Causative Factors of Low Water Use in a Typical Upland Irrigation District of West Japan

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Abstract An on-farm questionnaire survey was carried out in a typical upland irrigation district of western Japan to investigate factors which influenced water use during the 1994 early crop growing season. The survey included irrigation frequency, type and area of crops grown, farm labour, irrigation equipment and others; the variables were investigated by a form of quantification theory (‘suryouka-riron 1 and 2’). The partial correlations for the full-time farm households indicated that water use was most influenced by crop type while farm labour was the most influential factor in the part-time farm households; cropped area was least sensitive to water use in both cases. The combined farm households indicated an optimum irrigation frequency of 5 to 6 irrigations per month. About two-thirds of the irrigators preferred applying water during the morning and evening periods possibly to avoid the extremely hot, afternoon, weather usually associated with summer. Quantification method type 2 indicated that irrigation frequencies of 4 to 7 times per week were mostly on farms of about 0.1 to 0.4 ha which also grew various crops as the main crop. 3 to 4 irrigations per week were mostly on leafy vegetables usually grown on farms of about 0.5 to 0.9 ha and with water mostly applied through drip hoses. Irrigations of 1 to 2 times per week were usually on wet fruits mostly grown on farms of about 0.1 to 0.9 ha with water mostly applied through drip hoses and normal hoses. Irrigations of 1 to 2 times per month were mostly on grass (lawn) usually grown on farms of more than 1 ha with water mostly applied through sprinklers. The various on-farm factors identified in this study were hence associated with crop production, farm management and socio-economics; their influence on water use may have resulted in less water usage compared to the designed water duty of crops grown in the district.

Key Words: Upland irrigation, On-farm survey, Water use trend, Irrigation frequency, Quantification theory

I. INTRODUCTION

In most humid areas, water resources are generally considered to be adequate and upland irrigation is supplemental. However, despite the provision of irrigation facilities, average water use in most upland irrigation districts of Japan are widely said to be much less compared to the designed water duty. Yomota and Ndegwa (1995) observed that actual water use in a typical upland irrigation district was about 1 to 2 mm/day during rainless periods while the designed water duty was usually 3 to 5 mm/day. A similar water use trend was also observed by the authors in another upland irrigation district. There was hence a need to investigate the actual factors which influence water demand in irrigated upland farms with a view to establish possible causes of low water use. The objective of this study was to investigate on-farm variables which influence water use in a typical humid upland irrigation district of west Japan during an early crop growing season.

II. STUDY AREA AND DATA

The study area was one of the two upland irrigated areas of the Tohaku National Irriga-
tion Project; the other area is currently under development. The project is situated in the central part of Tottori Prefecture, Japan, at about 35.3° north, longitude of about 133.5° east and at an elevation of between 10 and 150 metres above sea level. The average annual precipitation is about 2,614 millimetres; however, during extreme weather conditions, successive no-rain days can be as long as 46 (days) in a typical year of probably once in ten years.

The main soils of the district are 'kuroboku', i.e. andosols, which are black soils of volcanic origin. Watermelon is the main crop and is usually planted in vinyl houses in early spring, mostly in March, and harvested in summer, especially in July; other crops grown include lawn grass, vegetables such as cabbage/broccoli, and fruit trees such as pear, grape and kiwi. Water for irrigation is supplied from a reservoir (Nishitakao dam); the water is then pumped to 6 farm ponds which supply it to about 1,227 hectares (ha) of upland fields.

An on-farm questionnaire survey was carried out in the district to investigate factors which influenced water use during the 1994 early crop growing season. Each farm household was requested to respond to questions on whether the irrigator was a full-time or part-time farmer and age of each household member contributing to farm labour. For each cultivated plot, data included (1) kind of crop, (2) period of cultivation, (3) cropped area, (4) irrigation equipment, (5) irrigation frequency and (6) time of water application. Since there are two extreme types of irrigation frequency, i.e. small application quantity but frequent irrigation, and large quantity but rare irrigation, frequency was requested from the farmers, for it is difficult to measure irrigation quantity in this type of survey. Irrigation frequency choices in the questionnaire were once in 1 to 2 days, 3 to 4 times per week, 1 to 2 times per week, and 1 to 2 times per month. The trend of irrigation in the various cropped fields could hence be obtained from the survey.

### III. ANALYTICAL METHOD

To investigate the influence of on-farm variables on water use during the cropping period, several groups of variables were identified from the survey information. Irrigation frequency was identified as a response variable of water use while the 'independent' variables were taken to be farmer status, on-farm labour, and four field plot variables mentioned above, i.e. numbers 1, 3, 4 and 6. The nature of this dependency was investigated by two multivariate analytical methods described in various references such as Tanaka (1983) as quantification theory (suryouka riron) type one (1) and two (2), respectively. Type 1 is a form of multiple regressional analysis where the dependent or 'outside' variable is usually quantitative while type 2 is essentially a discriminant analysis and is used where the outside variable is qualitative.

Since a given farm household usually had various cropped plots, the crop that was grown on the largest area in a household was assumed to use most of the farm labour. The total number of cropped fields were hence selected to correspond to the number of farm households; data from 217 farm households were used for the analysis. The analysis hence indicated the relation between irrigation frequency and farmer status, labour and field variables; it does not involve the direct relation between crop and irrigation frequency.

#### 1. Categorization

Since the on-farm variables had units of measurement which were not consistent, a preliminary, controlled transformation of the raw data was performed by categorizing each item into a discrete and small number of classes, thereby emphasizing relative variation in the data (Greenacres, 1984). The coding problem here was the choice of partitions and their boundaries; a summary of the code used for the various categories of each survey item is presented in Table 1 for ease of reference.
Table 1 Categorization of survey data for analysis by the quantification method

<table>
<thead>
<tr>
<th>Item/Category code</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Farmer status</td>
<td>Full time</td>
<td>Part-time</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Labour (no. of people)</td>
<td>1 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Crop type</td>
<td>Wet fruit</td>
<td>lawn</td>
<td>Leafy</td>
<td>Fruit</td>
<td>Root</td>
<td>Others</td>
</tr>
<tr>
<td></td>
<td>vegetables (grass)</td>
<td></td>
<td>vegetables trees</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Cropped area (ha)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Irrigation facilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Application period</td>
<td>Morning</td>
<td>Afternoon</td>
<td>Evening/night</td>
<td>M+E</td>
<td>Other</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(M)</td>
<td>(A)</td>
<td>(E)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Irrigation frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4~7/wk</td>
<td>3~4/wk</td>
<td>1~2/wk</td>
<td>1~2/month</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Drip hose is herein used for the various plastic tube types that emit water jets from single orifices and termed as 'sumi-sansui', 'sumi-rain' and 'aporo', in the irrigation district.

** Combination of two or more irrigation facilities.

2. 'Suryouka Riron I' method

1) Water use variable Since water quantities at the various farms was not metered, the applied depth in each field was assumed to be constant at each irrigation time; irrigation frequency was hence assumed to control the amount of water needed by the crops during the peak water use period, i.e., rainless period. The number of irrigations was obtained from ratios of the four (4) irrigation frequency groups presented in Table 1 by assuming that at least one irrigation was applied to 'rarely irrigated' crops; for a period of about one month, this corresponded to about 14, 10, 4 and 1 irrigation for respective frequency categories.

2) Quantification The number of irrigations corresponding to each farm household was presented as a linear combination of the respective categories of the 'independent' variables, i.e.,

\[ Y_i = a_0 + a_{11} \delta_i(11) + a_{12} \delta_i(12) + \cdots + a_{21} \delta_i(21) + a_{22} \delta_i(22) + \cdots + a_{31} \delta_i(31) + \cdots \]

\[ = a_0 + \sum_{j=1}^{3} \sum_{k=1}^{6} a_{jk} \delta_i(jk) \] (1)

where the 'outside' (objective) variable, \( Y_i \), is the number of irrigations in the plot during the period, \( a_0 \) is a constant term considered as basic irrigation frequency; it is the optimum irrigation frequency that was applied to the various 'main' crops grown in the farms during the period. \( a_{jk} \) is a scale value assigned to the element of category \( k \) of item \( j \) and is termed as a category-score; \( \delta_i(jk) \) is an element which takes the value of 1 when an attribute of farm household \( i \) corresponds to category \( k \) of item \( j \) and zero (0) if otherwise. The respective items and categories are presented in Table 1 whereby categories range from \( k = 1 \) to a maximum of 6 (\( p_j \)) for items \( j = 1 \) to 6 (\( Q \)).

The most appropriate constant values for all the \( N \) farm households are obtained by the least squares method which minimizes the sum of squared deviations between the observed outside variable, \( y_i \), and the objective variable, \( Y_i \), i.e.,

\[ \sum_{i=1}^{N} (y_i - Y_i)^2 \rightarrow \text{minimum} \] (2)

To explore collectively the effect of the various factors on water use in each farm household, the condensed data matrix of the dependent variable and categories of the 'independent' variables were analysed for 96 full-time and 121 part-time farm households.

3) Evaluation The associated category scores of an item were used to indicate the nature of the dependency; the higher the score, the greater the degree or relative effectiveness of the associated variable on the water use variable. The score ranges indicated the variation of the various scores within a category. The partial correlation coefficients, \( r \), between the various quantified items and irrigation frequency were used to indicate the variables which mostly influenced the dependent term and hence water use in the farms. The
overall multiple correlation coefficient, $R$, served as a measure of association between the dependent and independent variables.

3. 'Suryouka Riron 2' method

To further investigate variables that characterize water use in the farms, the categorized variables were analysed by quantification method type 2. In contrast to method type 1, method type 2 considers the partitions of the rows (and/or a partition of the columns). For example, let the rows $i = 1, 2, \ldots m$ refer to the irrigation frequency classes ($m = 4$) and the columns $j = 1, 2, \ldots Q$ to different items such as farm labour, crop type, cropped area, etc., (see Table 1). Then a partition of the rows would be the grouping of farm household plots into the four irrigation frequency classes while the items could be grouped into broader classes, i.e. categories. The rows of the original matrix $N$ (such as 217 plots) correspond to the sum of the partitioned farm household plots ($n_i$).

Since the dependent variable is categorized into a discrete and small number of classes, i.e. it is qualitative, then the analysis is regarded as a discrete form of regression. The resulting regression is essentially a discriminant analysis since the irrigation frequency partitions are known in advance. Quantification method type 2 utilizes a classification variable defining the irrigation frequency groups and the attribute variables to develop a classification model.

1) Quantification

In a given irrigated plot, $\alpha$, the objective variable, $Y_{ia}$, can be quantified as a linear combination of all categories of the items, i.e.

$$Y_{ia} = \sum_{j=1}^{Q} \sum_{k=1}^{m} a_{jk} \delta_{ia}(jk) \ldots \ldots \ldots \ldots (3)$$

where the element, $\delta_{ia}(jk)$, of the $k$ 'th column (category) of the $j$ 'th item takes the value of 1 when an attribute of row $i$ ($\alpha$) corresponds to category $k$ and 0 if otherwise. The term $a_{jk}$ is a category score, i.e. a scale value assigned to element in category $k$ of item $j$.

In order to discriminate between the irrigation frequency groups, the data matrix that has a high dimensionality (number of attributes) is decomposed into a linear combination of singular values (category scores) for any prescribed dimensionality $K*$. For $K* = 1$, the first linear combination of the categories and associated singular value provide the optimal solution and has the maximum possible variance. For $K* = 2$, the second linear combination of categories and associated singular value provide the optimal solution, and so on. The analysis involves the eigen value problem usually described in the concepts of singular value decomposition (or basic structure) and low rank matrix approximation (Greenacres, 1984). Typically, the first two or three linear combinations of singular values (herein referred to as principal component axes PC1, PC2, and PC3) account for much of the variation in the data. When the irrigation frequency is partitioned into four classes, the total number of principal component axes expected from the analysis is three, i.e. PC1, PC2, and PC3.

For each principal component axis computed, the decision of category weight, $a_{ia}$, is determined by the correlation ratio, $\eta^2$, i.e.

$$\eta^2 = \sigma_b^2 / \sigma^2 \rightarrow \text{maximum} \ldots \ldots \ldots \ldots (4)$$

where $\sigma_b^2$ is the variance within a group of outside variables (irrigation frequency), and $\sigma^2$ is the variance within the whole set of irrigation frequency groups. The respective group variances can be determined as:

$$\sigma_b^2 = 1/N \sum_{i=1}^{m} n_i (Y'_{ia} - Y')^2 \ldots \ldots \ldots \ldots (5)$$

where, $N$ is the total number of farm household plots, $n_i$ is the total farm household plots in each irrigation frequency group, $Y'_{ia}$ is average within a group of outside variables, and $Y'$ is average of total farm household plots. Variance within the whole set of irrigation frequency groups can be determined as:

$$\sigma^2 = 1/N \sum_{i=1}^{m} \sum_{\alpha=1}^{n_i} (Y'_{ia} - Y')^2 \ldots \ldots \ldots \ldots (6)$$

The condensed data matrix of the 4 irrigation frequency groups and the 6 categorized items (see Table 1) for the 96 full-time and 121 part-time farm households were analysed by
quantification method type 2 and principal axes of its profiles computed. The analysis is effectively a discriminant analysis between the groups defining the irrigation frequency and the various categories.

(2) Evaluation The partial correlation coefficients from the various PC axes were used as indicators of the influence of an associated variable on the classification variable defining the irrigation frequency. A high correlation indicates that the associated variable explains a large amount of the outside variable; a low correlation, however, indicates that other factors may be influencing water use in the farms. The most important variables that influence irrigation frequency could then be selected from the analysis. The overall measure of association between the outside and independent variables was indicated by the correlation ratio, \( \eta^2 \).

(3) Pattern of water use In a given farm household, the overall irrigation frequency category score was computed from the linear combination of respective category scores derived from the obtained principal axes. The scores derived from the first two principal axes were constructed on a two-dimensional space so as to observe the visual presentation of the relationship between the separated irrigation frequency groups as described by the two axes of the analysis. The result is an efficient summarization, which lends itself well to visual presentation and interpretation (Lebart, 1984). Irrigation frequencies that do not fit well into the group with which they were originally classified by the farmers can be identified. The clustered irrigation frequency groups were then related to the original variables of the survey by correlation.

IV. RESULTS AND DISCUSSION

1. On-farm Water Use Trend

(1) Categorized water use variables The derived set of standardized category scores and their ranges are presented in Table 2 for 217 farm households. The range indicates the variation of the various scores within a category; however, it is noted that the range is small when the number of categories are low and increases with the number of categories within an item. Among the same number of categories, the variation of the range indicates the relative influence of an item on the water use variable.

On-farm labour indicated a large, positive score for the category with four (4) people working on the farm which may suggest that this was the optimal work force required for efficient water use in the farms. The crop type item indicated positive scores for leafy vegetables (such as cabbage, broccoli, spinach), fruit trees (such as pear, persimmon, apple, kiwi), and root crops (such as raddish, chinese yam, sweet potato), hence indicating positive influences on water use. Grass (sold for establishing lawn) and wet fruits (water melon, tomato) indicated negative scores; these crops hence had a very low influence on water use possibly because the crops, especially water melon, was usually harvested during the summer period when much irrigation is expected. Irrigation frequency requested in the questionnaire was for a rainless period.

The cropped area item indicated positive scores for 'medium' and 'low' categories, hence farms of about 0.1 ha to about 1 ha had positive effects on water use. Farms of less than 0.1 ha indicated a very low influence on water use; however, the low, negative score for farms greater than about one (1) ha may indicate that crops grown in these farms (such as lawn grass) required less water, hence indicating that other factors influenced water use in these farms apart from their relatively large size which may be associated with more water use.

The facilities used for water application indicated positive scores for sprinklers and 'other' facilities; the positive influence of sprinklers on water use may be attributed to the higher water application rates associated with the facility. The other irrigation facilities, i.e., drip hose, normal hose (for water works) and
Table 2 Standardized category-scores and their ranges for irrigation frequencies in 217 farm households, Tohaku irrigation district (1994)

<table>
<thead>
<tr>
<th>Item</th>
<th>Category</th>
<th>Frequency</th>
<th>Category-score</th>
<th>Range</th>
<th>Partial correlation, r</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Farmer status</td>
<td>1 (Full-time)</td>
<td>96</td>
<td>-0.153</td>
<td>0.274</td>
<td>0.042</td>
</tr>
<tr>
<td></td>
<td>2 (Part-time)</td>
<td>121</td>
<td>0.121</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Labour</td>
<td>1</td>
<td>16</td>
<td>-0.518</td>
<td>1.769</td>
<td>0.178</td>
</tr>
<tr>
<td>(No. of people)</td>
<td>2</td>
<td>87</td>
<td>-0.270</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>71</td>
<td>-0.178</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>36</td>
<td>1.251</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>7</td>
<td>-0.095</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Crop type</td>
<td>1 (Wet fruit vegetables)</td>
<td>103</td>
<td>-0.226</td>
<td>3.338</td>
<td>0.166</td>
</tr>
<tr>
<td></td>
<td>2 (Lawn grass)</td>
<td>76</td>
<td>-0.155</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 (Leafy vegetables)</td>
<td>8</td>
<td>1.955</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 (Fruit trees)</td>
<td>5</td>
<td>1.809</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5 (Root crops)</td>
<td>21</td>
<td>0.756</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 (Others)</td>
<td>4</td>
<td>-1.382</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Cropped area</td>
<td>1 (Large)</td>
<td>51</td>
<td>-0.043</td>
<td>1.738</td>
<td>0.111</td>
</tr>
<tr>
<td></td>
<td>2 (Medium)</td>
<td>72</td>
<td>0.123</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 (Low)</td>
<td>83</td>
<td>0.132</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 (Very low)</td>
<td>11</td>
<td>-1.606</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Irrigation facilities</td>
<td>1 (Drip hoses)</td>
<td>136</td>
<td>-0.184</td>
<td>2.757</td>
<td>0.216</td>
</tr>
<tr>
<td></td>
<td>2 (Sprinklers)</td>
<td>35</td>
<td>1.532</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 (Normal hoses)</td>
<td>28</td>
<td>-0.592</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 (Micro-sprinklers)</td>
<td>11</td>
<td>-0.771</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5 (Others)</td>
<td>3</td>
<td>0.470</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 (Two or more)</td>
<td>4</td>
<td>-1.225</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Application period</td>
<td>1 (Morning, M)</td>
<td>53</td>
<td>0.409</td>
<td>2.114</td>
<td>0.179</td>
</tr>
<tr>
<td></td>
<td>2 (Afternoon, A)</td>
<td>64</td>
<td>-0.430</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 (Evening, E)</td>
<td>49</td>
<td>0.203</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 (M+E)</td>
<td>24</td>
<td>0.888</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5 (A+M/E)</td>
<td>20</td>
<td>-1.227</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 (M+A+E)</td>
<td>7</td>
<td>-0.122</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Constant term = 5.424
Multiple correlation coefficient, $R = 0.363$, $R$-square = 0.133
+The response of irrigation frequencies: 15 farm households irrigated 'main' crop at 4−7/wk while 34, 153, and 15 farm households irrigated at 3−4/wk, 1−2/wk and 1−2/month, respectively.

micro-sprinklers, had lower effects on water use as indicated by the relative magnitude of their respective scores. The 'other facilities' and 'two or more' facilities indicated low frequency of observations, hence their effect could not be clarified from the analysis.

The item on water application period during a day indicated positive scores for morning, evening, and for both morning and evening irrigations. This implies that water applications during these periods had a positive influence on water use; the negative scores associated with the afternoon periods indicated very low water use during this time of day. About two-thirds of the irrigators preferred applying water during the cooler periods in a day possibly to avoid the extremely hot, afternoon, weather usually associated with the summer period.

(2) Quantified water use variables The various correlation coefficient results from the quantified on-farm water use variables are presented in Table 3 for a sample size of 96 full-time and 121 part-time farm households. In the full-time farm households, partial correlations of the quantified items indicated that water use was most influenced by crop type, followed by irrigation equipment, farm labour,
Table 3 Correlation coefficients from Quantification one (1) analysis of irrigation frequency and various on-farm water use variable categories.

<table>
<thead>
<tr>
<th>Model</th>
<th>Partial correlation coefficients, r</th>
<th>Constant term</th>
<th>Farmer status</th>
<th>Labour</th>
<th>Crop type</th>
<th>Cropped area</th>
<th>Equipment</th>
<th>Applic. period</th>
<th>R</th>
<th>R^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Full-time farm households</td>
<td></td>
<td>5.19</td>
<td>×</td>
<td>0.193</td>
<td>0.310</td>
<td>0.115</td>
<td>0.217</td>
<td>0.190</td>
<td>0.389</td>
<td>0.152</td>
</tr>
<tr>
<td>(N = 96)</td>
<td></td>
<td>5.19</td>
<td>×</td>
<td>0.172</td>
<td>0.300</td>
<td>×</td>
<td>0.200</td>
<td>0.168</td>
<td>0.378</td>
<td>0.143</td>
</tr>
<tr>
<td>b. Part-time farm households</td>
<td></td>
<td>5.62</td>
<td>×</td>
<td>0.320</td>
<td>0.217</td>
<td>0.079</td>
<td>0.234</td>
<td>0.243</td>
<td>0.476</td>
<td>0.227</td>
</tr>
<tr>
<td>(N = 121)</td>
<td></td>
<td>5.62</td>
<td>×</td>
<td>0.323</td>
<td>0.215</td>
<td>×</td>
<td>0.263</td>
<td>0.240</td>
<td>0.473</td>
<td>0.223</td>
</tr>
<tr>
<td>c. All sample farm households</td>
<td></td>
<td>5.42</td>
<td>0.042</td>
<td>0.178</td>
<td>0.166</td>
<td>0.111</td>
<td>0.216</td>
<td>0.179</td>
<td>0.363</td>
<td>0.133</td>
</tr>
<tr>
<td>(N = 217)</td>
<td></td>
<td>5.42</td>
<td>0.033</td>
<td>0.178</td>
<td>0.146</td>
<td>×</td>
<td>0.224</td>
<td>0.172</td>
<td>0.354</td>
<td>0.125</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.42</td>
<td>×</td>
<td>0.177</td>
<td>0.170</td>
<td>0.107</td>
<td>0.225</td>
<td>0.177</td>
<td>0.363</td>
<td>0.131</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.42</td>
<td>×</td>
<td>0.176</td>
<td>0.158</td>
<td>×</td>
<td>0.230</td>
<td>0.172</td>
<td>0.353</td>
<td>0.124</td>
</tr>
</tbody>
</table>

* Partial correlation coefficients, r, in first line of Model c are obtained from results of Table 2.

\( \times \) indicates an excluded item from an analysis.

and period of water application; cropped area indicated the least influence on water use in the farms. When the crop area item was excluded from the analysis, crop type and irrigation equipment still indicated a similar water use trend as in afore-mentioned case. However, water use by the part-time farm households was most influenced by farm labour, followed by water application period in a day, equipment, and crop type; cropped area was least correlated to water use. The combined farm households indicated strong correlations for equipment, application period, labour, and crop type; however, cropped area indicated a relatively lower correlation while farmer status had the least influence on water use.

The overall multiple correlation coefficient, \( R \), was about 39% for the full-time farm households, about 48% for the part-time farm households, and about 36% for the combined case. This indicated a large variability in the responses received from the survey; it may also indicate that other factors may have influenced water use during the period. However, exclusion of variables with very low partial correlations indicated negligible effects on the respective multiple correlation coefficients; the order of relative importance of the quantified on-farm variables was also retained for the respective cases considered.

The constant term indicated basic frequencies of about 5.2, 5.6, and 5.4 irrigations per month for the full-time, part-time and the combined farm households, respectively, i.e. about 5 to 6 irrigations per month.

2. Water use and principal component axes

The correlation coefficients of various on-farm water use variables with principal component (PC) axes are presented in Table 4 for full-time, part-time, and for the combined farm households.

1) Full-time farm households

The first two components of the analysis, i.e. PC1 and PC2, accounted for about 48% of the variation while the third principal axis explained a much lower variation, i.e. about 7%. PC1 indicated that crop type was most correlated to irrigation frequency; this was followed by period of water application in a day. PC2 indicated a strong correlation for water application period (significant at 0.1% level) and also crop type while PC3 exhibited a relatively strong correlation for water application period.

2) Part-time farm households

PC1 and PC2 accounted for about 57% of the variation. PC1 indicated the most correlation for period of day when water was applied, followed by labour and irrigation equipment; crop type indicated a lower correlation. PC2 indicated significant correlations for equipment and labour (0.1%
Table 4 Correlation coefficients of various on-farm water use variables with principal component (PC) axes and correlation ratio for each axis

<table>
<thead>
<tr>
<th>Item</th>
<th>Correlation coefficient, $r$</th>
<th>PC 1</th>
<th>PC 2</th>
<th>PC 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Full-time farmers ($N = 96$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Crop type</td>
<td>0.463***</td>
<td>0.329**</td>
<td>0.129</td>
<td></td>
</tr>
<tr>
<td>2. Application period</td>
<td>0.274**</td>
<td>0.343***</td>
<td>0.179*</td>
<td></td>
</tr>
<tr>
<td>3. Labour</td>
<td>0.251*</td>
<td>0.244*</td>
<td>0.127</td>
<td></td>
</tr>
<tr>
<td>4. Equipment</td>
<td>0.243*</td>
<td>0.250*</td>
<td>0.084</td>
<td></td>
</tr>
<tr>
<td>5. Cropped area</td>
<td>0.090</td>
<td>0.180</td>
<td>0.153</td>
<td></td>
</tr>
<tr>
<td>Correlation ratio, $\eta^2$,</td>
<td>0.265</td>
<td>0.213</td>
<td>0.074</td>
<td></td>
</tr>
<tr>
<td>b. Part-time farmers ($N = 121$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Application period</td>
<td>0.368***</td>
<td>0.293**</td>
<td>0.235*</td>
<td></td>
</tr>
<tr>
<td>2. Labour</td>
<td>0.308**</td>
<td>0.323***</td>
<td>0.238*</td>
<td></td>
</tr>
<tr>
<td>3. Equipment</td>
<td>0.272**</td>
<td>0.341***</td>
<td>0.235*</td>
<td></td>
</tr>
<tr>
<td>4. Crop type</td>
<td>0.224*</td>
<td>0.205*</td>
<td>0.146</td>
<td></td>
</tr>
<tr>
<td>5. Cropped area</td>
<td>0.181</td>
<td>0.159</td>
<td>0.059</td>
<td></td>
</tr>
<tr>
<td>Correlation ratio, $\eta^2$,</td>
<td>0.318</td>
<td>0.253</td>
<td>0.155</td>
<td></td>
</tr>
<tr>
<td>c. All full/part-farmers ($N = 217$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Application period</td>
<td>0.263**</td>
<td>0.301**</td>
<td>0.113</td>
<td></td>
</tr>
<tr>
<td>2. Crop type</td>
<td>0.244*</td>
<td>0.222*</td>
<td>0.106</td>
<td></td>
</tr>
<tr>
<td>3. Equipment</td>
<td>0.234*</td>
<td>0.139</td>
<td>0.173</td>
<td></td>
</tr>
<tr>
<td>4. Labour</td>
<td>0.221*</td>
<td>0.126</td>
<td>0.161</td>
<td></td>
</tr>
<tr>
<td>5. farmer status</td>
<td>0.164</td>
<td>0.113</td>
<td>0.116</td>
<td></td>
</tr>
<tr>
<td>6. Cropped area</td>
<td>0.140</td>
<td>0.135</td>
<td>0.062</td>
<td></td>
</tr>
<tr>
<td>Correlation ratio, $\eta^2$,</td>
<td>0.211</td>
<td>0.159</td>
<td>0.075</td>
<td></td>
</tr>
</tbody>
</table>

*, **, *** indicate correlation coefficient values which are significant at the 0.05, 0.01 and 0.001 levels, respectively.

significance level) while the two items and water application period were significant at 5% level for PC3. Cropped area indicated the least correlation with the outside variable of water use for the three principal axes.

(3) Combined farm households PC1 accounted for about 21% while the other two axes accounted for about 23% of the variation. PC1 indicated that water use on the 217 farms was mostly influenced by period of water application in a day while PC2 indicated a strong correlation for application period. PC3 had no item that had partial correlations significant even at the 5% level and was only slightly sensitive to equipment and farm labour.

3. Water use patterns in the farms

The results of the ‘suryouka-riron 2’ classification of irrigation frequency groups are presented in Fig. 1 for the full-time, part-time, and the combined farm household cases; the overall score of each irrigation frequency category for the first and second PC axes are expressed along the $x$ and $y$ axes, respectively. Each irrigation frequency of the main crop in a farm household was hence plotted on a two-dimensional PC space as a single point.

(1) Full-time farm households The PC indicated a distinct pattern of the irrigation frequency groups (Fig. 1 a). Positive loadings (scores) of PC1 mostly corresponded to 1 to 2 irrigations per week (×). Positive loadings of PC2 and a significant negative loading of PC1 mostly indicated 1 to 2 irrigations per month (+) while negative loadings of both PC1 and PC2 corresponded to 3 to 4 times per week (△). However, some of the irrigation frequencies did not fit well into the groups with...
which they were originally classified by the farmers. This was evident from observations of the various group overlaps especially for some farms which were irrigated at about 4 to 7 times per week.

(2) Part-time farm households  Positive loadings of both PC1 and PC2 corresponded to 1 to 2 irrigations per week. Significant negative loadings of PC1 mostly corresponded to irrigations of 3 to 4 times per week; frequencies of 1 to 2 times per month were mostly characterized by positive loadings of PC1 and negative loadings of PC2. However, the irrigation frequency of 4 to 7 times per week had much overlap with all the other three groups especially that of 1 to 2 irrigations per month; hence, responses for this category were not homogeneous.

A comparison of irrigation patterns for the full-time and part-time farm households indicated that water use was almost similar for frequencies of 3 to 4 irrigations per week and for 1 to 2 irrigations per week; however, farm households irrigated at about 4 to 7 times per week had much overlap with all the other three groups especially that of 1 to 2 irrigations per month; hence, responses for this category were not homogeneous.

(3) Combined farm households  In this case, relatively large negative loadings of PC1 corresponded to a frequency of 3 to 4 times per week while positive loadings of PC1 and negative loadings of PC2 corresponded to 1 to 2 irrigations per week. Irrigations of 1 to 2 times per month mostly corresponded to positive loadings of PC2 and negative loadings of PC1 despite some overlaps with some farms which were irrigated 1 to 2 times per week; however, relatively high positive loadings of PC2 mostly corresponded to a frequency of 4 to 7 irrigations per week.

4. Characteristics of the Clustered Irrigation Frequency Groups

The importance of the constructed scatter plots of the clusters was that the plots assisted in the identification of irrigation frequencies that fitted well into the groups with which they were originally classified by the farmers. The clustered frequency groups, which were considered to be homogeneous, were observed to have the following characteristics for the combined farm households:

(1) 4 to 7 times per week  This frequency was observed in some farms cropped with wet fruits, grass, fruit trees and root crops. The farm sizes were usually about 0.1 to 0.4 ha with a work force of about 2 people. Sprinklers and drip hoses were used for water application mostly during the morning period.

(2) 3 to 4 times per week  This frequency was mostly from farms cropped with leafy vegetables apart from some which had wet fruits, fruit trees, root crops, and 'other' crops. The crops were grown on 0.5 to 0.9 ha though a few farms were 1 ha and above; the work force was usually composed of about 4 people, however, a few farms had 3 and 5 people. Water was usually applied during mornings, afternoons, and evening periods mostly through drip hoses though a few farms used sprinklers and 'other' facilities.

(3) 1 to 2 times per week  Most farms cropped with wet fruits were irrigated at this frequency, followed by farms cropped with grass while a few farms had 'other' crops. The crops were usually grown on farms of about 0.1 to 0.9 ha with a work force of about 2 people though a few had 1, 3, and 4 people. Water was usually applied during morning and/ or evening periods, only a few farm households were irrigated during the afternoon periods. Drip hoses and normal hoses were mostly used for water application, however, a few farms with 2 or more facilities also irrigated at this frequency.

(4) 1 to 2 times per month  Grass was mostly irrigated though a few farms also irrigated wet fruits, and fruit trees at this frequency. The crops were grown mostly on areas equal to or more than 1 ha with a work force of about 3 to 4 people. Water was applied through sprinklers while a few farms used drip hoses, normal hoses, and 'other' facilities; applications were mostly during the morning
periods, however, some farms were irrigated during evening periods.

Comparison of irrigation frequencies of 4 to 7 times per week and 1 to 2 times per month indicated a similarity between some crops, irrigation facilities and period of water application in a day; this may have caused the observed closeness of the two frequency groups in the scatter plots.

V. SUMMARY AND CONCLUSIONS

1. Water use by the full-time farm households was most influenced by crop type, followed by irrigation equipment, farm labour, and period in a day when water was applied. However, water use by the part-time farm households was mostly influenced by farm labour, followed by water application period in a day, equipment, and crop type. Cropped area and farmer status had the least influence on water use.

2. Leafy vegetables, fruit trees, and root crops had positive influences on water use, however, grass and wet fruits (mostly watermelon) indicated much lower influences on water use; water applications to watermelon may have been withheld or reduced just before harvest so as to improve the quality of its produce.

3. Irrigations of 4 to 7 times per week were mostly on farms of about 0.1 ha to 0.4 ha which also grew various crops as the main crop; 3 to 4 irrigations per week were mostly on leafy vegetables usually grown on farms of about 0.5 ha to 0.9 ha, water was mostly applied through drip hoses. Irrigations of 1 to 2 times per week were usually on wet fruits mostly grown in farms of about 0.1 ha to 0.9 ha while irrigations of 1 to 2 times per month were mostly on grass usually grown on farms of more than 1 ha with water mostly applied through sprinklers.

4. Water was mostly applied through drip hoses. An optimal work force of 4 people was required for efficient water use in the irrigated farms.

5. About two-thirds of the irrigators preferred applying water during the morning and evening periods possibly to avoid the extremely hot, afternoon, weather.

The various factors that influence actual water use in the farms were hence associated with crop production, farm management and socio-economics. The various factors identified in this study may have resulted in less water usage compared to the designed water duty of crops grown in the district.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to the Tohaku National Irrigation Project administration office, farmers/irrigators in the project and to Ms. Kondo of MAFF Chugoku-shikoku Administration Bureau for their cooperation in this survey; the assistance of Associate Professor T. Miura in the preparation and administration of the questionnaires is also deeply acknowledged.

REFERENCES


【研究論文】
ガラスピース充填層への水浸入過程と水浸入圧
—浸潤前線不安定化による指針成長と
その維持メカニズム（Ⅱ）—
出澤 重祥・安中 武幸

細／粗成層における浸潤で明白なfinger流が生じる
ためには、下層への水圧が支配的に高い圧で制御されること
が必要である。本論では、ガラスピース充填層を対象に、
水浸入を生じる水圧の必要性、および初期水分条件の
水浸入過程への影響を検討した。まず、給水水圧
圧過程で水浸入を生じる水圧を測定した。次いで、得
られた水圧値より低い水圧下で浸潤フラックスの測定と
水浸入状況の観察を行った。その結果、初期乾燥試料で
は給水水圧上昇過程で水浸入を生じる水圧が高い値と
見なせるが、図構試料ではしぶといことが不明瞭になること、
および図構試料では乾燥試料より低い水圧下で水浸入が生
じたことが示された。

キーワード
水浸入圧、finger流、成層浸潤、ガラスピース充填層、finger維持

（農土論集 186, pp. 1－6）

【研究論文】
ファジィ推論によるドリップ灌漑の灌水量の制御
筑波 二郎、Eduardo Villavicencio Florian

ドリップ灌漑における灌水量を少なくするため、ファジィ
理論に基づいた制御を考案し、メロンの畑地栽培試
験を行い、その手法の検討を行った。制御条件や灌水量
が異なる6つのドリップラインに田植えし、その灌水
量は土壌水分分岐値と水分変化量から決定した。その
結果、土壌水分量は、いずれのドリップラインにおいても
0.06－0.12 cm cm⁻³の範囲で制御された。また、
毎週灌水の場合、実験灌水量の収支を考慮することによ
る約20－30％節約できた。一日置き灌水の場合、50％以上
の節約で栽培が可能であったが、収量が多少減少した。
適切なファジィ制御は、ドリップ灌漑における灌水量の
節約を行うのに有用であることがわかった。

キーワード
ドリップ灌漑、ファジィ理論、TDR、土壌水分、節水

（農土論集 186, pp. 17－24）

【研究論文】
水田バイブライオン区における管理用水量の
シミュレーションについて
中山 修・Giveson ZULU・豊田 勝・三沢 真一

新潟県平野の水田バイブライオン灌漑2地域で、管理用水
の発生機構を把握するため、水管理方法に関するアン
ケート調査を行った。その結果、供給水流量が十分と感じ
る点は、バルブ操作回数が少なく、取水が長時間に及
ぼす管理を行うことが判断し、水利学的に不利な
水田水流量に満たない場合に粗放管理水田では管理用
水量が発生する。そこで、出水算出可能な節水エネル
ギー法を提案し、水端出水単位時間やバブル開度を変化させ
て管理用水量をシミュレーションした結果、単位水流量と
管理用水量に差異となり、管理学的な不利なバルブを
適切に構成する傾向を示した。この管理計算法が
水管理方法を検討する際に用いる上で

キーワード
水田バイブライオン、節水エネルギー法、管理用水、水
管理方法

（農土論集 186, pp. 37－41）

【研究論文】
寒冷地における造成農地法面の土壌侵食
—十勝地域における農地保全に関する研究（1）—
辻 修・松田 豊・土谷富士夫

寒冷・少雪な十勝地域の稲作地において、この地域
の特徴である土壌凍結が侵食に及ぼす影響を調査した
この結果、凍結後の造成農地の土壌侵食は、圃場面よ
リも農業において侵食被害が多いことが明らかとなっ
た。また法面方向による土壌侵食の危険性は、北向き法
面が南向き法面と比較して、その侵食の高いことが明ら
かとなった。その原因としては、冬期間の積雪が水路断面を覆う
ことにより、凍結後に水路を通過した排水が面に土壌
侵食を発生させることや、春先、土壌凍結状態が面中に
残存する期間、浸透水が、表面で破壊面に浸透することなどが詳細に影響して
いることが明らかとなった。

キーワード
土壌侵食、造成農地、土壌凍結、農田、法面方向

（農土論集 186, pp. 43－51）