Evaluation of Water-Saving Rice-Winter Crop Rotation System in a Suburb of Tokyo

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Abstract: Water-saving rice-winter crop rotation systems were repeated for 4 cycles from 2000 to 2004 in an urban area, Nishitokyo, Japan, to assess the effects of water-saving (i.e. non-flooded vs. flooded) on grain yield of rice (Oryza sativa L.) and chemical constituents of percolating water. The effects of pre-rice winter cropping compared with fallow on rice yield were also examined. The pre-cultivated crops were wheat (Triticum aestivum L.), Italian ryegrass (Lolium multiflorum Lam.) or spinach (Spinacea oleracea L.) with their above-ground parts removed, Chinese milk vetch (Astragalus sinicus L.) or rapeseed (Brassica napus L.) with their above-ground parts incorporated before rice transplanting. Neither winter cropping effects nor its interaction with water-saving were significant for rice yield, although the yield after rapeseed incorporation tended to be 9% higher than that after fallow. In 2001, 2003 and 2004, when more than 70% of irrigation water was saved in the non-flooded trial, average yield in non-flooded trial was 58% of flooded trial, but water productivity increased (from 0.10 to 0.16 kg m⁻³). Among the 3 years, yield in non-flooded trial was highest in 2004 when the amounts of irrigation and total water supply was larger, the frequency of dry spells was the lowest, and 2 seedlings were transplanted per hill. The nitrate and nitrite concentrations in the percolating water were far below the environmental standard values by WHO. The study showed that incorporation of winter crops had no negative effects on water-saving rice production at least for the first 4 years, and that under extreme water-saving, irrigation and planting methods could minimize yield reduction.

Keywords: Rice-based cropping system, Urban agriculture, Water-saving, Winter crops.

Agricultural water intake amounts to 58.6 billion cubic meters per year in Japan, which is about two thirds of available fresh water resources, and paddy rice production is estimated to occupy 95% of them (Tsukui, 2003). Water is more costly near urban areas, and saved water in agricultural sector can be utilized for industrial and urban activities, or wetland conservation.

The paddy field near an urban area is known to have many functions other than food production, such as water reservoir to moderate flood, decrease air temperature, ecosystem and biodiversity, recreational landscape for urban citizens (Tokyo Agricultural Promotion Office, 2005). Therefore, it would be desirable to maintain paddy fields near the urban area without consuming too much water but in the manner of water-saving and with appropriate amounts of water input.

Water management for constant flooding requires a lot of labor, and if a water-saving irrigation method can be developed, it will not only use resource efficiently, but also will help to reduce the rice farmer’s labor for water management. In Japan there has been a practice of midsummer drainage to increase soil hardness and anchoring ability of roots for minimizing lodging (Terashima et al., 2003) and intermittent irrigation techniques for high-yielding rice to decrease initiation of unproductive tillers (Matsushima, 1973; Matsuo et al., 1995), but few studies have been conducted to develop water-saving paddy rice cultivation techniques, partly because of assumption that water is unlimited resource in Japan. Now in the 21st century, the situation is changing and it will be worthwhile to study the water-saving paddy rice production system. In that new rice production system, it would be essential to appropriately control weeds and to maintain soil fertility under the reduced supply of water with possibly tentative absence of standing water.

Most of the studies on urban agriculture are from the viewpoints of urban planning and policy making, and not many studies have analyzed productivity of urban agriculture. Efficient resource use and least harmful effects on environments are needed in urban agriculture (e.g. concentration of nitrate in percolating water, Ishikawa et al., 2005). Higher productivity is also desirable, in spite of the fact that current rice yield in urban areas, e.g. Tokyo, is generally lower than that in rural rice fields in Japan (Kamoshita, 2007).

Urban paddy fields would be better utilized in the
The experiments on rice-winter crop rotation systems were conducted from 2000 to 2004 in Field Production Science Center, Nishitokyo, Japan (lat. 35°43’ N. Long. 139°32’ E. Alt. 67 m). The area is located in Northern Tama (Kamoshita, 2007), also known as Musashino Tableland, where the soil from surface to about 30 cm depth is Haplic Andosols (FAO/Unesco, 1990), loamy soil (L), with pH 6.7, made of volcanic ash with well-developed hume layers, and the soils below 30 cm depth are called Tachikawa loam, a clay loam soil made of volcanic ash (CL). Paddy fields in Northern Tama were developed on lower valleys of diluvial tableland, and the paddy fields in this experiment are dry paddy with high percolation rate and are usable for rotation with upland crops.

2. Cropping sequences

Four cycles of rice-winter crop systems (rice in summer and other crops in winter) started from winter crops sown in October 2000 and finished by rice harvested in October 2004 (Table 1). Sowing time of winter crops were late October to early November across four years, and their harvest times were middle to late April (for Italian ryegrass, Chinese milk vetch, rapeseed and spinach) and early to middle June (for wheat), except for the earlier harvest of wheat in mid-May at premature stage in 2002. Transplanting times of rice were earliest in 2002 (31 May) and latest in 2004 (25 June), and their harvest time were around the middle of October.

3. Experimental design

One paddy field, 27 m × 36 m was divided into half by the central bunds of 20 cm height and 2 m width; one for flooded trial, and the other for non-flooded trial. Rice was grown during summer mostly with flooded irrigation with the presence of standing water in flooded trial, and with non-flooded irrigation for the sake of minimizing water supply (water-saving) in non-flooded trial. Non-flooded irrigation method was similar to the alternative wetting and drying system (illustrated by Takai (1959) reviewed by

| Table 1. Cropping schedules of 5 winter crops (a) and rice (b) during the 4 year-cycle from 2000 to 2004. Dates of sowing (S), transplanting (T) and harvest (H) were shown. |
|-------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Species     | 2000/01         | 2001/02         | 2002/03         | 2003/04         |
|-------------|-----------------|-----------------|-----------------|-----------------|
| Wheat       | 1 Jun           | 13 May          | 1 Jun           | 11 June         |
| Italian ryegrass | 27 Apr*  | 19 Apr          | 18 Apr          | 23 Apr          |
| Chinese milk vetch | 24 Oct | 27 Apr          | 31 Oct          | 2 Nov           | 7 Nov           | 23 Apr          |
| Rapeseed    | 27 Apr          | 19 Apr          | –              | 23 Apr          |
| Spinach     | 27 Apr          | 19 Apr          | 18 Apr          | 23 Apr          |
| *; Regrowth plants were harvested on 1 June. |

| (b) Rice |
|-------------|-----------------|-----------------|-----------------|-----------------|
| Species     | 2001            | 2002            | 2003            | 2004            |
|-------------|-----------------|-----------------|-----------------|-----------------|
| Rice        | 15 June         | 12 Oct          | 31 May          | 11 Oct          | 13 June         | 17 Oct          | 25 June         | 18 Oct          |
Kamoshita (2003), but the frequency of water supply differed among the 4 years. The diagrams of water management of the 4 years of water-saving non-flooded trials were compared with conventional flooded trial in 2001 in Fig. 1; in non-flooded trials in 2001, only minimum irrigation was supplied with scarce rainfall, resulting in least moist conditions, in 2002 frequent and the largest amount of irrigation was supplied to maintain wettest conditions, and 2003 and 2004 were in-between.

During winter, winter crops were grown in rainfed upland conditions in both trials. In each trial, 6 different land uses during winter were randomly assigned with 3 replicates; (1) wheat (Triticum aestivum L.) production and its above-ground removal, (2) ground cover with italian ryegrass (Lolium multiflorum Lam.) and its above-ground removal, (3) ground cover with chinese milk vetch (Astragalus sinicus L.) and its incorporation into soil as bio-fertilizer, (4) rapeseed (Brassica napus L.) flower production and its whole plant incorporation (around flowering stage) into soil as bio-fertilizer, (5) spinach (Spinacea oleracea L.) production and its above-ground removal, and (6) fallow. One plot size was 2.7 m × 7 m. For the four years, the same winter crop was grown in the same plot, and there were 12 different rice-winter crop rotation systems in total.

4. Cultural details

(1) Winter crops

Before this experiment, the paddy fields had been planted with rice during summer and fallowed during winter over the last 20 years. In 2000, rice grains were harvested early in October, and rice straw was incorporated and rotary-harrowed twice before the winter crops were sown. Five winter crops were broadcasted at the seedling rates of 10, 5, 4, 2 and 1.6 g m⁻² for wheat, italian ryegrass, chinese milk vetch, rapeseed and spinach, respectively. They were mixed with soils and pressed by roller to facilitate germination by better capturing capillary rise of soil water. One week prior to sowing, calcium silicate was applied at 100 g m⁻², and nitrogen, phosphate and potassium were applied at 5 g m⁻² each as ammonium sulfate, superphosphate, and potassium chloride, respectively.

In spring, all the above-ground parts of wheat, italian ryegrass and spinach were removed from the fields. Below-ground parts of wheat, italian ryegrass and spinach, and the whole plants of chinese milk vetch and rapeseed were incorporated into soil with a rotary tiller. Directions of tractor movements were along the 7 m - longer length of the rectangle plots to minimize soil mixings between the neighboring plots.

(2) Rice

Rice seeds (cv. Nipponbare) were treated with benenate (1 g L⁻¹, 12 hours) and soaked in water at 16°C for 3 days, and the pre-germinated rice seeds were sown on nursery boxes of 30 cm × 60 cm. Twenty-one day-old rice seedlings were transplanted in the spacing of 0.3 m × 0.15 m, with 1 plant per hill (22.2 plants m⁻²) on the paddy that had been applied with 3 g m⁻² of nitrogen, 1.9 g m⁻² of phosphorus and 3.3 g m⁻² of potassium (as ammonium sulfate, di-ammonium phosphate and potassium chloride), and twice puddled. This hill spacing is similar to Japanese conventional transplanting but the rates of basal fertilizer are lower (i.e. about half). Flooding irrigation was similarly applied in both trials for 2 weeks after transplanting to facilitate rooting and establishment. After that, in non-flooded trial irrigation supply was reduced and standing water never present except at times of heavy rain and occasional irrigation. A herbicide was applied about 1 week after transplanting in both trials. In non-flooded trial, another herbicide (clincher bus) was applied about 1 month after transplanting and hand weeding was conducted.

Fig. 1. Diagrams of water management of conventional flooded trial in 2001 and of the 4 years of watersaving non-flooded trials from 2001 to 2004. Presence of standing water and near-saturated soil moisture are illustrated with lines and dotted areas. Times of transplanting are marked with the strips at the left.
at once. Nets of 2 cm mesh were used to protect from bird damage after heading. Rice plants were harvested at the ground level by a combine harvester, chopped rice straw were left on the paddy fields, and incorporated during land preparation before winter crop planting. The cultural details of rice production were similar in 4 years except slightly earlier transplanting in 2002 (cf. Table 1) and transplanting of two seedlings per hill in 2004.

5. Measurements

Mean daily air temperatures, solar radiation, and rainfall were measured at the weather station inside Field Production Science Center. During rice planting season, rainfall was less in 2001 (i.e. 347 mm) compared with that in the other years (805 - 898 mm). Amount of irrigation supply during rice planting was monitored by two flow meters, FMDS20, with its diameter 33.2 mm and its standard flowing rate 4 m$^3$ per hour (Aichi-tokei-denki, Co., Japan), each attached at the water inlet between the irrigation canal and paddy field in flooded and non-flooded trials, and it was connected with the data logger (Hobo H06-001-02, Onset Inc., Bourne, USA).

Heading dates of rice were recorded. Above-ground biomass of winter crops at harvest and rice at maturity were determined for 1 m $\times$ 1 m and 0.6 m $\times$ 0.9 m of each plot, respectively, after drying at 80°C for more than 3 days. Grain yield of rice plants were also determined after threshing, by adjusting moisture content to 14%. Harvest index was determined as the ratio of oven dried grain to above-ground biomass.

Total amounts of water supply during rice growth were calculated both for flooded and non-flooded trials by summing the amounts of irrigation water and rainfall, and water productivity (Tuong, 1999) was calculated as grain yield divided by the total amounts of water supply for each trial. Nitrogen concentration per dry matter was measured by NC analyzer (Sumigraph NC-90A, SCAS, Oosaka, Japan) for the above-ground parts of winter crops at the final harvest in 2002 and 2004. Concentrations of total nitrogen in irrigation water, rainfall, and standing water were measured with a total nitrogen analyzer (TN-301P, Anatec Yanaco, Kyoto, Japan). Percolating water below 20 cm depth were sampled by soil water samplers (DIK-8390, Daiki Rika Kogyo Ltd., Saitama, Japan), and the concentrations of nitrate-nitrogen and nitrite-nitrogen were measured by high performance liquid chromatography (L-6000, Hitachi, Ltd., Tokyo, Japan) (Ishikawa et al., 2003). Concentrations of sulphate, fluoride and chloride were also determined. These measurements were conducted both at the beginning and the end of one irrigation cycle, or at the beginning of heavy rainfall, in both flooded and non-flooded trials.

6. Economic analysis

A simple analysis of cost, income and profit was conducted for the 12 rice-winter crop rotation systems. Production costs both for materials and labors were basically estimated from the available statistical information (MAFF, 1993, 1995a,b, 2005a,b, 2006) but modified considering the unique aspects of management in this experiment (e.g. less intensive management). For example, material cost for Italian ryegrass were estimated from the actual fertilizer cost in this experiment (57,000 yen ha$^{-1}$) instead of 151,000 yen ha$^{-1}$ (MAFF, 1995a). Labor requirement for spinach is large (2633 hours ha$^{-1}$; MAFF, 2005b) and we assumed that only 0.67 ha out of 1 ha of the paddy could be assigned as spinach and the other 0.33 ha as winter-fallow, considering the realistic available labors (cf. 0.67 ha is average farm size for spinach farmer, MAFF, 2005b). Unit wage was assumed as 1,000 yen hour$^{-1}$. Material (785,000 yen ha$^{-1}$) and labor (467,000 yen ha$^{-1}$) costs for rice production (MAFF, 2005a) were both multiplied by 0.7 to take into account less agricultural material and labor input in this experiment and in general in urban rice production (e.g. one thirds of fertilizer amount) for the calculation in flooded trial. In non-flooded trial the additional herbicide cost (11,000 yen ha$^{-1}$) was added to material cost. It was also taken into account that labor for water management was much less in non-flooded trial (10 hours ha$^{-1}$) than under conventional flooded water management (i.e. 70 hours ha$^{-1}$ out of the total labor of 326 hours ha$^{-1}$, MAFF, 2006). Labor for hand-weeding once and spraying the additional herbicide (10 hours ha$^{-1}$) was added in non-flooded trial. Considering possible future water crisis (Brown, 2006), a hypothesis was made that agricultural irrigation water would be charged, and the cost of irrigation water was intentionally set as 27 yen m$^{-3}$ (approximately 0.24 US$ m$^{-3}$), with which value the incomes from non-flooded trial becomes comparable with those from flooded trial in this study. This value is roughly 15% of the average city water price in Japan (Takeda, 2001).

The revenues from winter crops and rice were calculated from the measured average yield in this experiment and the unit price from the statistical information; with the producer’s price of wheat 158.4 yen ha$^{-1}$ (on average from 2001 to 2004, MAFF, 2005a), the price of fresh Italian ryegrass 8.3 yen kg$^{-1}$ (MAFF, 1995a), the price of spinach 347.5 yen kg$^{-1}$ fresh weight (MAFF, 2005b). In case of the landscape crops (i.e. Chinese milk vetch and rapeseed), local government subsidiary for promotion of creating good urban landscapes (e.g. flowery scenery in spring) was assumed to be 300,000 yen ha$^{-1}$, which is almost equivalent to the amounts of support for one agricultural or landscape creation project in the local government of Nishitokyo city in 2004 (Nishitokyo...
City, 2005; www.city.nishitokyo.lg.jp/siseizyoho/zaisei/hozyo_hutankin/files/16jigyo.pdf). For rice, we used 403 yen kg\(^{-1}\) of polished rice as a retailers’ price in urban areas in Japan (MAFF, 2005a) instead of producers’ price of brown rice (ca. 250 yen kg\(^{-1}\)), by assuming that rice produced in urban paddy can be directly sold to consumers. Polished rice weight was assumed as 80% of rice grain.

Income and profit of winter crop and rice were calculated as revenue minus material costs, and revenue minus material and labor costs, respectively. For rice, both of the calculation was conducted to include/exclude the hypothetical irrigation water cost. Total income in each of the 12 rice-winter crop rotation systems was calculated, and presented as the relative values with flooded rice-winter fallow system regarded as 100%.

### Table 2. Irrigation water supply (mm), proportion of irrigation water to total water supply (%), total water use (mm), numbers of dry spell of longer than 7 consecutive days and its cumulative duration (days) (a), and biomass (g m\(^{-2}\)), harvest index, and grain yield (g m\(^{-2}\)) and water productivity (kg m\(^{-3}\)) of (b) rice in flooded (F) and non-flooded (NF) trials from 2001 to 2004. The percentage of irrigation water supply and total water use and grain yield in non-flooded trial compared with flooded trial were also shown in parenthesis. Effects of year (Y), water-saving (Wat), winter cropping (Win) and their interactions (Y x Wat, Y x Win, Wat x Win, Y x Wat x Win) were shown for biomass, harvest index and grain yield in combined analysis of all 4 years.

#### (a)

| Year | Irrigation water supply (mm) | Proportion of irrigation water (%) | Total water use (mm) | Numbers of dry spell | Cumulative duration of dry spell (days) |
|------|-----------------------------|-----------------------------------|----------------------|---------------------|----------------------------------------|
| 2001 | F 4317                      | 85                                | 5077                 | 2                   | 18                                     |
|      | NF 504 (12)                  | 40                                | 1265 (25)            | 10                  | 71                                     |
| 2002 | F 2171                      | 72                                | 3024                 | 1                   | 8                                      |
|      | NF 3468 (160)                | 80                                | 4321 (143)           | 1                   | 8                                      |
| 2003 | F 3323                      | 80                                | 4162                 | 1                   | 12                                     |
|      | NF 629 (19)                  | 43                                | 1468 (35)            | 3                   | 29                                     |
| 2004 | F 3070                      | 79                                | 3876                 | 0                   | 0                                      |
|      | NF 903 (29)                  | 53                                | 1709 (44)            | 3                   | 21                                     |

#### (b)

| Year | Biomass (g m\(^{-2}\)) | Harvest index | Grain yield (g m\(^{-2}\)) | Water productivity (kg m\(^{-3}\)) |
|------|------------------------|---------------|-----------------------------|------------------------------------|
| 2001 | F 743                  | 0.446         | 392                         | 0.077                              |
|      | NF 463*                | 0.345*        | 186* (47)                   | 0.147                              |
| 2002 | F 1103                 | 0.419         | 535                         | 0.177                              |
|      | NF 884                 | 0.425         | 424* (79)                   | 0.098                              |
| 2003 | F 771                  | 0.443         | 392                         | 0.094                              |
|      | NF 506*                | 0.419         | 230* (61)                   | 0.165                              |
| 2004 | F 850                  | 0.475         | 455                         | 0.117                              |
|      | NF 656                 | 0.416         | 312 (64)                    | 0.183                              |

| Y    | ** | ** | ** | n.a. |
|------|----|----|----|------|
| Wat  | ** | ** | ** | n.a. |
| Win  | ns | ns | ns | n.a. |
| Y x Wat | ns | ** | * | n.a. |
| Y x Win | ns | ns | ns | n.a. |
| Wat x Win | ns | ns | ns | n.a. |
| Y x Wat x Win | ns | ns | ns | n.a. |

**, *, +, ns; significant difference at P=0.01, 0.05, 0.10 and non significant difference at P=0.10, respectively. Values in non-flooded trial followed by * show significant effects of water-saving in separate analysis for a year. n.a.; not available.
Analysis of variance was conducted for winter crop biomass, and grain yield, biomass and harvest index of rice with split-plot design with water-saving as the main effect and winter cropping as sub effect:
\[ X = \mu + \text{wat} + \text{wat}^*\text{b} + \text{win} + \text{win}^*\text{wat} + \varepsilon, \]
where \( \text{wat}, \text{win}, \text{wat}^*\text{b}, \text{win}^*\text{wat}, \) and \( \varepsilon \) were effects of water-saving, and winter cropping, interactions between water-saving and block, and between winter crops and water-saving, and residual errors. Combined analysis of both 4 years and 3 years excluding 2002 were also conducted to estimate yearly effect and interactions of year with either water-saving or winter cropping.

Results

1. Rice production

(1) Water management for rice production

In the flooded trial, standing water was maintained almost all the time until early grain-filling stage in all 4 years (cf. Figure 1). The amounts of irrigation water ranged from 2171 to 4317 mm, with the largest requirement in 2001 and smallest in 2002 (Table 2a). No irrigation water was supplied after flowering in 2002 because of sufficient and frequent rainfall in September. In the non-flooded trial, irrigation supply was much lower in 2001, 2003 and 2004 (12, 19 and 29% of the amounts in flooded trial of the corresponding year), with their amounts ranging from 504 to 903 mm. In 2002, surface soil moisture was intended to maintain near soil saturation level even after cracks developed in surface soil, and greater amount of irrigation (i.e. 3468 mm) was required to overcome increasing infiltration through cracks (Table 2a). The proportion of irrigation water to total (=irrigation + rainfall) water supply were 72 to 85% in flooded trial, while the corresponding values were 40 to 53% except for 2002 (i.e. 80%) in the non-flooded trial. The volumetric soil water content in flooded soils in 2003 were around 75% which declined to 65% at the early grain-filling stage after standing water disappeared, while in the non-flooded trial, soil volumetric water content in the 0-20 cm soil layer was 66% on 12 July, which declined to 59% during the early grain-filling stage. The number and cumulative duration of dry spells of longer than 7 days were less frequent and fewer in flooded (0 to 2 times and 0 to 18 days) than non-flooded (1 to 10 times and 8 to 71 days) trials, and among the non-flooded trial they were least in 2002 and greatest in 2001.

(2) Grain yield and water productivity of rice

Biomass production and grain yield was highest in the flooded trial in 2002, due to slightly earlier transplanting and consequent longer growth duration (Table 2b). Grain yield in 2004 was second highest (significant yearly effects were observed both in 4 years and in 3 years excluding 2002). Grain yield in non-flooded trial reduced compared with flooded trial, and the larger the amounts of saved water, the lower the yield (Figure 2). In 2002, grain yield in the non-flooded trial was reduced 21% compared with that in the flooded trial; the reduction rate was highest in 2001 (53 %) and moderate in 2003 (40 %) and 2004 (32 %). Water productivity in flooded trial varied among years, but that in the non-flooded trial was reduced 21% compared with that in the flooded trial; the reduction rate was highest in 2001 (53 %) and moderate in 2003 (40 %) and 2004 (32 %). Water productivity in flooded trial varied among years, but that in the non-flooded trial (0.164 kg m\(^{-3}\)) on average, ranging from 0.147 to 0.183 kg m\(^{-3}\)) than flooded trial (0.096 kg m\(^{-3}\) on average, ranging from 0.077 to 0.117 kg m\(^{-3}\)), except for 2002 when water productivity was higher in the flooded trial than in the non-flooded trial.
Winter-crop production and its effects on rice production

(1) Winter cropping

Biomass of 5 winter crops at harvest greatly varied with the kind of crop. It was largest in wheat, followed by Italian ryegrass, rapeseed, spinach, and Chinese milk vetch in this order (Table 3). Yearly variation was also large, and biomass was highest in 2001. In 2003, due to the scarce rainfall after sowing, emergence and seedling establishment were poor, and rapeseed and Chinese milk vetch did not grow well. Seedling establishment of wheat was also poor in 2004. Among the 3 years except for 2003, effects of year, winter cropping, and their interaction were significant in combined analysis (P < 0.01). There was only a small and non-significant effect of water regimes for rice cultivation (i.e. flooded or non-flooded) on biomass production of winter crops in 4 years, although in 2003 wheat biomass after flooded rice production was greater than that after non-flooded rice production (i.e. significant interaction of water regime and winter cropping). At the harvest time in both 2002 and 2004, Chinese milk vetch had the highest nitrogen concentration (3.0%), while wheat (1.2%) had the lowest values on average of 2002 and 2004. Nitrogen accumulation was least in spinach (3.7 g m⁻²), followed by rapeseed (4.9 g m⁻²), vetch (3.0 g m⁻²), and Italian ryegrass (5.7 g m⁻²) in this order, and was by far highest in wheat (14.0 g m⁻²).

(2) Effects of winter cropping on rice production

There were no-significant effects of winter cropping and interaction of winter cropping with water-saving on rice grain yield, harvest index and biomass in...
Table 5. Concentrations of nitrogen, sulphate \((\text{SO}_4^2-)\), fluoride (Ft), and chloride (Cl) in water sources (irrigation water or rainfall), standing water and percolating water in flooded (F) and non-flooded (NF) trials, after irrigation and after heavy rainfall. Average values and standard errors were presented. Standing water and percolating water were sampled both at the beginning and at the end of irrigation or rainfall events.

| Chemical concentrations | trial | Water source (irrigation/ rainfall) | Standing water beginning of event | Percolating water beginning of event | end of event | end of event |
|-------------------------|-------|-------------------------------------|----------------------------------|-------------------------------------|--------------|--------------|
|                         |       | after irrigation (average of 4 cycles) |                                  |                                     |              |              |
| Nitrogen* (mg L\(^{-1}\)) | F     | 5.54 ± 0.96                         | 4.40 ± 1.10                     | 2.17 ± 0.93                        | 0.27 ± 0.09  | 0.07 ± 0.02  |
|                         | NF    | 5.35 ± 0.37                         | 11.90 ± 1.05                    | 11.67 ± 0.73                       | 22.75 ± 0.94 | 23.24 ± 1.12 |
| Sulphate (mg L\(^{-1}\)) | F     | 9.93 ± 5.38                         | 8.33 ± 1.34                     | 0.45 ± 0.05                        | 0.44 ± 0.14  | 0.45 ± 0.12  |
|                         | NF    | 0.27 ± 0.02                         | 0.47 ± 0.02                     | 0.38 ± 0.09                        | 0.40 ± 0.11  |              |
| Fluoride (mg L\(^{-1}\)) | F     | 16.36 ± 0.84                        | 15.56 ± 1.05                    | 15.57 ± 0.11                       | 14.81 ± 0.90 | 13.92 ± 1.24 |
|                         | NF    | 16.67 ± 1.50                        | 16.67 ± 1.50                    | 15.89 ± 0.60                       | 14.75 ± 0.29 |
|                         |       | after heavy rainfall (average of 3 occasions) |                                  |                                     |              |              |
| Nitrogen* (mg L\(^{-1}\)) | F     | 1.32 ± 0.77                         | 4.19                            | -                                   | 0.04 ± 0.02  | -            |
|                         | NF    | 1.01                                | 4.44                            | -                                   | 0.10 ± 0.08  | -            |
| Sulphate (mg L\(^{-1}\)) | F     | 2.04 ± 0.62                         | 8.44                            | -                                   | 29.54 ± 13.80 | -         |
|                         | NF    | 4.26                                | 4.26                            | -                                   | 35.74 ± 15.65 | -         |
| Fluoride (mg L\(^{-1}\)) | F     | 0.08 ± 0.03                         | 0.33                            | -                                   | 0.54 ± 0.22  | -            |
|                         | NF    | 0.32                                | 0.32                            | -                                   | 0.50 ± 0.19  | -            |
| Chloride (mg L\(^{-1}\)) | F     | 1.36 ± 0.57                         | 9.30                            | -                                   | 11.16 ± 0.97 | -            |
|                         | NF    | 2.00                                | 2.00                            | -                                   | 11.85 ± 0.63 | -            |

*: Total nitrogen concentration for water source and standing water, and sum of nitrate- and nitrite-nitrogen concentrations for percolating water.
- : not measured.

combined analysis of 4 years (Table 2b). In separate analysis of each year, the effects on harvest index were significant in 2001 (P<0.10 for interaction), in 2003 (P<0.05 for winter cropping), and in 2004 (P<0.01 for winter cropping effect and P<0.05 for interaction). Grain yield of rice after any 5 species of winter crops on average of 4 years yielded slightly higher than after-fallow rice yield both in flooded and non-flooded trials, though not significant (Table 4). Rice after rapeseed showed the highest relative yield on the average of the 4 years (109 and 108% in flooded and non-flooded trials, respectively).

3. Chemical constituents of paddy water

Irrigation water contained 5.5 mg L\(^{-1}\) of total nitrogen on the average, ranging from 3.4 to 6.9 mg L\(^{-1}\) across the 4 occasions (Table 5). Most of the nitrogen was in the form of nitrate (data not shown). Standing water immediately after the start of irrigation contained slightly less total nitrogen (4.4 and 5.4 mg L\(^{-1}\) in flooded and non-flooded trials, respectively) than irrigation water in the canals. Total nitrogen concentration of standing water in flooded trial decreased by the end of the first cycle of irrigation (ca. 2.2 mg L\(^{-1}\)). The concentration of total nitrate-nitrogen and nitrite-nitrogen in the percolating water was low, due to the rapid heterotrophic denitrification or absorption by rice plants in both flooded and non-flooded trials. The concentrations of nitrate-nitrogen and nitrite-nitrogen in percolating water in a non-flooded trial were slightly higher than in flooded trial, and the concentrations were higher at the beginning of the irrigation cycle (0.27 and 0.71 mg L\(^{-1}\) for flooded and non-flooded trials, respectively) than at the end of the cycle (0.07 and 0.19 mg L\(^{-1}\), respectively). Concentrations of fluoride and chloride were stable across measurements but the sulphate concentration was slightly higher in percolating water than the water resources or standing water.

4. Economic analysis

A simple analysis of cost, income and profit analysis was conducted for the 12 rice-winter crop rotation systems (Table 6). For rice production, the hypothetical irrigation water cost was set as 27 yen m\(^{-3}\) so that the income of non-flooded trial was comparable with that of the flooded trial. The sum of cost excluding hypothetical water cost was slightly
Table 6. Simple economic analysis of costs, income and profit of winter crops and rice production for relative comparison of 12 rice-winter crop rotation systems.

| Cost/revenue/income/profit | Winter cropping | Wheat | Italian ryegrass | Chinese milk vetch | repseed | spinach | fallow | rice production |
|----------------------------|-----------------|-------|------------------|------------------|--------|---------|--------|-----------------|
| Material cost (1) (1000 yen ha\(^{-1}\))\(^{a}\) | Flood trial | Material cost | 414 | 131 | 42 | 160 | 318 | 0 |
|                       | Non-flooded trial | Material cost | 87 | 61 | 8 | 77 | 1764 | 0 |
| Labor cost (2) (1000 yen ha\(^{-1}\))\(^{b}\) | Flood trial | Labor cost | 501 | 191 | 50 | 237 | 2083 | 0 |
| Sum cost (3) (=1+2) (1000 yen ha\(^{-1}\)) | Flood trial | Sum cost | 4500 | 23130 | 1s | 1s | 6570 | 0 |
| Yield (4) (kg ha\(^{-1}\)) | Flood trial | Yield | 713 | 61 | 288 | 140 | 1211 | 0 |
| Revenue (5) (1000 yen ha\(^{-1}\))\(^{c}\) | Flood trial | Revenue | 299 | 61 | 288 | 140 | 1211 | 0 |
| Income (6) (=5-1) (1000 yen ha\(^{-1}\))\(^{d}\) | Flood trial | Income | 212 | 0 | 250 | 65 | 553 | 0 |
| Profit (7) (=5-3) (1000 yen ha\(^{-1}\)) \(^{e}\) | Flood trial | Profit | | | | | | |
| Material cost (8) (1000 yen ha\(^{-1}\))\(^{f}\) | Flood trial | Material cost | 550 | 131 | 42 | 160 | 318 | 0 |
|                       | Non-flooded trial | Material cost | 560 | 131 | 42 | 160 | 318 | 0 |
| Labor cost (9) (1000 yen ha\(^{-1}\))\(^{g}\) | Flood trial | Labor cost | 87 | 61 | 8 | 77 | 1764 | 0 |
| Sum cost (10) (=8+9) (1000 yen ha\(^{-1}\)) \(^{h}\) | Flood trial | Sum cost | 877 | 877 | 877 | 877 | 877 | 877 |
| Sum cost including hypothetical water cost (10) (1000 yen ha\(^{-1}\)) \(^{i}\) | Flood trial | Sum cost | 838 | 838 | 838 | 838 | 838 | 838 |
| Yield (11) (kg ha\(^{-1}\)) | Flood trial | Yield | 1746 | 1746 | 1746 | 1746 | 1746 | 1746 |
| Revenue (12) (1000 yen ha\(^{-1}\)) \(^{j}\) | Flood trial | Revenue | | | | | | |
| Income (13) (=12-8) (1000 yen ha\(^{-1}\)) \(^{k}\) | Flood trial | Income | | | | | | |
| Income considering hypothetical water cost (15) (1000 yen ha\(^{-1}\)) \(^{l}\) | Flood trial | Income | | | | | | |
| Profit (14) (=12-10) (1000 yen ha\(^{-1}\)) \(^{m}\) | Flood trial | Profit | | | | | | |
| Profit considering hypothetical water cost (14') (=12'-10') (1000 yen ha\(^{-1}\)) \(^{n}\) | Flood trial | Profit | | | | | | |

**Notes:**

\(^{a}\) Material costs for wheat from MAFF (2005a), Italian ryegrass from MAFF (1995a) modified by reducing the fertilizer costs from 151,060 yen ha\(^{-1}\) (MAFF, 1995a) to 56,679 yen ha\(^{-1}\) in this experiment (i.e. 1.000 kg ha\(^{-1}\) of calcium silicate (29.6 yen kg\(^{-1}\)), 228 kg ha\(^{-1}\) of ammonium sulphate (34.3 yen kg\(^{-1}\)), 294 kg ha\(^{-1}\) of superphosphate (49.2 yen ha\(^{-1}\)), 83 kg ha\(^{-1}\) of potassium chloride (54.2 yen kg\(^{-1}\)) (Fertilizer Association, 2005)), and Chinese milk vetch from the value of pasture legume (2002 yen 100 kg\(^{-1}\); MAFF, 1995a, since there were no statistical data for chinese milk vetch per se) multiplied by the average yield of chinese milk vetch in this experiment (2000 kg ha\(^{-1}\)) harvested from MAFF (1995a), spinach from MAFF (1995b) multiplied by 0.67 assuming the attainable field size of spinach production as 0.67 ha which were the average field size of spinach farmers in Japan (MAFF, 2005b).

\(^{b}\) Labor cost for wheat from MAFF (2005a), Italian ryegrass assuming the wheat value multiplied by 0.7, Chinese milk vetch from the value of pasture legume (MAFF, 1995a, since there were no statistics of chinese milk vetch per se) modified by reducing from (806 yen 100 kg\(^{-1}\)) to (403 yen 100 kg\(^{-1}\)) considering the much less intensive management in this experiment and multiplied by the average yield of chinese milk vetch in this experiment (2000 kg ha\(^{-1}\)) harvested from MAFF (1995a) multiplied by reducing from 250290 yen ha\(^{-1}\) to 72294 yen ha\(^{-1}\) considering the plants were incorporated after flowering without harvesting nor threshing the crop, spinach from the required labor (265.35 hours 10\(^{3}\) ha\(^{-1}\); MAFF, 2005b) multiplied by assumed unit labor cost (i.e. 1.000 yen hour\(^{-1}\)) multiplied by 0.67 assuming the attainable field size of spinach production (see the note of a).

\(^{c}\) Average yield of 4 years from this experiment; grain of 14% moisture content, 94% fresh weight of above-ground part for Italian ryegrass, fresh weight of above-ground part for spinach, flowery landscape (b) for Chinese milk vetch and rapeseed.

\(^{d}\) Revenue from yield multiplied by average unit price from 2001 to 2004 (158.4 yen kg\(^{-1}\) for wheat, 8.29 yen kg\(^{-1}\) for fresh Italian ryegrass, 347.5 yen kg\(^{-1}\) fresh spinach).

\(^{e}\) The factor 0.67 was multiplied for spinach assuming the attainable field size of spinach production (see the notes a and b). For Chinese milk vetch and rapeseed, it was assumed to be 300,000 yen ha\(^{-1}\) of subsidy from local government for creation of better urban landscape and land use.

\(^{f}\) Income is calculated by subtracting material costs from the revenue.

\(^{g}\) Profit is calculated by subtracting total sum of costs (both material and labor costs) from revenue.

\(^{h}\) Material cost for rice production in flooded trial from MAFF (2005a) (i.e. 785,260 yen ha\(^{-1}\)) as Japanese average) modified by multiplying 0.7 considering the smaller agricultural input in this experiment and the general situations of urban rice production (e.g. smaller input of fertilizers). For non-flooded trial, the cost for extra herbicides use was added (10,815 yen ha\(^{-1}\) for 250 ml of clonicher bus).

\(^{i}\) Labor cost for rice production in flooded trial from MAFF (2005a) multiplied by 0.7 considering slightly shorter rice growing period in this experiment compared with common average rice growing duration in Japan, and also generally less labor input in urban paddly rice farmers. In non-flooded trial, labor for water management was much less (1 hours 10\(^{a}\) ) than flooded trial (7 hours 10\(^a\) ) but extra labor for hand weeding plus spraying the additional herbiide (1 hours 10\(^a\) ) was needed. Using the reported value of 32.59 hours 10\(^a\) (MAFF, 2005a), the labor cost for rice production in non-flooded trial was calculated.

\(^{j}\) Hypothetical water cost was added to the sum cost (10). The hypothetical water cost was calculated by multiplying the average amounts of irrigation water supply in 4 years (32,200 m\(^3\) and 15,760 m\(^3\) in flooded and non-flooded trial, respectively) by the hypothetical rate (27 yen m\(^{-1}\); about 15 % of city water cost), considering possible future water crisis.

\(^{k}\) Average yield of 4 years from this experiment with grain of 14% moisture content (Table 4).

\(^{l}\) Revenue of rice production from polished rice yield multiplied by consumers price in urban areas (403 yen kg\(^{-1}\) polished rice; MAFF, 2005a). Polish rice to rice grain ratio was assumed 0.8.

\(^{m}\) Income is calculated by subtracting material costs from the revenue.

\(^{n}\) Hypothetical water cost is calculated by subtracting material costs including the hypothetical water cost from the revenue.

\(^{o}\) Profit is calculated by subtracting total sum of costs (both material and labor costs) from revenue.

\(^{p}\) Profit is calculated by subtracting the hypothetical water cost from the hypothetical water cost calculated by subtracting total sum of costs including the hypothetical water cost from revenue.

\(^{q}\) Positive and negative values show higher and lower than flooded rice-fallow rotation system, respectively.

Sources: Fertilizer Association 2005, Ministry of Agriculture, Forestry and Fisheries (1993, 1995a,b, 2005a,b, 2006).
higher in flooded (877,000 yen ha$^{-1}$) than in the non-flooded (838,000 yen ha$^{-1}$) trials due to higher labor cost for water management. The sum cost including the hypothetical irrigation-water cost was much higher in the flooded trial than in the non-flooded trial (1,419,000 vs. 932,000 yen ha$^{-1}$), due to the higher cost of agricultural irrigation water. The revenue, income and profit excluding hypothetical-water cost were much higher in the flooded trial due to its higher rice yield and high price of rice in this study (403 yen kg$^{-1}$). Because of crude assumption of the high hypothetical irrigation water cost, the income becomes low and profit becomes negative if including hypothetical water cost; the income is similar between the two trials, and the profit becomes higher (i.e. less negative values) in non-flooded trial.

Among the five winter crops, as was expected, spinach production resulted in the highest income (1,211,000 yen ha$^{-1}$) and it was also higher than the income from rice, because of its high price (348 yen kg$^{-1}$). However, the labor requirement for spinach is large and hence its profit became negative value (~553,000 yen ha$^{-1}$). The second highest income is from wheat (299,000 yen ha$^{-1}$), followed by chinese milk vetch (258,000 yen ha$^{-1}$) and rapeseed (140,000 yen ha$^{-1}$). Production cost for chinese milk vetch was low (i.e. 50,000 yen ha$^{-1}$) due to less intensive management, and its profit was highest (250,000 yen ha$^{-1}$) among the 6 winter cropping including the winter fallows. The rice-spinach system had highest relative income among the 6 rice-winter crop rotation systems (257 and 192 % in flooded and non-flooded trials excluding hypothetical water cost, respectively). The second is the rice-wheat system, followed by a rice-chinese milk vetch system, and rice-rapeseed system.

Discussion

1. Water-saving rice culture

Under the extreme water-saving and semi-rainfed conditions, with about 40 to 50 % contribution of irrigation to total water supply, under which with more than 70% of irrigation water was omitted in the non-flooded trial compared with the flooded trial (i.e. 3 years of 2001, 2003 and 2004 except for 2002), water productivity was higher (0.16 kg m$^{-2}$) in non-flooded trial compared with flooded trial (0.10 kg m$^{-3}$) in spite of lower grain yield (58 % in non-flooded trial compared with flooded trial). Among these 3 years, both grain yield and water productivity of non-flooded trial was largest in 2004 because of largest amounts of irrigation and total water supply, least frequent dry spells, and transplanting of 2 seedlings per hill. As is discussed later, the transplanting of multiple seedlings per hill would be recommended under water-saving rice-winter crop rotation, to secure sufficient numbers of panicles and biomass. This is because rice tiller production is often reduced under water-limited conditions (Hayashi et al. 2006; Kato et al. 2006a), and late transplanting after winter crop harvest shortens the duration of biomass production of rice (Hasegawa and Horie, 1995). In 2002, grain yield in the non-flooded trial in 2002 was higher than 2004 due to slightly earlier planting and more frequent irrigation supply, but small cracks developed in non-flooded paddy soils after short dry spells increasing the percolation rate, and irrigation water-saving was not achieved reducing the value of water productivity.

In non-flooded paddy fields, the soil water content was not so low, but both vegetative growth and reproductive organ development and grain formation were restricted more or less. The content of total nitrogen dissolved in and delivered from irrigation water (i.e. 5.5 mg L$^{-1}$, average of measurements) was estimated to be lower in non-flooded trials than in flooded trials (7.6 vs 17.8 g m$^{-2}$, average of 4 years). Heterotrophic denitrification in surface soil water increased in non-flooded conditions due to increases in easily decomposable organic matter, reducing availability of nitrogen in non-flooded trial. It would be noteworthy that rainfed upland rice sometimes achieves greater water productivity than comparable grain yield with flooded rice under the favorable conditions without long dry spells and with sufficient fertilizer application (Kato et al., 2006a, b). In their report, growth duration was longer and vegetative growth was greater under upland conditions than under flooded lowland conditions. More detailed physio-morphological responses of rice plants under non-flooded lowland conditions will be reported in a subsequent paper.

Nitrate and nitrite concentrations in the percolating water were slightly higher in non-flooded trial. This would be because the irrigation water quickly passed through the small cracks developed on surface soil layers in the non-flooded trial, after several days of disappearance of standing water. Nevertheless, those concentration values (0.1-1.3 mg L$^{-1}$ immediately after irrigation started and 0.0-0.4 mg L$^{-1}$ just before next cycle of irrigation) were greatly lower than the environmental standards value (<10 mg L$^{-1}$) set by WHO (CAST, 1992) and those reported in studies of nitrate contamination of groundwater in rice-based cropping systems in Philippines (Bouman et al., 2002). The concentrations of sulphate, fluoride and chloride were also below the environmental standard values.

2. Rice-winter crop rotation system

In spite of rather extensive management such as broadcasting and no additional fertilizer application, winter wheat produced over 1200 g m$^{-2}$ of above-ground biomass in 3 out of the 4 years. This is higher than the biomass of rice in flooded trial in summer, partly because of longer planting durations of wheat (i.e. more than 7 months) compared with rice (i.e. 4
months). Currently, Ministry of Agriculture, Forestry
and Fisheries in Japan is promoting to increase plant
biomass production in Japan, known as "Biomass Japan
Project", with the emphasis on summer crops such as
kenaf and sugarcane (http://www.maff.go.jp/biomass/
shiryo_top.htm). However, cultivation of winter cereals
such as wheat, barley, rye and triticale, may play an
important role for biomass production and nitrogen
accumulation as well as land conservation. Using high
dry-matter-producing rye plants, which can be used
as domestic forage or for producing fuel-alcohol, and
row seeding rather than broadcasting, rye over 2000 g
m$^2$ of above-ground biomass was produced in Tokyo
(Kamoshita, 2002).

As is well-known, the cropping schedule of the
rice-winter crop rotation system, particularly rice-
wheat rotation, is tight (e.g. the interval between
rice harvest and winter crop seeding ranged from 19 to 22 days, while that between the wheat harvest
and rice transplanting was from 12 to 18 days), and
transplanting time of rice was several weeks to a month
later (i.e. 31 May to 25 June) in this experiment than
the current conventional transplanting time of rice (i.e.
early to mid May in mono-culture in Kanto district in
Japan). Besides, one seedling was planted per hill in all
years except for 2004, and these resulted in rather low
yield in this experiment (i.e. 392 to 535 g m$^{-2}$ in
flooded trials in the 4 years). Transplanting multiple
seedlings per hill or denser planting may improve
productivity of late transplanted rice in rice-winter
crop rotation systems, as indicated in the results of
2004.

The effect of winter cropping for 4 years on rice
yield was slight but positive on average. There are some
reports of yield decline in the long-term rice-wheat
system (Timsina and Connor, 2001), which may be
due to nutrient imbalance, at least partly as reported
elsewhere (Fujisaka et al., 1994). In this experiment on
the contrary, winter cropping did not negatively affect
rice yield. Rice yield after the incorporation into soil
of rapeseed recorded high relative yields (121 and 130
% in 2001 and 2002 in flooded trial, 120 % in 2004 in
non-flooded trial, data not shown), and overall average
of 4 years were also highest in this cropping system (109
and 108 %; Table 4). The incorporated rapeseed and
Chinese milk vetch contained nearly the same amounts
of nitrogen as green manure or bio-fertilizer (ca. 5 g
m$^2$), but rapeseed had greater biomass and organic
materials, which may have more favorable effects on
soil amendments and rice growth compared with the
incorporation of chinese milk vetch (overall relative
yield 102 and 105 %). By enhancing the growth of
chinese milk vetch and rapeseed in winter, through
selection of superior cultivars or slightly earlier
sowing in autumn, a larger amount of nitrogen can be
accumulated as green manure, as reported for white
clover (e.g. 14 g m$^2$ of nitrogen, Cho et al., 2003),
resulting in a further increase in rice yield (Schulz et
al., 1999a,b). Nevertheless, the effects of these rice-
based cropping systems should be investigated for a
longer term, in order to judge the sustainability and
trend of productivity.

A simple analysis of cost, income and profit analysis
was conducted for the 12 rice-winter crop rotation
systems from the available statistical information
(MAFF, 1993, 1995a,b, 2005a,b, 2006; Fertilizer
Association, 2005) with modification considering 4
unique aspects of the management; less intensive
management, hypothetical irrigation water cost for
rice production as large as 27 yen m$^3$, high price of
rice through direct sales of rice to urban consumers
(i.e. 403 yen kg$^{-1}$), and local government subsidiary
for landscape winter crops (i.e. 300,000 yen ha$^{-1}$) (Table
6). Although this economic analysis is based on a
few hypotheses and the conclusions drawn from this
discussion are putative, our estimation of the economic
value of the different rice-winter crop rotation systems
is as follows.

Our study justified, with quantitative data, the
importance of development of water-saving rice
production system, under the condition that water
resource would become more and more limiting and
expensive. It is well known that the cost of water differs
greatly among the sectors and among countries; for
example, in Japan costs of city water and industrial
water are about 180 and 23 yen m$^3$, respectively, on
the average (MLIT, 2006) while the cost of agricultural
water is estimated as 64,120 yen ha$^{-1}$, that would
be converted into about 2 yen m$^3$ if the irrigation
requirement per area is the same as the flooded trial
in our study (i.e. 3220 mm). Because of government
policy to set agricultural water price at relatively low
level for food security and because of lower cost of
agricultural water management compared with city
and industrial water, current agricultural water cost
is much lower than city and industrial water in many
other countries too (JIID, 2003). The exception is
Austria and Netherland, where agricultural water is
also high in cost, more than 100 yen m$^3$ (e.g. 164 yen
m$^3$ or 1.44 US$ m$^3$ in Netherland; OECD, 1999). As
long as fresh water resources for paddy rice production
is abundant, both revenue and income continue to be
higher in flooded trial than non-flooded trial, but if
agricultural water should become more costly in future
(e.g. 27 yen m$^3$, a little bit higher than the cost for
industrial water and 15% of city water cost in Japan by
decreasing rainfall, fresh water pollution, promotion
of non-farming wet land conservation, or any changes
in government policy), water-saving non-flooded rice
production would become more important as shown
in this paper. In our calculation in this study, polished
rice was assumed to be sold at as high as 405 yen kg$^{-1}$
to urban affordable consumers, but if the price is set
lower, for example, 250 kg yen$^{-1}$ (brown rice basis)
(MAFF, 2005a), the income from non-flooded trial becomes comparable with that from the flooded trial with a lower hypothetical agricultural irrigation water cost (e.g. 18 yen m⁻³, which is roughly 10% of the current city water cost). Technical innovation of water-saving rice production is important, because both income and profit of non-flooded trial becomes higher if we could establish techniques to have a higher yield under non-flooded conditions.

As is expected, because of the high price of spinach (348 yen kg⁻¹), the rice-spinach system had the highest income among the 6 rice-winter crop rotation systems, but it may not always be recommended because of possible limitation of available labor and negative value of profit (cf Table 6). The second highest income was from rice-wheat system, followed by rice-chinese milk vetch system and rice-rapeseed system. High yielding wheat production with less material and labor input would be further pursued, which can be extended to urban farmers with greater chances. Production cost of chinese milk vetch was low due to less intensive management, and its profit was calculated as highest (250 yen ha⁻¹) among the 6 winter crops. Chinese milk vetch or rapeseed production for flowery landscape and for incorporation after flowering as bio-fertilizer, may be economically feasible due to their requirement of less input. As is well-known, most of the paddy fields in Japan before 1960 were used for winter crop production, unless the paddies are ill-drained (MAFF, 1960); wheat and barley were cultivated in 691,000 and 899,000 ha, respectively, in 1953, while each of rapeseed and chinese milk vetch in 240,000 ha overall Japan (MAFF, 1955). Cultivation of such winter crops stopped due to relative disadvantages of production costs compared with imported agricultural products from overseas, and due to smaller revenues from winter crop production compared with other industry. However, for improvement of the land use system and food self-sufficiency rate in Japan, development of sustainable rice-winter crop rotation system is probably inevitable. The role of urban civic society and/or urban local government will be particularly large for development of rice-landscape winter crop rotation system, as is shown for chinese milk vetch or rapeseed in this experiment. In Nishitokyo city, where this experiment was conducted, the annual subsidiary in this experiment was only 200,000 yen, about 0.04% of the city's total collected tax of 26,800,000,000 yen. The hypothetical value we set as subsidiary for chinese milk vetch or rapeseed cultivation during winter and spring in this study was only 300,000 yen ha⁻¹, which is similar to the amount distributed to the individual agricultural or landscape improvement project in Nishitokyo city in 2004 (Nishitokyo City, 2005; www.city.nishitokyo.lg.jp/siseiyoho/zaisei/hozyo_hutankin/files/16jigyo.pdf). In other local government in Japan, it is proposed as much as 5% of fixed property tax of a local government was proposed to be used as landscape tax, to maintain and promote better landscapes (Chubu Region Development Research Center, 2006).

Conclusions

In water-saving non-flooded trial, more than 70% of paddy irrigation can be saved and water productivity increased from 0.10 to 0.16 kg m⁻³, with the sacrifice of yield reduction (i.e. 58% of flooded trial). Yield reduction in water-saving non-flooded trial was minimized by frequent irrigation supply and transplanting of multiple seedlings per hill. From the first 4 years of rice-winter crop rotation systems tested in a suburb of Tokyo, any 5 species of winter crops did not negatively affect yield of rice, but rather, incorporation of rapeseed tended to increase yield of rice by about 9%. There were no harmful effects of nitrogen concentration of percolation water, and the income and profit were comparable between water-saving non-flooded trial and conventional flooded trial under the hypothesis that the cost of agricultural irrigation water is 15% of that of city water.

Acknowledgment

We thank Prof. A. Kiminami, University of Tokyo for his useful advice on economic analysis of rice-winter crop rotation systems. All the field experiments were technically assisted by N. Washizu, K. Ichikawa, C. Sasaki, H. Kimura, S. Nakata, and C. Yamazaki (Field Production Science Center) and financially supported by the special funds for inter-department studies from Graduate School of Agricultural and Life Science, The University of Tokyo.

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