Contributed paper

Influence of rural socioeconomic characteristics on rice yield damage: A case study using GIS in Motegi-cho and Ichikai-cho, Tochigi

Toshichika IIZUMI*, Kenji ISHIDA**, Shintaro HIRAKO***, and Masakazu NAGAKI****
National Institute for Agro-Environmental Sciences *
National Institute for Rural Engineering **
Department of Agrobiological Resources, Meijo University ***
Graduate School of Life and Environmental Sciences, University of Tsukuba ****

(Received 4 October 2006; in final form 21 May 2007)

Summary

Crop yield variation caused primarily by extreme weather events is a major risk in farm management. Farmers try to reduce yield damage through sufficient cultivation management. The damage can be correlated to the socioeconomic characteristics of rural areas, and such characteristics are represented by indices of labor, land, and capital. Understanding the nature of these relationships is important for the effective planning of agricultural policies. In addition, the understanding would allow a more realistic assessment of the impact of global warming on agricultural production when they are included in assessment models. Thus, an objective of this study was to reveal the qualitative relationship between damage in paddy rice and rural socioeconomic characteristics. The results showed that both the magnitude and interannual variability of damage is comparatively larger in areas with a higher ratio of non-commercial farm households, smaller cultivated paddy land under management, larger abandoned arable fields, lower percentage of young residents, and higher percentage of elderly ones. Such relationships are consistent throughout various topographic conditions. Two hypotheses are suggested to explain the comparative largeness in the magnitude and variability of damage: first, the deterioration of quantity and/or quality in labor resources; second, the lack of willingness to manage cultivations efficiently due to the lower percentage of on-farm income. The hypotheses propose the possibility that commercial farm households succeed in mitigating the damage by applying sufficient labor resources and self-reliant efforts, while elderly farmers fail at effective management due to shortage in resources and/or willingness.

Key Words: Agricultural Census Settlement Card, Agricultural insurance, GIS, Global warming, Yield damage

1. Introduction

Crop yield variability is a major risk in farm management (Nagaki, 1997; Amano, 1999; 2006), and it is mainly caused by natural disasters, i.e., meteorological disasters,

* 3-1-3 Kannondai, Tsukuba, Ibaraki 305-8604, Japan
** 2-1-6 Kannondai, Tsukuba, Ibaraki 305-8609, Japan
*** 1-501 Shiogamaguchi, Tempaku-ku, Nagoya, Aichi 468-8502, Japan
****1-1 Tennodai, Tsukuba, Ibaraki 305-8572, Japan
(Correspondence: iizumit@affrc.go.jp)

plant diseases, and pests (Ray, 1967). Since weather conditions are responsible for pest patterns, they are a serious concern to farmers. Farmers try to reduce damage with cultivation management and the introduction of technology. Therefore, the features of the damage can be correlated to the socioeconomic characteristics of farms and rural areas. The characteristics are represented by the indices relating to labor, land, and capital, e.g., the number and age of workers engaged in farming, the acreage under management, and the incomes of the farm from on-farm and off-farm work.

Understanding these relationships is important for planning effective agricultural policies in a situation in
which elderly farmers account for a high percentage of the total farmers. Elderly farmers, relative to younger ones, are frequently at a disadvantage with regard to their physical ability, and, as a result, they are less efficient. They may be less prepared to fend off natural hazards. Furthermore, a high percentage of elderly farmers in rural areas may also have a reduced quality of management regarding common production infrastructures in the area.

The relationship between damage and socioeconomic characteristics is still unclear, with the exception of findings from case studies of paddy rice damage caused by cool summers in northern Japan (Hasebe, 1999; 2000). Understanding this type of relationship should result in more realistic impact assessments of global warming on agricultural production when aspects of the relationship are factored into assessment models (Iizumi et al., 2006; 2007). Thus, an objective of this study is to reveal the qualitative relationship between yield damage in paddy rice and rural socioeconomic characteristics as a first step to improve a new assessment model.

2. Study area, data, and method

2.1 Study area

The study area includes the towns of Motegi-cho and Ichikai-cho in eastern Tochigi, which is a major source of paddy rice in the Kanto Plain in eastern Japan (Fig. 1a; b). Motegi-cho includes four main areas: Sudo, Nakagawa, Motegi, and Sakagawa. Ichikai-cho has two areas: Kokai and Ichihane (Fig. 1d).

Both towns have almost equal paddy acreage; however, their yields differ significantly. The agricultural statistics of the local government in 1993 show that the paddy acreage and yield are 955 ha and 3.75 t/ha in Motegi-cho, whereas they are 1,180 ha and 4.17 t/ha in Ichikai-cho, respectively. The difference in yield corresponds roughly with that in

![Fig. 1 Location of study area in eastern Japan (a), topography around Tochigi (b) and study area (c), and names of the main areas in Ichikai-cho and Motegi-cho (d). In (b), the solid line and dotted line indicate a prefectural border and a city border, respectively. The shaded area indicates elevation; the black shading is above 1,000 m. In (c), the solid line shows the city border in Tochigi. The shade indicates elevation, and the contour interval is 20 m. In (d), the line represents the rural border, and the shade indicates the main areas in the cities.](image)
damage, thus, the adjacent towns are suitable for the comparison of damage.

The towns have similar economic conditions with considerably different topography. Yasunaga (2003) reports the similarity in distance from the market, non-agricultural employment opportunities, and local agricultural policies. On the other hand, the towns have different topographies (Fig. 1c): Ichihane is on a plain; Kokai is also on a plain with ridge lines running east and west; Sudo and Sakagawa are in the mountains; Nakagawa includes a gorge, uplands, and the Kuji River; and Motegi is in the lowlands.

2.2 Yield damage data

The yield damage data was obtained from the agricultural insurance records, which were provided by the National Agricultural Insurance Association of Japan (NAIA). The insurance is called "mutual relief" and is operated on the basis of the agricultural disaster compensation system (Tsujii, 1986). The records include yield damage that is greater than or equal to 30 percent of the standard yield in all insured paddy plantations. The standard yield is the estimated value based on the assumption of normal weather conditions according to the definition of the Ministry of Agriculture, Forestry, and Fisheries of Japan (MAFF, 1998). The accuracy of the records is confirmed by Iizumi (2005) with regard to the features of yield damage in rural areas. The records cover a five-year, discontinuous period (i.e., 1993, 1995, 1998, 1999, and 2000). The paddy rice yield was heavily damaged by the cool summer of 1993. However, we used the records in 1993 after confirming that the spatial distribution of yield damage was similar to those of other years.

According to the insurance policy, the payout for damage is based on a reduction in production below 70% of the standard. Therefore, the records include no data regarding slight damage that is below 30% of the standard production. Because of this lack of data, the analysis for this study may underestimate the damage. However, since almost all rice farms purchase the insurance provided by the NAIA, the data regarding the planted acreage is quite accurate.

The mean yield damage in the unit area in the rural area $i$ in the year $j$ ($D_{i,j}$ [t/ha]) was given by using the data in the insurance records as follows:

$$D_{i,j} = \frac{1}{n_k} \frac{1}{n_i} \sum_{k=1}^{n_k} \sum_{i=1}^{n_i} TD_{i,j,k,l} A_{i,j,k,l},$$

(1)

where $TD_{i,j,k,l}$ is the damaged production [t] of the paddy plotage $l$ of farm $k$, $A_{i,j,k,l}$ is the damaged acreage [ha] of the plotage $l$ of farm $k$, $n_i$ is the number of damaged paddy plots of farmer $k$, and $n_k$ is the number of farms in the rural area $i$.

We then prepared two indices to categorize the damage: first, $D_{ave,i}$ is the 5-year mean yield damage [t/ha] in the rural area $i$; the index was defined by

$$D_{ave,i} = \frac{1}{n_j} \sum_{j=1}^{n_j} D_{i,j},$$

(2)

where $n_j$ is the number of years (i.e., $n_j = 5$), second, $D_{sd,i}$ is the interannual variability of damage [t/ha] in the rural area $i$; the index was defined as the standard deviation of the $D_{i,j}$ for five years by

$$D_{sd,i} = \left[ \frac{1}{n_j} \sum_{j=1}^{n_j} (D_{i,j} - D_{ave,i})^2 \right]^{\frac{1}{2}}.$$

(3)

2.3 Rural socioeconomic characteristics

The data regarding rural socioeconomic characteristics was obtained from the 2000 Agricultural Census Settlement Card (ACSC) provided by the Association of Agriculture and Forestry Statistics of Japan (AAFS). The ACSC is the minimum unit data of the agricultural census carried out every five years by the MAFF. The ACSC has sufficient accuracy to analyze the city scale (Sato et al., 1998); however, it is insufficient to use as a substitute for a local field survey (Takahashi, 2000). Our study covers two adjacent towns; thus, the ACSC data is sufficiently accurate to support our study.

The ACSC includes two kinds of datasets since 1990, one deals exclusively with commercial farms, and the other, with the composition of commercial and non-commercial farms. Considering the coupling of the ACSC with insurance records, we adopted the latter. Paddy rice is cultivated on both commercial and non-commercial farms. Furthermore, to couple the time period of the ACSC with that of the insurance record, the new dataset was prepared by the temporal linear interpolation using the ACSC 1990, 1995, and 2000. The 5-year mean data was converted and
served for analysis. The primary focus of this study is on the general relationship between damage and rural socioeconomic characteristics. For this reason, we used 5-year mean values. In addition to the above, four terrain variables were also used in the analysis, i.e., plain, basin, mountain, and valley.

Eight variables were selected as the rural socioeconomic characteristics from 86 variables in the ACSC, i.e., (1) ratio of farm households to total households, (2) percentage of farm households with regular workers engaged in farming, (3) ratio of non-commercial farm households to total farm households, (4) per-farm-household cultivated paddy land under management, (5) per-farm-household cultivated paddy land rented from others, (6) per-farm-household abandoned arable field, (7) percentage of population between 15 and 29 years of age, (8) percentage of population 65 years of age or older. These variables were simply screened by two steps. First, the linear regression analyses were conducted between the time-series of socioeconomic variables and that of yield damage during the five years. In particular, the variables whose correlation coefficients are equal or greater than 0.3 were proposed as the next step. Second, the proposed variables were selected manually while rejecting overlapping variables.

2.4 Method

An ArcMap 9 was used for mapping. It was provided commercially by the ESRI. The “shape file ("shp") for the rural areas was used by those in the AAFS. The format of the shape file was converted using software developed by the National Institute for Rural Engineering. The datasets regarding the rural socioeconomic characteristics and yield damage were coupled using a function in the ArcMap 9. In total, 182 rural areas were available in the analysis; however, the two rural areas of Ichihane and Motegi were unavailable. This failure is the result of a mismatch in the rural names between the insurance record and the ACSC.

The spatial features of damage are visually analyzed by mapping. The analyses were conducted on the basis of two kinds of datasets, i.e., the aggregated data by Eq. 2 and the categorized damage patterns. The categorization was conducted as follows: first, the yield damage was divided into nine categories on the basis of the magnitude and interannual variability of damage (Fig. 2). Large circles are used when the magnitude of damage is equal to or greater than the 75 percentile of the $\text{D}_{ave,j}$, whereas small circles are used for a magnitude of damage that is equal to or less than the 25th percentile. Large and small crosses are used in the same manner as the circles; however, they designate the interannual variability of damage. As a result, six damage patterns were obtained. The symbols in Fig. 2 correspond to those in Fig. 5.

A composite analysis was also conducted regarding the rural socioeconomic characteristics for each topography. The comparisons of the composed characteristics were restricted by the topography because no weather data was included in this study. The magnitude and interannual variability of damage are primarily affected by the weather. Local weather conditions generally correlate with the topography. Thus, the difference in the damage can be assumed to be the result of rural socioeconomic conditions by comparing rural areas located in similar topography. For convenience of the display in the bar chart, the rural socioeconomic characteristics were normalized by the following equation:

$$NI_{i,j,k} = \frac{(I_{i,j,k} - \mu_{j})}{\sigma_{i,j}}, \quad (i = 1...8, \ j = 1...4), \quad (4)$$

where $NI_{i,j,k}$ is the $i$th normalized index of rural area $k$ in the topographic area $j$. $I_{i,j,k}$ is the $i$ th original index, $\mu_{j}$ is...
the mean of the \(i\) th index among rural areas of the topography \(j\), and \(\sigma_{i,j}\) is the standard deviation of the \(i\) th index among rural areas in the topography \(j\). \(N_{i,j,k}\) ranges from -2 to 2 as a result of the normalization.

3. Results

3.1 Spatial features of damage

A high standard yield is observed in Kokai, Ichihane, and western Sudo, whereas a low yield is observed in the lowlands of Nakagawa (Fig. 3a). The yield damage is particularly concentrated in Sudo, Nakagawa, and southeastern Sakagawa (Fig. 3b). The damage is inversely correlative with the yield. The distribution of the damage agrees relatively well with the high elevation area. This suggests that the magnitude of the yield damage is basically related to the elevation of the rural area.

There is more acreage planted in western Ichikai-cho and less throughout Motegi-cho (Fig. 3c). The spatial heterogeneity in the planted acreage is expected to result from the topography. The spatial distribution of the damaged acreage agrees with that of the planted acreage. An extensive amount of damaged acreage is concentrated in western Ichihane and Kokai, reflecting the amount of acreage planted (Fig. 3d).

According to the distributions of standard yield and planted acreage, a high standard production is observed in Kokai, Ichihane, and western Sudo. In Ichihane and Kokai, production is attributed to the high yield and the large acreage planted. In Sudo, production is due to the high yield more than to the acreage planted (Fig. 3e). The production damage shows a significantly different distribution from that of the standard production (Fig. 3f).

Heavy damage occurred in Kokai, southwestern Ichihane, Sudo, and part of Nakagawa. The heavy damage is derived from the intensive yield damage in northern Kokai, Sudo, and Nakagawa, whereas it is due to the large damaged acreage in southwestern Ichihane and western Kokai.

3.2 Damage patterns and socioeconomic characteristics

Figure 4 shows the magnitude and interannual variability of damage in four topographies. The result shows that the magnitude and interannual variability vary depending on the topography. The features of damage are characterized as fairly heavier magnitude and smaller interannual variability in the lowland area, both larger magnitude and variability in the basin area, and fairly smaller magnitude and larger variability in the mountain and valley areas. These results support the concept that the features of damage are fundamentally affected by the topography.

Figure 5 shows the distribution of damage patterns. Rural areas with heavy damage, such as Sudo, part of Kokai, and Motegi, tend to have large interannual variability. In contrast, rural areas with small damage, such as Nakagawa, have small variability. The damage pattern is spatially inconsistent, even in the same topography, with the exception that rural areas with both small magnitude and interannual variability are only found in the mountain and valley areas. The result implicitly supports the concept that the socioeconomic characteristics influence the features of damage.

Figure 6a shows the differences in composed rural socioeconomic characteristics between an area with heavier magnitude of damage and that with less in three topographies. The mountain and valley areas were combined as one topographic category because of their similarities in the features of damage. The rural areas were sorted in decreasing order of magnitude of damage, and the rural socioeconomic characteristics were composed by using areas included in the heavier 20% of damage. It corresponds to the averaged rural socioeconomic characteristics in the area with heavier magnitude of damage. The areas included in the lower 20% were used to compose the characteristics in the area with smaller magnitude. Figure 6b was designated in the same manner but for the interannual variability. Since it can be assumed that the local climate is similar among rural areas because of the uniform topographies, the differences in rural socioeconomic characteristics are factors that influence the magnitude (interannual variability) of damage.

The results shown in Fig. 6a agree with those in Fig. 6b. They are inextricably linked with the results in which the rural areas with less (more) damage often have smaller (larger) interannual variability. The magnitude (interannual variability) of damage is heavier (larger) in the area with a higher ratio of non-commercial farm households, smaller cultivated paddy land under management and rented from others, larger abandoned arable fields, a smaller percentage of young residents, and a higher percentage of elderly
Fig. 3 Spatial distributions of the standard yield (a), yield damage (corresponds to $D_{ave}$; b), planted acreage (c), damaged acreage (d), standard production (e), and production damage (f). The presented values are averaged over all paddy rice farms in each rural area.
residents. Such results are consistent in all topographies with exceptions in the ratio of farm households and percentage of farm households with regular workers engaged in farming in mountain and valley areas. The results are discussed in the next section.

4. Discussion

The damage is both larger in magnitude and interannual variability in the area with a lower percentage of young residents, higher percentage of elderly ones, and larger cultivated paddy land under management and rented from others. More damage is also found in areas with a higher ratio of non-commercial farm households and larger abandoned arable fields, especially in the basin, mountain, and valley areas. Such areas correspond to disadvantaged areas. Cultivation management of paddy rice is certainly lighter than that of other crops, such as vegetables. However, the management level frequently deteriorates relative to the aging of farmers. Thus, the first hypothesis suggests that increased damage in magnitude and interannual variability are caused by the deterioration of the quantity and/ or quality of labor resources.

In the lowlands, the magnitude and interannual variability of damage were smaller in areas with larger cultivated paddy land under management and rented from others. In general, the damage is heavier in large-scale management farm households (e.g., Higuchi, 1983). Our

Fig. 4 Magnitude and interannual variability of damage in four topographies. The white bars and numbers indicate the 5-year mean yield damage. The error bars indicate the heaviest and smallest damages during 5 years (roughly corresponds to interannual variability of damage).

Fig. 5 Spatial distribution of the damage patterns (DPs).

Fig. 6 Differences in rural socioeconomic characteristics averaged over the areas with heavier and lower magnitudes of damage in three topographies (a). b is designated in the same manner with the exception of interannual variability.
results are due to the limited cultivated paddy land in the objective area. The typical acreage of cultivated paddy land under management was approximately less than 4 ha even in the lowlands, with the exception of a few large-scale management farm households (≥ 10 ha). Such results were also observed in the basin, mountain, and valley areas. Thus, the second hypothesis suggests that more damage is caused by the inability to manage efficiently due to a smaller percentage of on-farm income than off-farm income. Inversely, it suggests the possibility that commercial farm households succeed in mitigating the damage by using sufficient labor resources and self-reliant efforts.

The abovementioned relationship between the damage and socioeconomic characteristics is revealed, along with two hypotheses to explain such a relationship. However, unfortunately, the verification is not completed in this study because of data limitations. The verification would require a dataset of off-farm income and on-farm income other than paddy rice in each rural area.

5. Conclusion

This study qualitatively reveals that the features of damage are influenced by the rural socioeconomic characteristics. Both the magnitude and interannual variability of damage are comparatively larger in areas with a higher ratio of non-commercial farm households, smaller cultivated paddy land under management and rented from others, larger abandoned arable fields, a lower percentage of young residents, and a higher percentage of elderly ones. Such a relationship is consistent throughout various topographies. Two hypotheses are suggested, relating to deterioration of the quantity and/or quality of labor resources and the lack of willingness to manage cultivation effectively when the ratio of on-farm income to total farm income is low.

Further improvements will be needed to quantify the influence of the rural socioeconomic characteristics on damage. Such improvements are expected to enhance the damage assessment models that are used to assess the impact of global warming. These, among other issues, will be addressed in future studies.

Acknowledgements

The authors acknowledge the National Agricultural Insurance Association for providing the insurance records. The acknowledgement is extended to the National Institute for Rural Engineering for accommodating the use of data in the Agricultural Census Settlement Card and the GIS software. The authors acknowledge that discussions with the reviewers resulted in significant improvements in the manuscript.

References


研究論文

集落の社会・経済属性が水稲収量被害に及ぼす影響：
栃木県、市見町・茂木町におけるGISを用いた事例研究

農業環境技術研究所** 飯泉 仁之直
農村工学研究所*** 石田 憲治
名城大学農学部**** 平見 慎太郎
筑波大学生命環境科学研究科***** 永見 正和

要旨
主に異常気象から生じる収量変動は農業経営上の主要なリスクである。農業生産者は栽培管理を通じて収量被害を
減らそうと試みるため、収量被害の特徴は農家や集落の社会・経済特性と関係があると考えられる。そうした関係の理解
は、効果的な農業政策を検討するうえで重要であるだけでなく、その関係を被害評価モデルに組み込むことで、農業生
産に対する温暖化の影響評価をより現実的なものへと発展することが期待される。そこで本研究では、水稲の収量被害と
集落の社会・経済特性との定性的な関係の解明を目的とする。解析の結果、被害の強度と年々変動は共に、自給率の農
家率が高く、経営水田面積が小さく、耕作放棄面積が多く、高齢農業人口割合が高く、若年農業人口割合が低い地域で
相対的に大きいことが示された。こうした傾向は地形条件が異なる場合でも貫いている。相対的に大きな被害量と年々
変動を説明するために、次の二つの仮説を提案した。一つは高齢化からくる労働力の量あるいは質の低下、もう一つは
低い農業収入比率からくる手厚い管理を行う意欲の低さ、である。この仮説は、販売農家は確保された労働力と自助努
力により被害を軽減している一方、高齢農家は、労働資源と意欲の不足から十分な栽培管理を断念しているという可能
性を示唆している。

キーワード：温暖化、水稲、収量被害、農業センサス集落カード、GIS

* 〒305-8604 茨城県つくば市観音台3-1-1
** 〒305-8572 茨城県つくば市天王台1-1-1
*** 〒468-8502 愛知県名古屋市天白区塩釜口1-501
**** 〒305-8666 茨城県つくば市観音台3-1-1
(Correspondence: iizumit@affrc.go.jp)