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ARTICLE

Comparative analysis of temporal changes of multifunctionality benefit of two major rice paddy plains in Taiwan

Chen-Wuing Liu · Shih-Wei Zhang · Kuo-Hua Lin · Wei-Taw Lin

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Abstract Recently, free trade of farm land, changes of agricultural policy and global climate changes have resulted a significant reduction of rice planting area and the multifunctionality values of paddy field in Taiwan. This study aims to evaluate the temporal changes of multifunctionality benefit of two major rice paddy plains in Taiwan. The main agricultural production regions of the Chou-Shui river alluvial fan and Ping-Tung plain are selected for the comparative study. The replacement method is adopted to quantify the multifunctionality of the paddy field. The results show that percentage of cultivated paddy to the total paddy gradually decreases from 92 to 80% and the external value remains from 572,000 to 668,000 NT$/ha in the Chou-Shui river alluvial fan. Whereas, the percentage of area of cultivated paddy to the total paddy markedly decreases from 37 to 23% from 1999 to 2006 and resulting the external values of paddy only ranges from 156,000 to 258,000 NT$/ha in the Ping-Tung plain. To maintain the sustainable agriculture in the paddy field, government needs to formulate incentive policy to conserve the paddy farming, promote, and transmit the general understanding of the environmental and livinghood multifunctionality values to the people.

Keywords Chou-Shui river alluvial fan · Ping-Tung plain · Paddy field · Multifunctionality

C.-W. Liu (✉) · S.-W. Zhang
Department of Bioenvironmental Systems Engineering, National Taiwan University, Taipei 106, Taiwan
e-mail: cwliu@ntu.edu.tw; lcw@gwater.agec.ntu.edu.tw

K.-H. Lin · W.-T. Lin
Department Irrigation and Engineering, Council of Agriculture, Taipei 100, Taiwan

Introduction

Paddy rice is the staple food in Taiwan, Japan, Korea, as well as other rice-growing countries in Monsoon Asia. Paddy fields and their associated irrigation systems provide various functions not only for rice production but also for improving living and eco-environmental conservation. The multifunctionality of rice paddy has evolved to the unique rice culture for thousands of years in the Monsoon Asia. (Tsai et al. 2003; Kim et al. 2006).

After join the World Trade Organization (WTO), Taiwan has faced various problems including import of cheap foreign good, over production of local rice, and water resources allocation. Rice paddies are forced to convert to upland plant, set-aside or abandon. The multifunctionality value of the paddy farming is significantly damaged. Moreover, it will jeopardize the national food security and the sustainable agricultural management.

Chang and Ying (2005) estimated the willingness to pay (WTP) of the water preservation and land protection function for rice fields in Taiwan by the assumption that the water preservation and land protection function would completely disappear without government payment. Aizaki et al. (2006) used a realistic assumption to measure the multifunctionality of agriculture and rural areas in Japan. Huang et al. (2006) adopted the replacement method to evaluate the multifunctionality of paddy field in Taiwan. Chiueh and Chen (2008) used a realistic assumption to evaluate a selected pool of samples' willingness to pay (WTP) for the environmental multifunctionality of paddy fields. However, these studies do not considered the temporal changes of the multifunctionality of rice paddy.

The objective of this study is to evaluate the temporal reduction of multifunctnality benefit of paddy field. The replacement cost method is adopted to quantify the monetary value of rice paddy. Two major rice production areas, Chou-Shui river alluvial fan and Ping-Tung plain are selected to illustrate the annual decrease of the internal and external economic benefits of the rice paddy from 1999 to 2006. The significant reduction of the external value of the paddy field sends a late caveat to the society. It pleas that the government should take strong measures to preserve the rice paddy and maintain its multifuntionality.

Method

Study area

Figure 1 shows the Chou-Shui river alluvial fan and Ping-Tung plain located in the central-western and southern Taiwan with areas of 1,800 and 1300 km^2, respectively. Ground water resources are abundant in both regions. Agriculture is the major income source of the local resident. High quality of rice is produced and supplied the national need. In the 1980, aquacultural farming was intensively developed in the coastal area of these two plains. Large amount of groundwater had been withdrawn resulting seriously land subsidence.

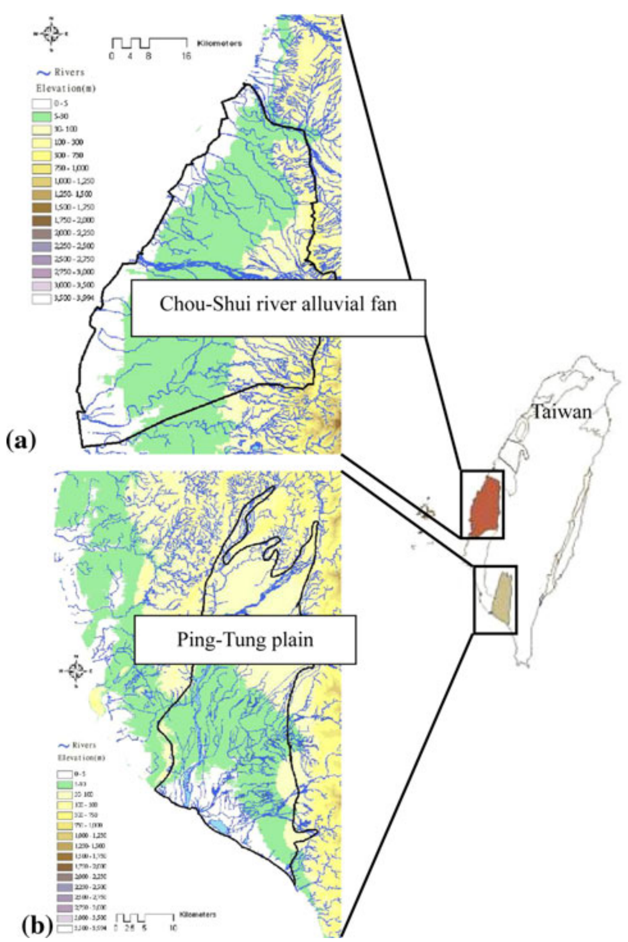

Fig. 1 Study regions **a** Chou-Shui river alluvial fan and **b** Ping-Tung plain. The boundary of two regions denotes by *black lines* in the map

Evaluation model

The study uses the replacement cost method to quantify the multifunctionality of paddy field. The quantified items are rice production, summer temperature cooling, CO_2 reduction, methane pollution, oxygen production, BOD removal, recreation, flood mitigation, groundwater recharge, and land subsidence reduction. Notably, the methane pollution represents a negative externality benefit and other evaluated items are considered as positive benefits of the rice paddy.

Rice production

The data of annual rice production are obtained from Annual Statistics of Agriculture (COA 1999–2006). Rice planting area, amount of rice production, and the unit sale price are compiled to evaluate the economical value of rice production annually.

Summer temperature cooling

When water evaporated from the ponding surface of paddy, it takes up heat from surrounding air, lowering the air temperature, especially in the summer. Using the thermal band of Landsat 7 satellite image, Tan (2004) has shown a 7.81°C temperature difference between paddy field and urban land cover. To evaluate the air-cooling effect, Wu (2003) shown that the net electric power saving of rice paddy is 4,497 unit power/ha/day. The total saving value of electrical power can be described by Eq. 1

$$\begin{aligned}&\text{Electric saving value(NT\$)}\\&= \text{rice plant acreage(ha)} \times \text{summer period(day)}\\&\quad \times \text{unit electric saving(unit power/ha/day)}\\&\quad \times \text{unit electric cost(NT\$ /unit power)} \qquad (1)\end{aligned}$$

where summer period (June 1–September 30) is 122 days, summer unit electric cost is 3.074 NT$/unit power based on the summer electric rate of the Taiwan Power Company.

Global warming gas

In the process of rice growing in the paddy field, air is purified through photosynthesis as it releases O_2 and fixes CO_2. Wu (2007) measured the CO_2 fixation of 1st and 2nd rice planting periods and they are 14.5 and 9.9 g/m^2/day, respectively. Various CO_2 reduction cost and CO_2 trading values are available (World Bank 2008). The Sweden government has set the carbon tax to 4,550 NT$/ton and the Chinese government set the CO_2 trading price to 1,000 NT$/ton. In Taiwan Lee et al. (2000) suggested the use of forest for CO_2 reduction. The estimated minimum cost for CO_2 fixation by forest was 1,960 NT$/ton. Liang et al. (2003) also calculated the social-economic cost of 1,937 NT$/ton for CO_2 fixation. The unit CO_2 reduction cost of 1,937 NT$/ton was adopted in this study. (Liang et al. 2003). The CO_2 reduction values of rice planting can be described by Eq. 2

$$\begin{aligned}&\mathrm{CO_2\ reduction\ value\ (NT\$)}\\&= \mathrm{unit\ CO_2\ fixation(kg/ha/day)} \times \mathrm{planting\ acreage\ (ha)}\\&\quad \times \mathrm{planting\ period(day)} \times \mathrm{unit\ fixation\ value(NT\$\ /ton)}\end{aligned} \quad (2)$$

Rice paddies also constitute a major source of methane CH_4, and may be responsible for 20% of the global total emission (IPCC 1992). The production of rice must increase from the current level of 460–758 million tons by the year 2020 to meet demand (IRRI 1998). Associated methane emission may increase by 40–50%. Therefore, the assessment of CH_4 emission from rice paddies is important in predicting atmospheric CH_4 concentration and assessing its global warming effect. The amount methane emission from rice paddy is adopted from the calculated result by the methane emission model (Liu and Wu 2004). The global warming potential of methane is about 21 times of the carbon dioxide as suggested by IPCC (1996). The unit cost for methane emission from rice paddy is thus set to 21 times the CO_2 fixation cost or 40,684 NT$/ton. This value is adopted herein to calculate the negative benefit resulting from the methane emission from rice paddies.

Oxygen production

Photosynthesis of rice plant emits the oxygen and refreshing the atmosphere. Wu (2004) measured the O_2 liberation rate of rice plant. The average O_2 emission rates of 1st and 2nd rice planting period are 520 and 465 kg/ha/day, respectively. There is a range of market prices of oxygen. For example the industrial oxygen is much cheaper than the medical one. We assume that the oxygen produced from rice paddy mainly serves for human inhalation. The oxygen price for medical purpose is adopted herein. The O_2 emission value of rice paddy can be described by Eq. 3.

$$\begin{aligned}&\mathrm{O_2\ production\ value(NT\$)}\\&= \mathrm{unit\ O_2\ emission(kg/ha/day)} \times \mathrm{planting\ acreage(ha)}\\&\quad \times \mathrm{planting\ period(day)} \times \mathrm{unit\ production\ value(NT\$\ /ton)}\end{aligned} \quad (3)$$

where unit production value of O_2 is set as the market price of the medical use oxygen 4,350 NT$/ton.

BOD removal

Rice paddy farming has a function of purifying water quality. In the past few year, several irrigation-quality indices such as chemical oxygen demand (COD), biological oxygen demand (BOD), nitrogen and phosphorous were used for the assessment of water purification function. Among many water-quality indices, DGBAS (2005) had selected BOD as an indicator for green GDP accounting in Taiwan. Accordingly, BOD was used herein. Lin (2002) investigated the BOD removal of paddy field in the Kuang-Tu plain. The results of BOD removal of the 1st and 2nd rice planting period are 15.2 and 18.9 kg/ha, respectively. The cost of processing BOD is 16,891 NT$/ton. The overall value of BOD removal from rice paddy can then be calculated straightforwardly.

Recreation

Paddy fields provide not only a beautiful rural landscape but also a unique natural, cultural and social environment. People especially for urban citizens visit rural areas with various amenities to find leisure and relaxation (Huang et al. 2006) The recreation value of paddy fields can be evaluated by Eq. 4.

$$\begin{aligned}&\mathrm{Recreation\ value(NT\$)}\\&= \mathrm{annual\ domestic\ recreation\ visitors}\\&\quad \times \mathrm{average\ spent\ per\ visitor}\\&\quad \times \mathrm{percentage\ of\ paddy\ land\ in\ all\ recreation\ sites}\end{aligned} \quad (4)$$

where the average spent per visitor varies from 2,200–2,700 NT$/person. The number of annual domestic recreation visitors can be found in the statistic year report from Tourist Bureau (Tourist Bureau 1999–2006). The percentage of paddy land to all recreation land can be estimated by the different land-use type from the geographical in formation system.

Flood mitigation

Paddy fields are surrounded by bunds that store rain or irrigation water to supply the consumption use of rice plant growth. The large amount of water stored in the paddy acts as many small reservoirs or farm dams. The retention of rain fall in field reduces the peak flow and preventing flood. Nishimura (1991) indicated that the effect of flood detention of paddy fields was 4 and 15 times to the upland and urban areas, respectively.

In Taiwan, the average bund height is 20 cm, and the ponding water depth is 6 cm. The remaining 14 cm height of bund can be used for flood storage. The Water Resources Agency (WRA 2006) reported that the damage caused by flooding is around 30 billion NT$/yr. The unit damage loss resulted by flooding in the urban and suburban area are 763 and 351 NT$/m^3, respectively. The reduction of flood migration value can be evaluated by Eq. 5.

$$\begin{aligned}&\text{Flood mitigation value(NT\$)}\\&= \text{bund height} - \text{ponding water depth(m)}\\&\quad\times\ \text{paddy acreage}\left(\text{m}^2\right)\times\text{unit damage loss}\left(\text{NT\$/m}^3\right)\end{aligned}\tag{5}$$

Groundwater recharge

A flooded paddy field can be considered as an artificial wetland and as a major source of groundwater recharge (Yoon 2009). Liu et al. (2005) estimated the extent of paddy field infiltration in Taiwan by adopting a one-dimensional Darcy-based soil/water balance model SA-WAH (Simulation Algorithm for Water Flow in Aquatic Habitats). The estimated infiltration is 1.8 billion m^3/year. The groundwater recharge values from paddy field can be estimated by Eq. 6.

$$\begin{aligned}&\text{Groundwater recharge value(NT\$)}\\&= \sum\text{infiltration rate of soil(m/day)}\\&\quad\times\text{paddy acreage}\left(\text{m}^3\right)\times\text{planting period(day)}\\&\quad\times\text{unit water price}\left(\$/m^3\right)\end{aligned}\tag{6}$$

where the unit water price is set to 11.15 NT$/m^3.

Land subsidence reduction

Taiwan has excessively extracted large quantities of groundwater resulted in decreasing of groundwater level and causing serious land subsidence especially in the coastal areas including Chou-Shui River alluvial fan and Ping-Tung plain. The spatial analysis using geographical information system showed that the land-use types in the land subsidence area in the Chou-Shui river alluvial fan and Ping-Tung plain were mainly for aquacultural farming and upland planting. Paddy field showed only mild to nil land subsidence (Liu 2009). Rice fields allow standing water gradually percolating to groundwater aquifer, raises the groundwater level and prevents the land subsidence.

The annual amounts of groundwater withdrawn for agricultural sector are obtained from the statistic year report of Water Resources Agency. The annual amount of groundwater recharge can be obtained from previous estimations of Eq. 6. The study uses the reported socioeconomic cost due to land subsidence by Water Resources Agency (WRA 1998). After collecting all the necessary data, the land subsidence reduction value of paddy field can be estimated by Eq. 7

$$\begin{aligned}&\text{Land subsidence reduction value(NT\$)}\\&= \text{groundwater recharge}\left(\text{m}^3\right)/\\&\quad\ \text{groundwater withdrawn}\left(\text{m}^3\right)\\&\quad\times\text{socioeconomic cost of land subsidence(NT\$)}\end{aligned}\tag{7}$$

Notably, the study estimates the land subsidence reduction value in the Chou-Shui river alluvial fan and Ping-Tung plain where these two regions have experienced seriously land subsidence due to excessive groundwater withdrawn. Table 1 shows as an example of the land subsidence reduction value estimated by Eq. 7 of rice paddies in the Ping-Tung plain in 1999 and 2000.

Results

The study applies the evaluation models to estimate the monetary values of the multifuntionalitly of paddy fields in the Chou-Shui river alluvial fan and Ping-Tung plain. Tables 2 and 3 list the estimated monetary values of various items of multifuntionality benefits of rice paddy from 1999–2006 in the Chou-Shui river alluvial fan and Ping-Tung plain, respectively. Temperature cooling and O_2 production are two most valuable multifunctionalities of rice paddy consisting of 65% of the total external benefit. The negative benefit caused by the methane production only reduces 5% of the total external benefit. Figures 2 and 3 plot the change of the external benefits, paddy acreage and 1st and 2nd planting period acreages from 1999–2006 of rice paddy in the Chou-Shui river alluvial fan and Ping-Tung plain, respectively. The rice planting area in the 1st planting period (February to June) is generally much higher than that of in the 2nd planting period (August to December). The internal value of rice production ranges from 11.549 to 14.07 billion NT$ and the external value of rice paddy ranges from 64.509 to 77.312 billion NT$ in the Chou-Shui river alluvial fan. The ratio of internal to the external benefits in the Chou-Shui river alluvial fan is around 1 to 5. The planting areas maintains at 80–92% of

Table 1 Estimated land and subsidence reduction values of rice paddy in the Ping-Tung plain in 1999 and 2000

Year	1999	2000
Groundwater recharge (in 10^6 m^3)	62.4	61.0
Groundwater withdrawn(10^6 m^3)	868	866
Socioeconomic cost (in 10^8 NT$)	107	107
Land subsidence reduction value (in 10^8 NT$)	7.69	7.53

Table 2 Evaluated multifunctionalilty benefit (in 10^8 NT$) of paddy field in the Chou-Shui river alluvial fan from 1999 to 2006

Benefit	Year							
	1999	2000	2001	2002	2003	2004	2005	2006
Total cultivable paddy land (ha)	115,796	115,381	114,604	112,818	112,812	111,449	111,046	110,951
1st period paddy (ha)	60,200	60,208	56,982	57,209	55,263	51,651	55,233	55,152
2nd period paddy (ha)	46,459	43,625	45,626	42,166	36,887	36,555	37,382	37,026
Ratio of cultivated area	92.11%	89.99%	89.53%	88.08%	81.68%	79.14%	83.40%	83.08%
Rice production	140.70	137.00	124.64	139.06	117.57	117.91	115.49	128.86
Temp. cooling	234.42	220.12	230.21	212.75	186.12	184.44	188.62	186.82
CO_2 reduction	30.99	30.34	29.71	28.99	27.12	25.82	27.22	27.11
O_2 production	276.18	269.32	265.42	257.64	239.54	228.93	240.66	239.58
BOD removal	0.30	0.29	0.29	0.28	0.26	0.25	0.26	0.26
Recreation	111.83	129.18	84.39	83.05	87.21	126.91	87.94	108.18
CH_4 pollution	−35.55	−33.58	−34.80	−32.42	−28.62	−28.19	−28.96	−s28.67
Flood mitigation	5.91	5.88	5.84	5.75	5.75	5.68	5.66	5.65
Groundwater recharge	51.93	50.55	49.96	48.38	44.87	42.95	45.09	44.88
Subsidence reduction	97.13	94.07	92.56	89.37	82.84	79.22	84.08	84.38
Σ external benefit	773.12	766.16	723.57	693.80	645.09	666.02	650.57	668.18
Average external benefit(10^3 NT$/ha)	668	664	631	615	572	598	586	602

Table 3 Evaluated multifunctionality benefit (in 10^8 NT$) of paddy field in the Ping-Tung plain from 1999 to 2006

Benefit	Year							
	1999	2000	2001	2002	2003	2004	2005	2006
Total cultivable paddy land (ha)	38,155	37,757	37,433	37,102	37,426	37,496	37,265	37,292
1st paddy (ha)	7,880	8,361	8,103	7,838	7,836	7,692	7,792	7,058
2nd period paddy (ha)	6,242	5,482	5,230	4,248	3,409	2,684	2,580	1,878
Ratio of cultivated area	37.01%	36.66%	35.62%	32.58%	30.05%	27.67%	27.83%	23.96%
Rice production	18.86	18.17	15.34	16.83	13.32	15.05	15.08	13.54
Temp. cooling	31.50	27.66	26.39	21.44	17.20	13.54	13.02	9.48
CO_2 reduction	4.09	4.08	3.94	3.62	3.43	3.21	3.22	2.81
O_2 production	36.54	36.00	34.69	31.59	29.55	27.40	27.41	23.72
BOD removal	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.02
Recreation	15.40	16.74	18.24	16.54	12.03	15.18	11.42	12.9
CH_4 pollution	−6.11	−5.46	−5.22	−4.33	−3.58	−2.92	−2.84	−2.16
Flood mitigation	2.40	2.36	2.33	2.31	2.32	2.33	2.31	2.32
Groundwater recharge	6.96	6.82	6.57	5.96	5.54	5.11	5.11	4.40
Subsidence reduction	7.69	7.53	7.26	6.58	6.12	5.65	5.64	4.86
Σ external benefit	98.51	95.77	94.23	83.73	72.64	69.52	65.33	58.36
Average external benefit (10^3 NT$/ha)	258	254	252	226	194	185	175	156

the total paddy area and the annual external benefits per hectare range from 572,000 to 668,000 NT$/ha in the Chou-Shui alluvial fan. However, the set-aside area in the Ping-Tung plain is much higher than that in the Chou-Shui river alluvial fan. The actual planting areas consist only 23–37% of the total paddy area and the annual external benefits per hectare significantly reduce ranging from 156,000 to 258,000 NT$/ha in the Ping-Tung plain. Both internal rice production value and external benefit are dropped steeply. Moreover, the internal value of rice production ranges from 1.332 to 1.886 billion NT$ and the external value of rice paddy ranges from 5.836 to 9.851 billion NT$ in the Ping-Tung plain.

The results of this study show that the external benefit is much higher than the internal benefit of rice paddy. To preserve the external benefit, rice paddy should be

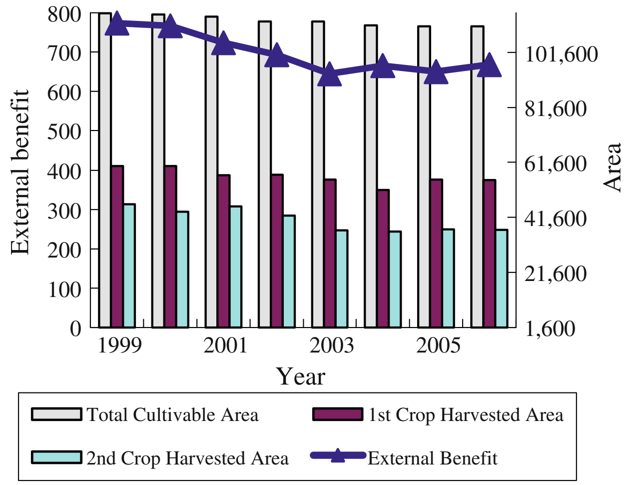

Fig. 2 Annual variation of external benefit (in 10^8 NT$) and planting area (in ha) of rice paddy in the Chou-Shui river alluvial fan from 1999 to 2006

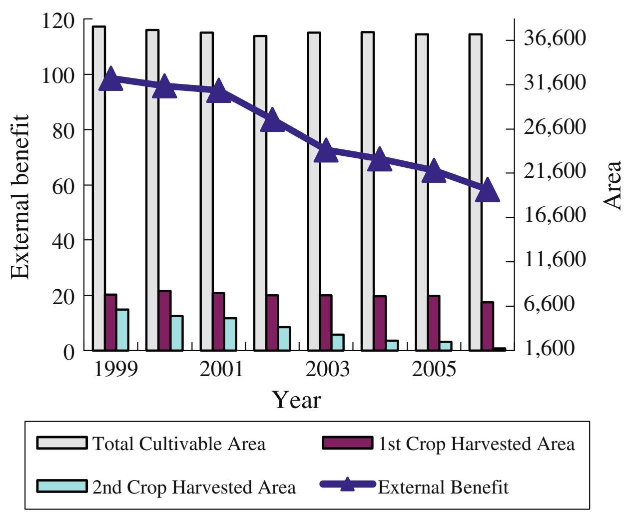

Fig. 3 Annual variation of external benefit (in 10^8 NT$)and planting area (in ha)of rice paddy in the Ping-Tung plain from 1999 to 2006

sustainably cultivated. Set-aside, abandon or conversion of rice paddy to upland plants can significantly reduce the multifunctionalilty benefit of paddy field, harmful to the environment and further jeopardize the national food security. In estimating the multifunctionality of rice paddy, concerns are arisen on the problems of double counting, the neglect or failure to recognize interactions among the outputs and failure to consider the potential outputs from other use of the land (Levine et al. 2006). The double counting occurs when the value for non-commodity output has already been internalized in the commodity output value. In our study, the external value of groundwater recharge is counted as water resources conservation and land subsidence reduction. Although the ponding water percolates to groundwater aquifer, the recharge water performs two different functions, thus the double counting and their interactions are not relevant to groundwater recharge. However, in determining the recharge contributing by the rice paddy, the net recharge must subtract the recharge from other land-use type which is not considered in the study. The problem is further complicated by variation in cropping practice and different land-usages. Detailed discussion can be found in Levine et al. (2006).

ICID (2006) reported that the estimated external benefits of rice paddy in Japan and Korea were 1,520,000 and 520,000 NT$/ha, respectively. The results of Chou-Shui river alluvial fan are 572,000-668,000 NT$/ha which are close to the value of Korea. But the results of Ping-Tung plain are much lower than both Korea and Japan due to a large set-aside area existed in Ping-Tung plain. Notably, the quantified items and methods of the multifunctionality of paddy field applied in Japan, Korea and Taiwan are varied which may also produce different results. To reduce the non-equal-based multifunctionality benefits estimated by these countries, a multinational cooperation program should be established to resolve the difference in the multifunctionality estimation of rice paddy in the future (Kim et al. 2006).

Conclusion

The study quantitatively evaluates the temporal changes of multifunctionality benefit of paddy field from 1999–2006 in the Chou-Shui river alluvial fan and Ping-Tung plain of Taiwan. The replacement cost method is adopted to quantify the multifunctionality. The quantified items include rice production, summer temperature cooling, CO_2 reduction, methane pollution, oxygen production, BOD removal, recreation, flood mitigation, groundwater recharge, and land subsidence reduction. The results show that percentage of cultivated paddy to the total paddy gradually decrease from 92 to 80% and the external values per hectare remains from 572,000 to 668,000 NT$/ha in the Chou-Shui river alluvial fan. Whereas, the percentage of area of cultivated paddy to the total paddy markedly decreases from 37 to 23% from 1999 to 2006 and the external values per hectare of paddy only ranges from 156,000 to 258,000 NT$/ha in the Ping-Tung plain. The temporal reduction of rice planting area not only decreases the multifunctionality but may also jeopardize the national food security. Government should formulate strong policy to maintain sustainable agriculture in paddy field. A multinational cooperation program is also suggested to be established to facilitate an equal-based estimation of multifunctionalilty of rice paddy in the future.

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