Development of the analytical model for farm management to decrease red soil runoff in Ishigaki Island

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1. Introduction

1.1 Preventing red soil runoff mainly with companion cropping at sugarcane fields in Ishigaki Island

Ishigaki Island with about 223km^2 in area and a population of approximately 43,000 is located at the west end of Japan. Its residents make a living predominantly from agriculture and tourism. On Ishigaki Island, red soil runoff induced by sugarcane growing has become a serious problem, so it is necessary to develop a solution to the problem as soon as possible. So far, they have adopted hard measures, such as gradient modification of firm lands, green belt, underdrain, grit chambers, and infiltration ponds, as well as soft measures, for example covering the section of sugarcane with vegetation. These methods, however, have been difficult to be carried out because of their high costs, and it is not easy to convince the farmers. Because of this, it is necessary to offer alternatives which are practical for the farmers. Recently, as a soft measure, furrow planting in sugarcane fields has attracted attention due to the additional revenue from sales of the vegetables such as pumpkin cultivated at furrows of sugarcane fields. It is well-known that the ridge surface of sugarcane fields is eroded by rainwater, then red soil drains through furrows from sugarcane fields into roads. Therefore, covering this ridge surface as completely with vegetation as possible is anticipated to protect it from raindrop erosion leading to the red soil runoff mentioned above. On the other hand, carrying out these soft measures in an effective manner requires cooperation from farmers and must be feasible in terms of farm management. To meet these conditions, it is essential to investigate the revenue and expenditure associated with companion cropping of vegetables and then to adopt an appropriate size of companion cropping so that a farmer can have a surplus.

1.2 Objectives

The ultimate purpose of this study is to establish the analysis model for an environmental management at watershed which can economically assess long-term farm management and also prevent red soil runoff. To accomplish this purpose, first of all, the model for a farmer's technical capability and willingness to cooperate is developed. Then, the analytical model for farm management is provided to figure out the real extent of their cooperation related to the analysis of farm management by farmers. Finally, this model is used for estimating the scale number of farms able to have a surplus from companion cropping of pumpkin from equal analysis.

2. The analysis model for an environmental management at watershed in Ishigaki Island

2.1 Overview of the analysis model for an environmental management at watershed

Figure 1 shows the entire picture of the analytical model for an environmental management at watershed in Ishigaki Island. The red soil runoff that has been a growing problem on Ishigaki Island is supposed to be improved by developing this model, which is appreciated with the reduction rate of red soil runoff. The reduction rate is calculated by two functions: the achievement of public projects and the

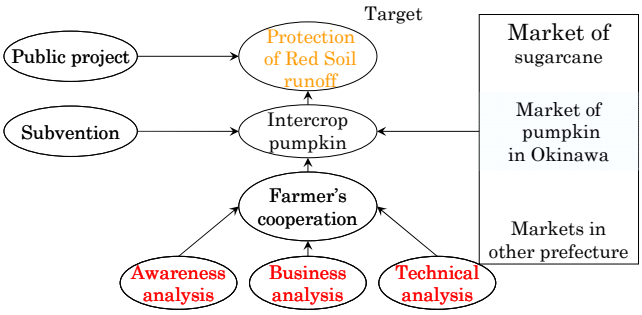

Fig.1 Overview of the analysis model for management of a regional environment in Ishigaki Island

proportion of introducing companion cropping into sugarcane fields. As for the achievement of public projects, we do not discuss it here since it should be addressed by the autonomous community. Therefore, we will talk about the proportion of introducing companion cropping into sugarcane fields. Before a farmer introduces the companion cropping into the sugarcane fields, three points should be mainly considered: whether it is appropriate for the farm management (business analysis), whether the owner will introduce it into his or her fields (attitude survey), and whether the owner has enough skills of companion cropping (technical issue). These three points affects the possibility for introduction of companion cropping whereby the proportion of companion cropping into sugarcane fields is worked out. For the business analysis, the market situation of sugarcane and vegetable is surveyed. Since the income of a farmer is affected by the market situation, the farmer would make a decision about the introduction of the companion cropping based on it. Taking into account the factors mentioned above, increasing the rate of the companion cropping would require the stability of the farm management and the raise of a market price of relevant vegetables by stimulating the demand for them with new businesses.

2.2 The procedure to assess the analysis model for an environmental management at watershed

Figure 2 shows the procedure to assess the analysis model for an environmental management at watershed. First of all, the vegetable to be interplanted at furrows of sugarcane fields (currently sugarcane is planted just in summer season) and its farming method are considered. Then, the farmer's attitude and technical capability for the companion cropping are quantified by a questionnaire survey. In addition, the demand curve for the related vegetables is plotted based on the information about the wholesale trade in vegetable market. Considering the area for the companion cropping, the balance between total revenue and expenditure in introducing the companion cropping is obtained by combining the information from the farmer's

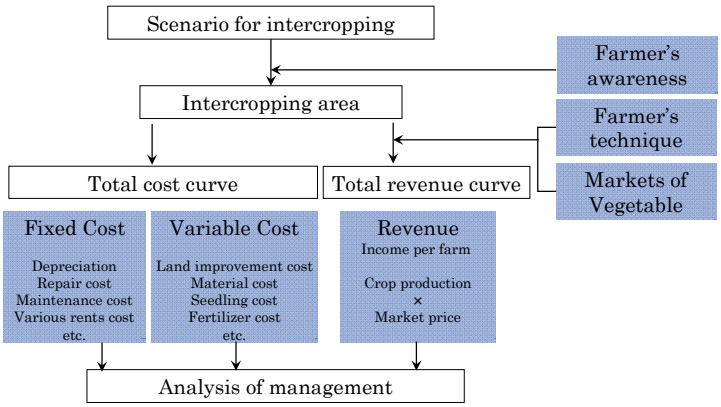

Fig. 2 Examination procedure of the analysis model for an environmental management at watershed

attitude, the technical capability, and the demand curve. The feasibility of the companion cropping at a sugarcane field is estimated in terms of the management by studying the balance.

3. The development of the analysis model for a farm management introducing the companion cropping of pumpkin

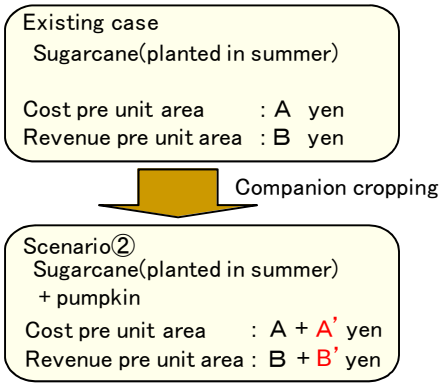

Fig. 3 Scenario for examination (sugarcane, summer + companion cropping of pumpkin)

The resources for management include ① financial resources, ② human resources, ③ physical resources, etc. The effective combination of these resources is evaluated as an environmental effect. The impact of the companion cropping of pumpkin on environment conservation is yielded by the combination of the introduction of the companion cropping of pumpkin (financial resource), the labor required for the companion cropping of pumpkin (human resources), and effects of environmental integrity resulting from prevention of red soil

runoff. Therefore, the companion cropping of pumpkin to reduce red soil runoff would be reasonable from the standpoint of management. In this study, we address the case of introducing the companion cropping of pumpkin into the furrows of a sugarcane field (sugarcane is cultivated only in summer) (see Fig.3).

In this case, since planting pumpkin at the furrows of a sugarcane field does not interfere with the cultivation of sugarcane, the income from pumpkin (B' yen) would be added simply to the income from sugarcane (B yen). Because of this, in the case of the companion cropping of sugarcane (summer planting) + pumpkin, the management analysis for only the area of pumpkin would be sufficient for making a decision on the introduction of the companion cropping.

3.1 The procedure to assess the analysis model for a farm management introducing the companion cropping of pumpkin

Figure 4 shows the procedure to assess the analysis model for a farm management introducing the companion cropping of pumpkin. To begin with, the number of farmers according to the size of farm is obtained from "Statistic of Ishigaki", a statistical data about Ishigaki city, to set the parameter of the farmer's attitude according to the size of farm and estimate the area for companion cropping. The price of pumpkin in the Tokyo market is determined, then the proportion of introducing companion cropping according to the size of farm is calculated based on the price. The area for companion cropping and the technical coefficient are established. They are used for estimation of all pumpkin production, and then the market value corresponding to the pumpkin production is presumed. As the next step, the production cost and the revenue per farm according to the size of farm are estimated from the cost function (fixed and variable costs), and the technical coefficient and the estimated market price, respectively. In each size of farm, the estimated income is compared with the estimated cost; companion cropping is not introduced if the estimated income is less than the estimated cost;

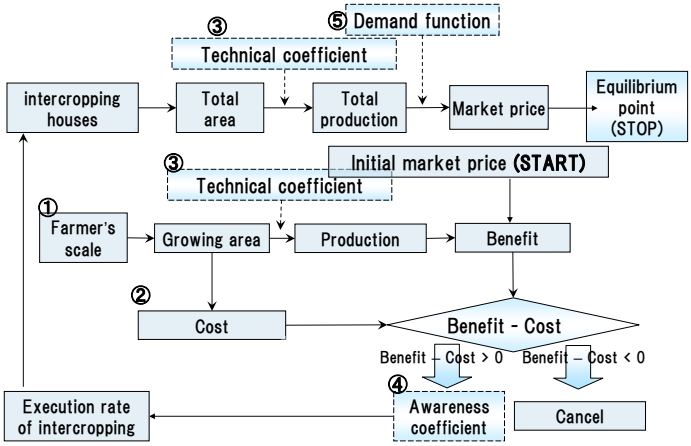

Fig. 4 Examination procedure of the analysis of farm management through companion cropping (pumpkin)

if the estimated income is higher than the estimated cost, the parameter of the farmer's attitude depending on the profit is calculated. Then, the factual proportion of introducing companion cropping is investigated, and the factual production according to the size of farm and the factual market price corresponding to it is recalculated. Repeating this procedure finally leads to the condition that the estimated market price gives close agreement with the factual one. This condition would provide the predicted values reasonable for farmer management: the predicted area for companion cropping, the predicted number of farmers, and the predicted production.

3.2 The estimation of the cost function, the parameter of a farmer's attitude, and the technical coefficient

In order to estimate the cost function, the parameter of a farmer's attitude, and the technical coefficient, interviews and a questionnaire survey were really conducted on Mr. Masaharu Iridakanishi, Ishigakijima farmer of farming corporation with limited liability; pumpkin growers in Ishigaki island; and sugarcane growers in Ishigaki island. These values were calculated based on the results of the surveys.

(1) The calculation of the cost function

The cost function represents the expenditure to introduce the companion cropping of

pumpkin. In this study, the items such as the working hours, equipment and so on were asked according to each step to grow pumpkin. The fixed cost includes land improvement, water, amortization of farm equipment, maintenance and fuel for a car, repair costs, and public dues. On the other hand, the variable cost consists of seedling, fertilizer, agrichemical, spreading material, workforce, and shipment box. These costs were estimated from each category. The interview about the companion cropping of pumpkin was given to five farmers. The items used in the interview are as follows:

a) Work items for cultivation from land improvement to harvest
b) Working hours for each work item
c) Farm equipment used for cultivation
d) The cost for land improvement (including the cost for water facility to improve land)
e) The cost for amortization
f) The cost for repairment and maintenance
g) Rental h) The cost for energy and power
i) The price of seedling per 10a
j) The price of fertilizer per 10a
k) The price of agrichemical per 10a

Figure 5 shows the fixed and variable costs, which were obtained from the interviews, based on the area under crops of pumpkin. To take into account a certain difference between the farmers, 15,933yen was obtained as the average of their fixed cost (the cost for amortization, the cost for repairment and maintenance, and rental). As for the variable cost, the data was linearly approximated, and equation 1 was established.

$y=6254.5x+34167$ ・・・Eq.(1)

y: Variable cost per area under crops (yen), x: Area under crops (a)

Figure 6 shows total cost (the fixed + variable costs) per area under crops of pumpkin. The cost curve of the companion cropping of pumpkin was expressed with linear relation to the area under crops as shown in equation 2.

$y=6254.5x+50100$ ・・・Eq. (2)

y: total cost per area under crops (yen), x: area under crops (a)

(2) The estimation of the parameter of a farmer's attitude

The items used in the interviews to estimate the parameter of a farmer's attitude are as follows. The equation to represent the relation between the proportion of the introduction and the profit was established from the results:

a) Do you introduce the companion cropping of pumpkin into your sugarcane field?
b) How much profit motivates you to introduce the companion cropping of pumpkin?
c) Does the fact that the companion cropping of pumpkin can contribute to protecting coral reef from red soil runoff change your attitude?

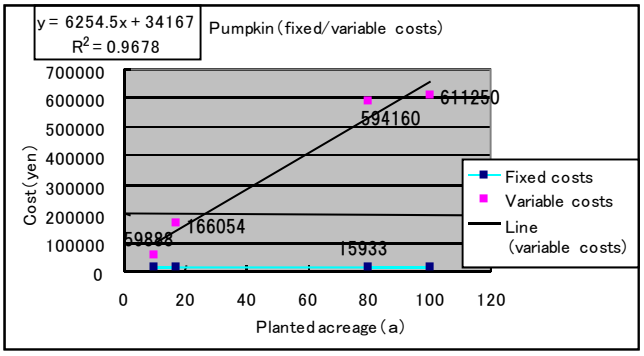

Fig. 5 The fixed and variable cost based on the area under crops of pumpkin.

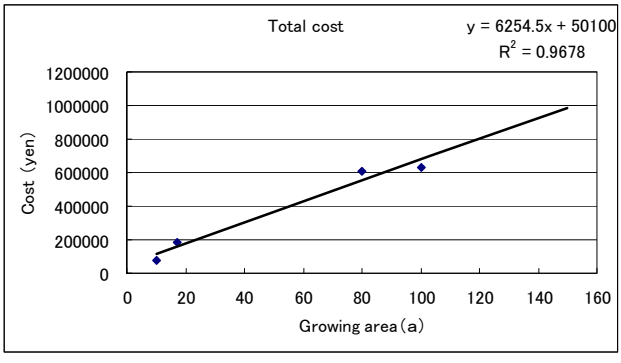

Fig. 6 Total cost per area under crops of pumpkin

Figure 7 shows the results from the attitude survey. The largest population, 44% of the people answered that they would introduce the

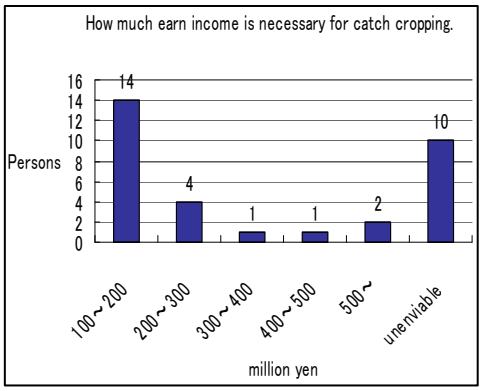

Fig.7 The results from the attitude survey

companion cropping with the profit of from 1 to 2 million yen. On the other hand, ten people answered that they would never introduce it regardless of the profit because they think “it would make their work harder” or “it would not be practical because of the difference of agrichemical between pumpkin and sugarcane.” Figure 8 shows the distribution of household membership by age. According to figure 8, about 59% of the total of 3346 people were 50 years of age or older. Because of this, some gave the reason “they do not have any successor” or “they do not have enough workforce” to introduce companion cropping.

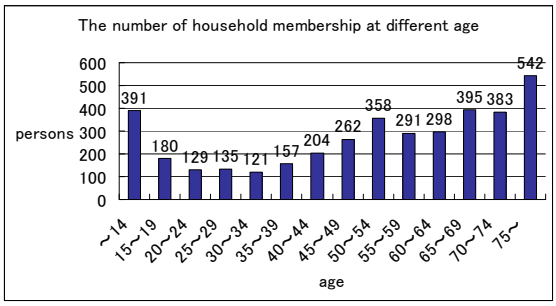

Fig. 8 Number of household members by age

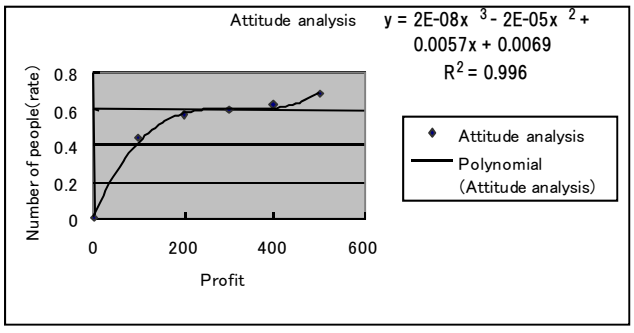

Fig. 9 Results of attitude analysis

Figure 9 shows the results of the attitude survey. In the case of the profit of more than 1 million and less than 2 million yen, the proportion of introducing the companion cropping is 44%; more than 2 million and less than 3 million yen, 56%; more than 3 million and less than 4 million yen, 59%; more than 4 million and less than 5 million yen, 63%; and more than 5 million yen, 69%. The data was approximated with multinominal, and the equation 3 was established (in this study, tertiary expression was used because of low collection rate of questionnaire).

$$y = 2E\text{-}8x^3 - 2E\text{-}0.5x^2 + 0.0057x + 0.0069 \quad \cdots$$

Eq.(3)

y: population (ratio), x: profit

(3) The estimation of the technical coefficient

The production of pumpkin depends largely on farming methods adopted, farming equipment owned, and so forth. According to the result of the technology survey asking five farmers their harvest of pumpkin per 10a, two farmers answered 0.75t, one said 0.8t, one provided 1t, and one gave 1.5t (but it is not exact because 1.5t is just an assumption).

In this study, it is assumed that the harvest per unit area ranges 0.6t/10a to 1.4t/10a. Therefore, the harvest per unit area is presumed as shown in table 1.

Table.1 The estimation of the technical coefficient per unit area

Amount of product per area (ton/10 are)	The number of person (rate)
0.6	0.1
0.8	0.2
1.0	0.4
1.2	0.2
1.4	0.1

3.3 The estimation of revenue function

In order to get total revenue curve, the market situation of pumpkin in Okinawa prefecture was investigated, and the relation

between the production of pumpkin and the market price was analyzed.

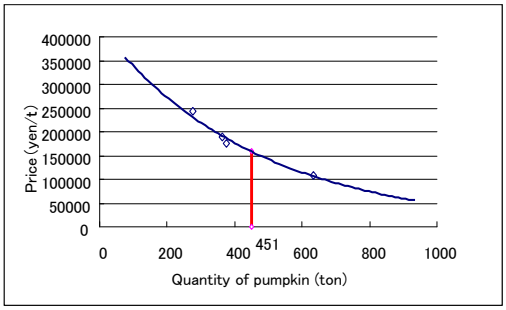

Fig. 10 Relation between market demand and supply of pumpkin produced in Okinawa

In 2004, Okinawa produced pumpkins of 2100t. Among them, pumpkins of 275t (13%) were consumed in Okinawa, and 1522t (72%) were exported to the other prefectures, meaning that the amount of exported pumpkins was relatively larger. On the other hand, in 2004, Okinawa central wholesale market imported pumpkins of 1192t including 397t (33%) from other areas in Japan and 520t (50%) from overseas, meaning that the amount of pumpkins got from overseas has been larger.

According to the relation between the amount of received pumpkins produced in Okinawa and the price per unit amount, as the amount of imported pumpkins increases, the price per unit amount decreases, and the relation is not linear (see fig. 10). The data was approximated exponentially, and the equation 1 was established.

$$y = 419776e^{-0.0022x} \quad \cdots (1)$$

where y: the price per unit amount of imported pumpkin (yen/kg) and x: the amount of imported pumpkin (t). In figure 9, the agreement between demand and supply offers the production of pumpkins of 433t. Figure 9 also indicates that the production more than this agreement leads to reduction of social redundancy.

The demand curve of pumpkin produced in Okinawa was used to get a total revenue curve according to the area for growing pumpkin. Figure 11 shows the total revenue curve per area for growing pumpkin based on the technical coefficient.

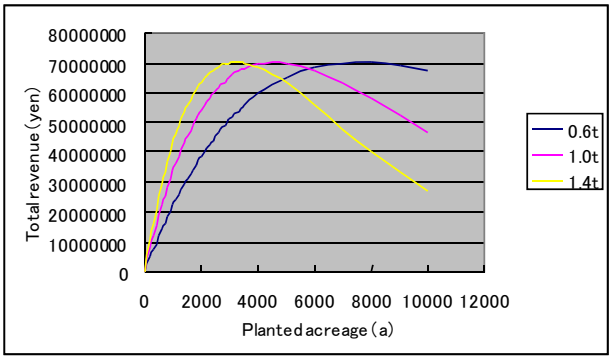

Fig.11 Total revenue curve per area for growing pumpkin based on the technical coefficient

3.4 The number of farmers according to the area for farm management

Table 2 shows the number of farmers in Ishigaki city according to the area for farm management (2004). The majority are 0.5ha～1.0ha and 2.0ha～3.0ha which are 232 and 224 farmers, respectively. The number of farmers possessing less than 1ha is 329 farmers, which is about 26% of the total, and the number of big farmers with more than 10ha is 34 farmers, 3%.

Table 2 Number of farmers according to the area for farm management

	Area size													
	Total	～0.3	0.3～0.5	0.5～1.0	1.0～1.5	1.5～2.0	2.0～3.0	3.0～5.0	5.0～10.	10.0～20.	20.0～30.	30.0～50.	50.0～100.0	100.0ha～
City of Ishigaki	1,284	17	80	232	175	143	224	213	164	27	6	0	3	0

4. The analysis for a farm management introducing the companion cropping of pumpkin

As mentioned above, the cost function, the technical coefficient, the parameter of a farmer's attitude, and the market function were estimated. Then, the area for companion cropping of pumpkin and the number of farmers introducing it, which are reasonable for farm management, were calculated.

Table 3 shows the area for companion cropping of pumpkin and the number of farmers introducing it, which are reasonable for farm management, according to the size of farm.

As the table shows, the number of farmers introducing companion cropping is 155 farmers, the area for companion cropping is 236.80ha,

Table 3 The area for companion cropping of pumpkin and the number of farmers introducing it, which are reasonable for farm management

	Cultivated acreage per farm(a)												
	3	10	17	30	39	57	101	169	349	573	911	1585	2249
Number of farmers introducing companion cropping (farm)	0	0	6	10	11	28	40	48	9	1	0	2	0
Total area for companion cropping (ha)	0	0	1.359	3.238	5.310	16.929	38.704	85.469	35.766	15.297	0	33.734	0
Pumpkin production (t)	0	0	11.469	31.485	48.014	174.291	388.614	866.959	317.098	56.223	0	337.338	0
Profit (10 thousand yen)	0	0	65.098	209.050	337.457	1283.000	2917.880	6673.123	2436.826	420.082	0	2540.534	0

and the total production of pumpkin is 2231.49t. In this case, the market price in Tokyo wholesale market is 138 yen/kg.

It is significant to investigate whether the farmers of Ishigaki Island in real life will act as unsteadily as they do in our assumption. Even if they act steadily, the proportion of introducing companion cropping based on the total area of sugarcane fields is 236.8ha÷667.6ha=35%. Since this proportion is too low, it is important to find some kind of solution such as official support and auxiliary business.

Through the fieldwork in this study, we recognized several problems on introduction of companion cropping of pumpkin; they need to convert to organic cultivation because of the difference of agrichemical between sugarcane and pumpkin; there are not so many farmers having the knowledge about the companion cropping of pumpkin; and so on. Therefore, they may not introduce it even though they make a profit with it. As for local environmental management, it is significant to consider the local management system whereby the management model of this study is accepted actually.

5. Future topic

The analysis model for an environmental management at watershed discussed in this study has not been practical because of limited information and many assumptions. Therefore, it is necessary to consider the following items and try really to apply them to actual places. This will help our analysis model for an environmental management at watershed gain higher credibility.

- To develop the best method to prevent red soil runoff in another case taking into account management
- To quantify a farmer's level of skill and attitude for companion cropping by conducting questionnaire survey
- To estimate the cost function of pumpkin more precisely
  - To define the relation between the size of farm and the variable cost
  - To investigate the laborsaving induced by farm expansion
- To assess the market situation of pumpkin more accurately
  - To research the sales of pumpkin to both the inside and the outside of this prefecture
  - To improve the precision of the demand curve