutive. People made a great number of *Shimabata* (i.e., island like field) in paddy field by raising ground level for about 30 to 80 cm (Takeuchi, 1975).

The input-output energy ratio of Asahi City declined acutely from



Letter symbols represent: P- potatoes, R- paddy rice, W- wheat, barley and other grain

Figure 11. Changes in energy efficiency and planted area of crops in Asahi City, Chiba Prefecture

Data source: Tables 5 and 5, The Ministry of Agriculture and Forestry (1955, 1961, 1971, 1976b), The Ministry of Agriculture, Forestry and Fisheries (1981, 1986, 1991, 1996).

1965 to 1980. The values changed from 2.6 in 1965 to 0.5 in 1980, and regional energy efficiency declined from middle to very low efficiency. According to the development stages, the years were consistent with "the developing period of greenhouse-vegetable horticulture." The planted area of greenhouse vegetables increased from 18 hectares (planted percentage: 0.5%) in 1965 to 121 hectares (6%) in 1980. On the contrary, the planted area of sweet potatoes declined from 1,044 hectares (31%) to 21 hectares (1%), and the planted area of wheat and barley declined from 1,215 hectares (31%) to nine hectares (0.5%) during the period. The calculation of crop combination of Asahi City was resulted in RWP in 1965, RW in 1970 and R in 1975 and 1980.

In the developing period of greenhouse-vegetable horticulture, the production of cucumber, tomato and strawberry spread with plastic greenhouse facilities that equipped heating systems. The number of farmers who owned plastic greenhouses increased from 407 to 739 during the 15 years. From 1971 to 1982, they developed seven large-scale greenhouse estates through subsidies such as Agricultural Structure Improvement Project II, and Asahi Agricultural Cooperative developed united shipment systems to the wholesale markets in the Keihin District. As the result of the efforts, the Government designated Asahi City as a production center of winter-spring cucumber for the Keihin District in 1981. At the period, though the starting salary was 36,000 yen per month for college graduates who were working for Chiba Prefecture in 1971, the selling price of greenhouse cucumber amounted to 1,590 thousand yen per 10a, and the earnings were up to 1,050 thousand yen per 10a (Kaisou Nougyou Kairyou Fukyujo, 1991). Through the wide spread of greenhouse horticulture, the number of farmers who worked as daily employment for construction companies in winter, agricultural off-season, decreased significantly. Besides greenhouse vegetables, the production of sweet potatoes for process in Asahi City declined through the removal of an embargo on the cornstarch produced in the United States, and field vegetables were specialized in western kinds such as parsley and broccoli.

The input-output energy ratio of Asahi City stopped decreasing after 1985. The values indicated 0.5 in 1985, and 0.4 in 1990 and 1995. They were classified into very low efficiency. According to the development stages, these years were consistent with "the stable period of greenhouse-vegetable horticulture." The planted area of greenhouse vegetables increased from 142 hectares (planted percentage: 6%) in 1985 to 179 hectares (9%) in 1995. As contrasted with the decline of wheat, barley and potatoes, the planted area of paddy rice didn't change largely, i.e., it changed from 1,538 hectares (68%) in 1985 to 1,478 hectares (72%) in 1995. The crop combination type of Asahi City was denoted by R after 1985.

In the stable period of greenhouse-vegetables horticulture, the number of farmers who owned plastic greenhouses leveled off at 740 generally. In the period, the farmers introduced new cultivation methods, varieties of vegetables, and agricultural materials such as heat-retaining coating plastics into greenhouse horticulture. The greenhouse horticulture in Asahi City converted into more industrialized one. In the meantime, some of the farmers began to cultivate flowers such as prairie gentian (*Lisianthus Russellianus*) and western orchids in their facilities. Besides greenhouse horticulture, the planted area of paddy rice was kept steadiness because of the adoption of mechanized and labor saving practices through the undertakings for broadening the rice paddy lots in the 1980s.

The input-output energy ratio of Asahi City declined from 3.3 in 1960 to 0.4 in 1995. Through the development of the industrial greenhouse horticulture, the energy efficiency of crop production declined to one eighth. The agriculture of Asahi City has been characterized by greenhouse horticulture since 1980, when the energy efficiency plunged into very low. Greenhouse vegetables, whose sales amounted to five billion yen in 1992, are ranked as the first place in terms of the agricultural economy of Asahi City. Although "R" was applied to the crop combination of Asahi City by the modified Weaver's method, paddy rice is the second place crop, whose sales amounted to 2.2 billion yen in 1992. "Very low efficiency" could be used as one of the indices that shows regional greenhouse horticulture.

Chapter 6

Discussion

6.1 Comparison with previous regional divisions

The spatial patterns extracted from the former examinations of energy efficiency are discussed in this section as compared with the previous studies that mentioned regional divisions in the Kanto Region. The author also focuses on the characteristics of regional agriculture of which he didn't make mention in previous analysis.

From the three scale analyses, the feature of Japanese agriculture in terms of energy efficiency is attributed to the considerable decline of input-output energy ratio. This study attempts to classify the degree of the degradation of energy efficiency into five levels.

Level-1: is the region that maintains high efficiency, and the region that changed from middle to high efficiency.

Level-2: is the region that maintains middle efficiency (this includes Kusatsu Town that changed from low to middle efficiency).

Level-3: is the region that changed from middle to low efficiency (this includes the region that changed from high to low efficiency).

Level-4: is the region that maintains low efficiency.

Level-5: is the region that changed from middle and low to very low efficiency.

The Level-1 regions are located in the eastern part of the Kanto Region, i.e., in the middle eastern part of Ibaraki Prefecture and the northern part of Chiba Prefecture (Figure 12). The regions are active in the production of high and middle efficiency crops, i.e., sweet potatoes, paddy rice, wheat and barley. Although the input-output energy ratio of these crops indicated high values, it is expected that the amount of input fossil fuel energy increased with the widespread of agricultural implements and chemicals in the two decades.

According to the regional divisions by former studies shown in Table 11, the Level-1 regions are included in the Paddy rice, Hog, Vegetable and Sweet Potato District in the Commercial Agriculture Region in the Outer Suburbs by Birukawa (1969)[5], and the Medium regions in terms of the economic land productivity by Yamamoto et al. (1983)[6]. Namely, the production of sweet potato for process and law-shipment is established as a commercial agriculture in the Level-1 regions.

The Level-2 regions lie mainly in the eastern part of the Kanto Region, i.e., in the northern and southern part of Ibaraki Prefecture, the northern part of Tochigi Prefecture, the middle part of Saitama Prefecture, the northern part of Chiba Prefecture and the middle part of the Boso Peninsula. These regions are active in the production of middle efficiency crops, i.e., paddy rice production, and paddy rice, wheat and barley production. As well as the Level-1 regions, though the regional energy efficiency didn't

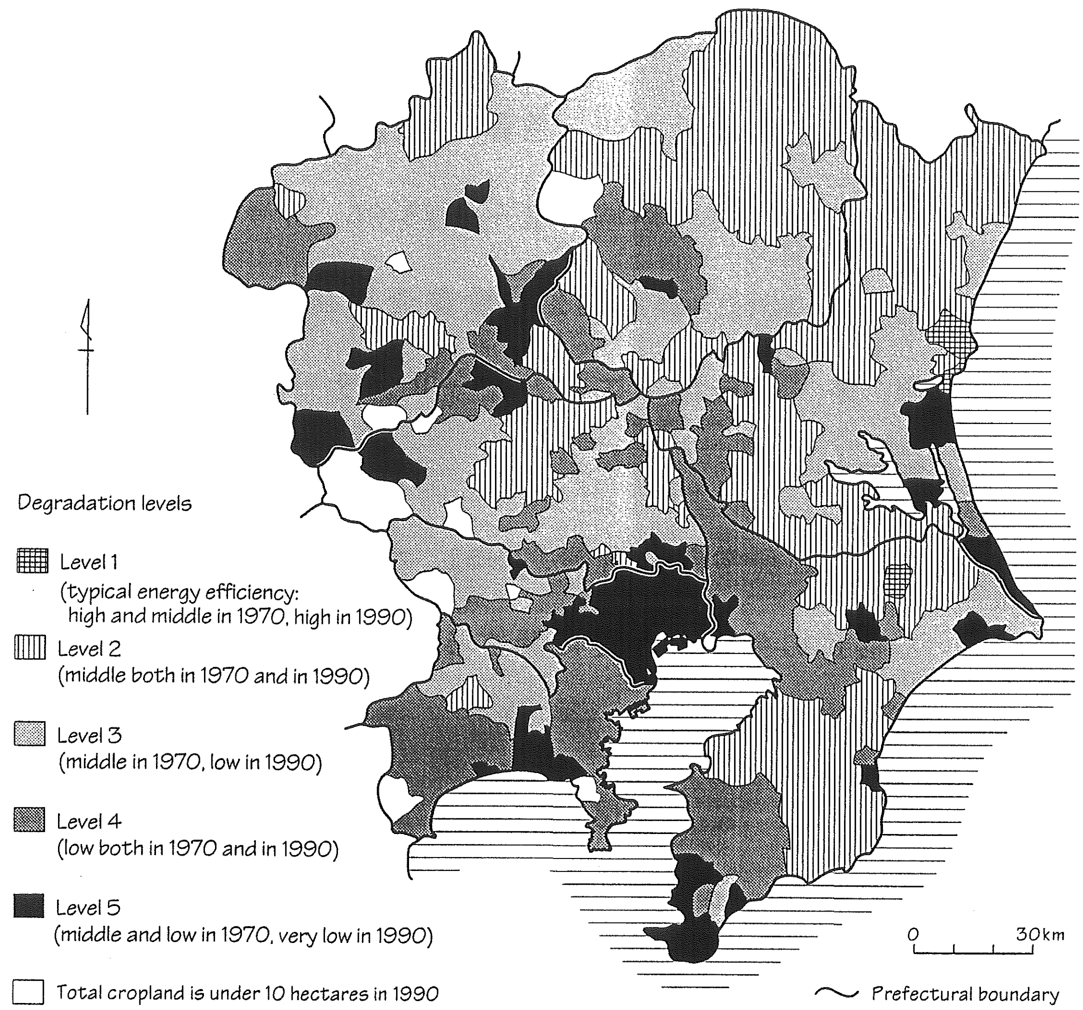


Figure 12. Degradation levels of energy efficiency for crop production in the Kanto Region

Table 11. Comparisons of agricultural regions in the Kanto Region

Name	Tokyo Urban Area (Shirahama, 1964)	Crop Combination (Birukawa, 1969)	Land Productivity (Yamamoto et al., 1983)	Multivariate Analysis (Yamamoto et al., 1988)	Rural Space (Yamamoto et al., 1987)	Energy Efficiency
Method and viewpoint	Historical basis Urbanization Development of transport facilities	Modified Weaver method Coefficient of specialization Primary crop in sales	Economic land productivity Mean values and standard deviation	Factor analysis Cluster analysis	Typology of rural space	Energy efficiency of crop production
Data	Fieldwork on the Keiyo District Census of Agriculture	Statistics Research of Farm Economy Census of Agriculture, etc.	1 km^2 mesh data in the Census of Agriculture	Census of Agriculture	Fieldwork Documentary records, etc.	Input-output Tables Production Cost of Crops Census of Agriculture
Analyzed year	1960	1965 and 1966	1975	1980	1985	From 1970 to 1990
Regional division	Urbanized Area (Extreme) Urbanized Area (Highly) Urbanized Area (Fairly) Urbanized Area (Moderate) Rural (Destructive in Agriculture) Rural (Unstable in Agriculture) Rural (Stable in Agriculture) Rural (Prosperity in Agriculture)	Suburban Agriculture Region Commercial Agriculture Region in the Outer Suburbs Sericulture Region Paddy Rice and Milk Cow Region in the Outer Suburbs Industrial Crop Region in Mountains Track Farming Region in Warm and Cool Temperature	Very High High Medium Low	Civic Center Urban Agriculture Region Suburban Agriculture Region Part-time Paddy Field Region Part-time Agriculture Region Upland and Paddy Field Region Stock Raising Region Paddy Field Region Outer Suburban Agriculture Region Industrial Crop Region Agricultural Inactive Region Track Farming Region	Urban Suburban Outer Suburban Periphery Agriculture Region (Full-time) Agriculture Region (Commercial Agriculture) Agriculture Region (Self-sufficient Agriculture) Depopulated Migrant Region Part-time Tourism Agriculture Region	Level - 5 Level - 4 Level - 3 Level - 2 Level - 1
Spatial pattern	Center and Periphery Cross-shaped	Center and Periphery East and West	Concentric Circles	Concentric Circle East and West	Concentric Circles	Center and Periphery East and West Randomness

change, it is expected that the amount of input fossil fuel energy increased with the wide-use of agricultural chemicals and machines during the period.

According to the regional division by former studies, the Level-2 regions are mostly accordance with the Paddy Field Region by Yamamoto et al. (1988)[7], and are included in the Commercial Agriculture Region in the Outer Suburbs by Birukawa (1969). Main reason for the occupation of the broad area by paddy field is ascribed to the spread of labor saving practice through mechanization and subsidies for broadening rice paddy lots, and to the stagnation of residential development. Many of the farmers in the Paddy Field Region began to work for companies and cultivate rice paddies only. The regions that are not active in agricultural production occupy a large area of the Level-2 regions. However, besides the part-time paddy rice farmers, viable farmings such as the production of Japanese pears, hogs, lotus roots (Tezuka, 1982), and tourist orchards of grapes (Tabayashi et al., 1998) also exist in the Paddy Rice Region.

The Level-3 regions are located in the mountainous area of Tokyo and in middle part of Kanagawa Prefecture, and spreads throughout the Kanto Region except for the Level-2 regions. The regions indicate high values of planted percentage in paddy rice, wheat, barley and field vegetables. Main reason for the decline of the energy efficiency is ascribed to the increase of field vegetable production in urban and suburban, and to the increase of greenhouse vegetables in the outer suburbs.

With reference to the regional division by former studies, the Level-3 regions are consistent with the Outer Suburban and the Depopulated Migrant Region by Yamamoto et al. (1987)[8]. In the former region, though sericulture and industrial crop production such as leaf tobaccos and konjack bulbs are active, there are many opportunities for the farmers to engage in unstable wage labor such as part-time construction workers. The latter region includes many depopulated municipalities because of the outflow of the youth. Especially in the mountainous regions, although charcoal making and forestation were flourishing until in the 1960s, the industry based on timber resources such as *shiitake* and *nameko* mushroom production doesn't bring them high earnings as compared with the charcoal production before the energy revolution. It is difficult to comprehend the general characteristics of the Level-3 regions since it covers an extensive area, however, the examples give us an estimation that the regions include a great number of inactive region in agriculture.

The Level-4 regions are sited in a large part of Kanagawa Prefecture, in the northwestern part of Chiba Prefecture, and field vegetable production centers in the outer suburbs. Although the energy efficiency of the municipalities categorized in this level didn't change from 1970 to 1990, it is considered that the regions include a large number of municipalities whose energy efficiency had declined before 1970, such as the production centers of field vegetables.

According to regional divisions by former studies, the Level-4 regions are consistent with the agricultural regions in urban and suburban, such as the Urbanized Area by Shirahama (1964)[9], the Suburban Agriculture Region by Birukawa (1969), the Urban and Suburban Agriculture Regions by Yamamoto et al. (1988) and the Urban and the Suburban by Yamamoto et al. (1987). The amount of vegetable supply from urban and suburban decreased under the influence of urbanization after the 1960s, though the production of field vegetables increased in truck farming regions (Shirahama, 1964). Many of the farmers in urban and suburban converted their cropland into apartments, parking lots, sports facilities, etc. (Birukawa et al., 1967: Saito and Kanno, 1990). Extant croplands are utilized for labor intensive practice such as the production of cut-flowers, foliage plants and blanching vegetables. Besides the urban and suburban, the Level-4 regions in the outer suburbs are also active in horticulture such as field vegetables and fruits. These municipalities are mainly consistent with the Very High and High regions in the economic land productivity by Yamamoto et al. (1983).

The Level-5 regions are placed in and around the 23-Wards of Tokyo, and scatters throughout the outer suburbs. The planted percentage of crops in the regions shows high values in field and greenhouse vegetables. The Level-5 regions located in the outer suburbs include the municipalities whose energy efficiency declined by the increase of greenhouse facilities, and also the municipalities whose energy efficiency declined by the decrease of cropland.

With reference to regional divisions by former studies, the Level-5 regions in and around the 23-Wards of Tokyo constitute the center of the agricultural regions in urban and suburban. Most intensive field vegetable cultivation such as eight-crop rotation of un-matured vegetables such as *tsumamina* is practiced in the area. The greenhouse crop production centers in the outer suburbs are consisted with the Very High and High regions in the economic land productivity by Yamamoto et al. (1983), and the Outer Suburban Agriculture Region by Yamamoto et al. (1988). However, the Level-5 regions in the mountainous area of Gunma and Saitama Prefectures correspond with the municipalities being on the decline in agricultural production, such as the Depopulated Migrant Region described by Yamamoto et al. (1987).

As these descriptions mentioned, the spatial pattern that emphasizes "center and periphery" and "east and west" appears in the Kanto Region in terms of the energy efficiency of crop production. That is to say the Level-4 and Level-5 regions in urban and suburban consist of the former pattern, and the Level-2 and Level-3 regions in the outer suburbs consist of the latter pattern. However, an irregular figure also appears considering the distribution of Level-5 regions in the outer suburbs.

6.2 A decline in energy efficiency with the development of modern agriculture

Since few studies tried to examine the characteristics of agricultural regions in terms of energy efficiency, the author gives an explanation of the decline in the energy efficiency of crop production in the Kanto Region in the context of food production, fossil fuel consumption, ecology and economy. Prospects of energy efficiency for future studies are also presented in the last paragraph.

The input-output energy ratio of the Kanto Region declined from 1.8 in 1970 to 1.1 in 1990. In other words, the energy efficiency of crop production in the region changed from middle to low. The degradation of energy efficiency can be attributed to a change in the planted area, since the input-output energy ratio of crop production unit didn't change by a great extent. The whole cropland in the Kanto Region decreased from 770 to 501 thousand hectares. Although the planted area of beans and greenhouse vegetables increased more than twice, the planted area of the other five groups decreased during the two decades. Especially, the planted area of potatoes, fruits, wheat and barely decreased as half as those of in 1970. With reference to Table 12, the decrease of 141 thousand hectares in paddy rice and 133 thousand hectares in wheat and barely were related to the fact that a great number of middle efficiency municipalities in 1970 changed into low efficiency in 1990. Still more, the increase of seven thousand

Table 12. Planted area of crops in the Kanto Region

(1,000 ha)

Year	Potatoes	Paddy rice	Wheat, barley, other grain	Beans	Fruits	Field vegetables	Greenhouse vegetables	Total
1970	32	414	213	15	22	105	2	770
1990	16	273	80	31	10	82	9	501

Data source: The Ministry of Agriculture and Forestry (1971), The Ministry of Agriculture, Forestry and Fisheries (1991).

hectares in greenhouse vegetables was related to the emergence of very low efficiency municipalities in 1990. The planted percentage of greenhouse vegetables occupied only 1.8 percent of all cropland in the Kanto Region. However, since the input fossil fuel energy of greenhouse vegetables is 20 to 110 times as large as those of other crops, the development of greenhouse facility results in a sharp decline of the regional energy efficiency.

With the decline of regional energy efficiency, the whole input fossil fuel energy in crop production of the Kanto Region increased from 263TJ ($1TJ=10\times10^{12}J$) in 1970 to 319TJ in 1990. The increase of input fossil fuel energy, which is used to control natural growth of plants and to modify natural components of soil, means the reinforcement its impact on the environment. The fossil fuel energy fixed in agricultural materials such as chemical fertilizers, pesticides, herbicides and fossil fuel for machines diminish microbes in the soil. This process will result in "death of soil" from the point of view ecology. Within the conduct of modern agriculture, we use more chemical substances that include fossil fuel energy in order to restore the condition of soil (Hattori, 1972). The "cycle" that makes a great impact on the natural environment supports the industrial agriculture nowadays, and a great amount of fossil fuel energy may support the cycle.

Low input practice of agriculture in terms of energy efficiency is to reduce the use of agricultural materials containing high energy intensity, such as fossil fuel for agricultural implements. This way of thinking should be applied especially to the greenhouse vegetable production, which requires a huge amount of fossil fuel energy. It is conjectured that the fossil fuel energy used in greenhouse vegetable production in the Kanto Region amounted to 149TJ in 1990. This occupied about 47 percent of all the input fossil fuel energy of crop production in the region. When other materials whose energy intensity is considerably lower than fossil fuel are taken into account, it had better adopt other indices, e.g., chemical composition of pesticide and herbicide.

The amount of output food energy could be used as another index to examine the value of crop production. Although the planted area of field vegetables has remained roughly constant, the planted area of paddy rice, wheat, barely and potatoes, which yield high food energy, has decreased over two decades. Assuming that a person requires 10MJ food energy per day, all crops harvested in the Kanto Region in 1970 could have supported 13 million persons for one year, however, this number fell to nine million in 1990. Consequently, the crop production in the Kanto Region has also degraded in terms of output food energy. Food energy is supplied not only from crop production but also stock farming and fishery, however, the degree of calorific self-sufficiency in Japan fell from 53 percent in 1970 to 47 percent in 1990 (The Ministry of Agriculture, Forestry and Fisheries 1992e).

Apart from producing calorific value, producing vitamins and protein may be advantageous for modern farming in the Japanese socioeconomic context. Greenhouse horticulture, which recently increased in planted area, is probably the best method of obtaining such benefits. Freshness is the market value of the crops produced in greenhouses, and these crops usually contain a little food energy per weight. Even being produced in winter, greenhouse crops can produce equal or higher food energy per planted area than grain on account of the large amount of input fossil fuel energy. The winter vegetables produced in greenhouses by burning fossil fuel are probably the most "expensive" in terms of their ecological impact. Although this is an extreme example quoted by Soussan (1992), it takes 2,200kcal of energy to produce 1kcal "diet" soft drink. The winter vegetables produced under the controlled temperature of greenhouse facilities may compare to the diet drinks sold by automatic vending machines.

An increase in greenhouse horticulture after the 1970s has the relevance of agricultural structure of Japan, i.e., the enlargement of subsidies for horticultural management, the reinforcement of set aside program for paddy rice, and the increase of imported crops such as wheat and barley. However, it is probably due to the high economic return that such cultivation entails for farmers. A case study of greenhouse horticulture in Asahi City showed that cucumber production in greenhouses produced sales of four million yen per 10a, which was about 28 times larger than that of the paddy rice production. The horticultural farmers owned only 50a upland field in average. The introduction of winter vegetable with plastic green-house and heating systems was the best selection of the farmers who had to utilize the small lots to carry the farm and family budget. To maintain the intensive crop production, farmers introduced new technology one after another from nursery companies, material sellers and agricultural co-operatives, and their management depends greatly on agro-companies outside the farm (Nihei, 1998).

The case of Asahi City showed a fact that a considerable number of horticultural farmers converted their crops from vegetables into flowers after the late 1980s. It is expected that the regional energy efficiency decreased through the spread of zero-output farming among the little-output farming. This study doesn't take into account the zero-output farming such as floriculture and pasture land, and it assumes that all crops are consumed directly by people. The evaluation of zero-output crops and the energy efficiency of animal husbandry will be ground for future work. Still more, though this study pays attention to the crop systems, it needs to expand the attention to the food chain that includes production, processing, shipment and consumption of agricultural products. For example, though they produce a lot of sweet potatoes in Hitachinaka City, they require a large amount of fossil fuel and labor in food processing. Although wheat is classified into middle efficiency crop in this study, the one imported from the United

States might be as good as domestic vegetables in terms of energy efficiency with taking account of the fossil fuel energy used in shipment. Needless to say, the results of this study do not suggest that only potatoes and grain should be cultivated. However, it is of some use to know the energetic value of crop production to seek the best utilization of fossil fuel energy.

Chapter 7

Conclusion

One of the fundamental purposes of agriculture is to produce food and other materials by utilizing solar energy efficiently. However, because of the usage of chemical fertilizer, pesticide and other industrial products, capital intensive agriculture often results in inefficiencies from the point of view ecology and energy balance. In fact, the fossil fuel energy fixed in the industrial products diminished the energy efficiency of agriculture. Examining agricultural efficiency in terms of the energy balance is a first step in practicing low-input sustainable agriculture, which will eventually provide aid in finding a solution to environmental problems such as the exploitation of natural resources. This study demonstrates a method of calculating the input-output energy ratio for crop production, and examines the changes in the energy efficiency of regional crop production based on the data of recent Japan and the Kanto Region.

Input-output energy ratio, which is calculated by input fossil fuel energy and output food energy, has been used as an index to explain the efficiency of agriculture. This study contrives a simplified method by means of input-output analysis and process analysis, and calculates the input-output energy ratio for 32 crops every five years from 1970 to 1990. The requisite statistics for the calculation are the *"Yearbook of Production,* *Supply and Demand of Petroleum, Coal and Coke,*" "*Linked Input-output Tables*" and "*Production Cost Crops*." The results of the calculation show that the energy efficiency of Japanese crop production is classified into four degrees, i.e., high efficiency crops (potatoes: the average input-output energy ratio is from 6.8 to 9.1), middle efficiency crops (grain and beans: 1.7-3.9), low efficiency crops (fruits and field vegetables: 0.6-1.1) and very low efficiency crops (greenhouse vegetables: 0.04).

The regional energy efficiency of crop production varies in accordance with the amount of input fossil fuel energy and the kinds of crops. This study creates a standard of regional energy efficiency by examining the typical combination of crops. As a result, the regional energy efficiency is also classified into four grades, i.e., (a) the high efficiency region that is represented by paddy rice, wheat and potato production (regional input-output energy ratio in 1990: more than 2.7); (b) the middle efficiency region that is represented by paddy rice and wheat production (1.6-2.6); (c) the low efficiency region that is represented by paddy rice and field vegetable production (0.6-1.5); (d) very low efficiency region that is represented by field and greenhouse vegetable production (under 0.5). The classification is used to examine the regional energy efficiency of prefectures in Japan and the municipalities in the Kanto Region.

The energy efficiency of crop production in Japan changed from middle efficiency (input-output energy ratio: 2.0) in 1970 to low efficiency

(1.2) in 1990. With regard to the cropland unit, average input-output energy ratio did not change significantly in the two decades. The decline of the energy efficiency can therefore be attributed to a conversion in the crops planted and not to an increase in fossil fuel energy fixed in the agricultural materials. The primary cause of this decline is due to an increase of 40 thousand hectares in the planted area of greenhouse crops, whose input-output energy ratio is 0.02-0.04. The secondary cause is in the decline by one million hectares in the planted area of paddy rice, whose input-output energy ratio is 2.5-3.1. The energy efficiency of crop production declined especially in the prefectures which have high percentage of fruits, field vegetabels and greenhouse crops, i.e., Tokyo, Yamanashi, Shizuoka, Osaka, Kochi, Kumamoto and Okinawa.

The regional pattern of the Kanto Region in 1970 is characterized by low efficiency municipalities sited in urban and suburban (regional input-output energy ratio: 0.6-1.6), middle efficiency municipalities extending in the outer suburbs (1.7-2.6), and low efficiency municipalities dispersing in the outer suburbs. Middle efficiency municipalities indicate high values in paddy rice, wheat and barley production, and low efficiency municipalities show high values in paddy rice and field vegetable production. The low efficiency municipalities in the outer suburbs are consistent with the intensive crop production centers of field vegetables and fruits.

The regional pattern of the Kanto Region in 1990 is characterized by very low efficiency (regional input-output energy ratio: under 0.5) and low efficiency (0.6-1.5) municipalities in urban and suburban, middle efficiency (1.6-2.6) and low efficiency municipalities extending in the outer suburbs, and very low efficiency municipalities dispersing in the outer suburbs. Middle efficiency municipalities indicate high values in paddy rice, wheat and barley production, low efficiency municipalities have high values in paddy rice and field vegetables production, and very low efficiency municipalities show high values in field and greenhouse vegetables production. The very low efficiency municipalities in the outer suburbs are consistent with the crop production centers of greenhouse vegetables and also with the mountainous regions whose cropland is decreasing.

The municipalities of the Kanto Region are classified into five levels in reference to the degradation degree of energy efficiency, i.e., Level-1 (the region that maintains high efficiency, and the region that changed from middle to high efficiency), Level-2 (the region that maintains middle efficiency), Level-3 (the region that changed from high and middle to low efficiency), Level-4 (the region that maintains low efficiency) and Level-5 (the region that changed from middle and low to very low efficiency). Through this classification, the spatial pattern that emphasizes "center and periphery" and "east and west" appears in the Kanto Region. Namely, the Level-4 and Level-5 regions in urban and suburban consist of the former, and the Level-2 and Level-3 regions in the outer suburbs consist of the latter. However, an irregular figure can be also seen considering the distribution of Level-5 regions in the outer suburbs. The Level-5 regions in the outer suburbs include the municipalities whose energy efficiency declined by the increase of greenhouse facilities and the decrease of cropland. Both of the municipalities may be placed as the degradation regions in terms of agricultural energy efficiency. These results also suggest that the aspect of the energy efficiency can be used as a general index to examine the regional characteristics of agriculture as it contains the aspect of ecology and economy.

The input-output energy ratio of crop production in the Kanto Region declined from 1.8 in 1970 to 1.1 in 1990. This decline is attributed to a conversion of crops. About half of the middle efficiency municipalities that had occupied a broad area in 1970 changed into low efficiency municipalities in 1990. The cause of the change is ascribed to the decrease of 274 thousand hectares in paddy rice and wheat production, which produce a considerable amount of output food energy (4-8GJ/10a). Furthermore, the emergence of very low municipalities in 1990 is related to the increase of seven thousand hectares in greenhouse vegetable production, which demands a great amount of input fossil fuel energy (12-22GJ/10a).

The results presented also imply that agriculture in Japan has increased its impact on the natural environment through an increased use of fossil fuel energy. The fossil fuel energy fixed in agricultural materials such as chemical fertilizers, pesticides, herbicides and fuel oil for agricultural machines modifies natural components of soil. We use a large amount of chemical substances that contain fossil fuel energy to restore the condition, and this cycle, which increases an impact on the environment, may support the agriculture of industrial counties.

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Tsukuba City,

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Notes

1) Not only agricultural studies, but also a great number of other disciplines that concerned with fossil fuel energy were published in the 1970s and 1980s. Besides *Scientific American* had a special issues for energy (Starr, 1971), interesting subjects were accumulated, e.g., a correlation between economic development and input energy (Costanza, 1980), suggestions for energy policy and food policy (Slesser, 1973: Baughman and Hnyilicza, 1975), estimation of fossil fuel energy use by means of input-output analysis (Cater, 1974), a dilemma between energy saving and time saving (Weinberg, 1977), seed oil as a substitute for fossil fuel energy (Stewart et al., 1981). After these studies, subjects on energy use in global scale attracted geographers, e.g., food production and consumption of the world (Grigg, 1985), energy use and the greenhouse effect (Nakicenovic, et al., 1998).

2) A typical study of process analysis conducted by Chapman (1975) examined the energy use in nuclear power stations. The result of the study shows that the input-output energy ratio for nuclear reactors varies from 10.2 to 16.5 on the assumption that these would be operated for 25 years. Taking account of payback time, it needs 1.2 to 2.4 years to produce the same amount of the energy that is used in the construction of a nuclear power station. Besides this example, a calculation of input-output energy ratio of crop production by means of process analysis was first conducted by Resources Council, Science and Technology Agency, Japan (1979). Although the study counted 12 sections of production cost except for labor in the *Production Cost of Crops*, this study excludes seven sections of production cost because of the vagueness in

their definition for the input energy of crop systems. It is assumed that this exclusions will prevent the overestimation of energy use in crop production.

3) Sugarcane and pineapples are known as special agricultural products of Okinawa Prefecture. This study excludes the planted area of sugarcane because of the vagueness of energy use for the production, and includes pineapples into the category of other fruit. If the calculation includes the energy balance of sugarcane, the input-output energy ratio of Okinawa Prefecture will become a much higher value (cf., Hudson, 1975). According to the *World Census of Agriculture and Forestry, 1970*, the planted area of sugarcane was 28,929 hectares (the number of the farm: 47,080), and the planted area of pineapples was 2,878 hectares (4,136). The planted area of pady rice was 2,945 hectares, about one tenth as large as the sugarcane's planted area. According to the *World Census of Agriculture and Forestry, 1990*, the planted area of sugarcane was 17,987 hectares (23,990), and the planted area of pineapples was 1,416 hectares (1,038). These values were about as half as those of 1970. The planted area of paddy rice was 674 hectares, about one fourth as large as that of 1970.

4) The crop combination types by means of the modified Weaver's method are calculated with a variance formula, and the variables are given by planted percentage or planted area of crops. Although the percentage of primary crops determines the combination, the range of the values varies in response to the numbers of crops. In a case of seven crops as this study tried, the planted percentage of the primary crop takes 71 percent for the sufficient condition of single-crop combination, and 56 percent for the necessary condition of single crop-combination. However, it is difficult to explain the range of the values if

more than one crop determines the combination. These procedures were practiced by the calculation tables devised by Doi (1970), however, we can calculate the types of crop combination swiftly by using the spreadsheet programs of personal computers. One of the latest study employing the modified Weaver method was performed by Saito et al. (2000). They analyzed the crop combination types in Kansas from 1964 to 1997 with reference to the Weaver's results in the Middle West from 1919 to 1949 (cf., Weaver, 1654a, b). Their results insist the emergence of irrigation crops such as corn and alfalfa in the single crop region of wheat in the High Plains.

5) Birukawa (1969) defined the regional divisions of agriculture in the Kanto Region by means of the modified Weaver method, coefficient of specialization and primary sales of crops. He divided the agricultural regions into seven categories, and 18 sub-categories. He insisted the patterns that emphasized "center and periphery" and "east and west." The Commercial Agriculture Region in the Outer Suburbs is the category that was located broadly in the eastern part of the Kanto Region.

6) Yamamoto et al. (1986) classified the economic land productivity of agriculture in the Kanto Region. They presented a pattern that emphasized "concentric circles" based on the classification. The Medium regions were located in 60 to 80 km from the civic center of Tokyo.

7) Yamamoto et al. (1988) classified the municipalities in the Kanto Region into 12 categories by means of factor analysis and cluster analysis. They insisted the patterns that emphasized "concentric circle" and "east and west." The Paddy Field Region was located from the northern part of Tochigi Prefecture to the southern part of Ibaraki Prefecture, and the Boso Peninsula in Chiba

Prefecture.

8) Yamamoto et al. (1987) explained the regional divisions of agriculture in the Kanto Region with reference to the data from their fieldwork and documentary records. They insisted the pattern that emphasized "concentric circles." The Periphery and the Depopulated Migrant Region by their classification were located in the outer part of the Kanto Region.

9) Shirahama (1964) referred the data from his fieldwork on the Keiyo District, and promulgated the patterns "center and periphery" and "cross-shaped." The latter was based on the development of transportation facilities in the early 1960s. He also classified the degree of urbanization into eight categories depending on the usage of farmland.

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