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Performance of Bondoyudo Mayang Irrigation System in East Java, Indonesia

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Abstract

The objective of this research is to evaluate the performance of Bondoyudo Mayang irrigation system, by conducting analysis on the water balance to determine the water productivity. The research was conducted in the Bondoyudo Mayang Irrigation area in 2006, which consists of three regencies in East Java Province; Lumajang, Probolinggo and Jember Regencies. The water insufficiency for several months of the year forced the rice farmers to change the wetland rice to dryland crops. If this was to continue, agriculture land-uses would change either temporarily or permanently.

The result showed that the irrigation performance in the study area was rather poor, mostly due to the lack of maintenance of the network and poor irrigation management. Consequently, there was a significant reduction in crop yield due to water irrigation insufficiencies each year. Improving the management of water distribution, network systems irrigation and farmer's skill in soil preparation are the possible solutions to improve the old irrigation system.

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1. Introduction

Irrigation is an artificial watering of land to sustain plant growth (Khan et al., 2006), which is practiced in all parts of the world where rainfall does not provide enough ground moisture. About 20% of the world's croplands are irrigated but they produce 40% of the global yield which means that irrigation more than doubles land productivity (Anonymous, 2003). In developing countries, irrigation improves economic returns and can boost production by more than 400%. Moreover, about 50% of the total fresh water resources of Asia are devoted to rice cultivation (Berg, 2002).

Despite its proven role and importance, irrigation also creates unwanted environmental consequences resulting in by several problems. About one-third of the world's irrigated lands have reduced productivity as a consequence of poor irrigation management practices that have caused water logging and increased salinity (Anonymous, 2006). In Asia, current estimates show that 2,025 million ha of the irrigated rice area may experience water scarcity (Boling et al., 2004). It is projected that global rice consumption in 2020 will increase by 35% from the yields of 1995, whereas water availability for agriculture over this period is expected to fall from 72 to 62% globally and from 87 to 73% in developing countries.

In the dry areas of East Java Province in Indonesia, irrigation must be maintained from the time a crop is planted especially during the dry season. In areas of irregular rainfall, irrigation is used only to ensure good harvests and to increase crop yields during the dry season. Irrigation has greatly expanded the amount of arable land and the production of food (Barmawi et al., 2007).

Similar to most developing countries, the current development scenario in Indonesia focuses more on commerce and industries which are easily managed and require less labor works. The Indonesian Agriculture Research Centre (2006) stated that the natural resources and human resources in agriculture sector are gradually decreasing due to the high cropping intensity and the decreasing of agriculture labor force.

Sustainable rice production is still needed due to high demand from Indonesian people, who consume rice as their main staple food. On the other hand, the irrigation performance is sometimes not performing optimally due to quite obsolete irrigation system. Moreover, there is significant competition from industrial crops which are more efficient in water consumption and more lucrative than the rice business. Therefore, in three times a year rice cultivation, some farmers cultivate other crops rather than rice (Wicaksono and Nakagoshi, 2009)

Over 16 % of the national rice consumption is supplied by East Java Province. To maintain the high productivity, intensifying rice cultivation by infrastructure such as irrigation facility is necessary to meet the production demand. These practices, in many cases, lead to the degradation of agriculture environmental quality. On the other hand, the intensive rice cultivation is needed due increasing demand and many cases of agricultural land conversion.

Singeleton et al. (2004) stated that increasing water scarcity threatens the sustainability of irrigated agriculture, food security and the livelihoods of rice producers and consumers. Increasing competition from domestic, industrial uses and more lucrative crops has further compounded the problem of water scarcity. The demand for freshwater for industrial, domestic, and industrial crops is growing rapidly in East Java. Therefore, less water is available for agriculture and for rice irrigation which consumes the largest amount of freshwater.

This study aimed to evaluate the irrigation system performance in the Bondoyudo Mayang Irrigation Area. The specific objectives of this research were to describe the alteration of the cropping system in irrigated rice field, to analyze the water balance of the irrigation system and to determine the water productivity.

2. Description of study area

The Bondoyudo Mayang irrigation area (Figure 1) has a total land area of 21, 898 ha. It consists of six sub irrigation sites; the Curah Menjangan with 1,575 ha land area, Jatiroto with 4,337 ha, Bondoyudo1 with 887 ha, Kottok with 1,879 ha, Karanglo with 2,323 ha and Bondoyudo 2 with 10,897 ha. Geographically, the Bondoyudo Mayang irrigation area borders Probolinggo Regency in the North, Situbondo and Bondowoso regencies in the East, Malang regency in the west and Indonesian Ocean in the South. Several mountains with rivers support the Bondoyudo Mayang Irrigation area, which stretch from the west to the east such as Semeru, Lamongan, Argopuro, Raung and Kumitir Mountain (East Java Statistics, 2006).

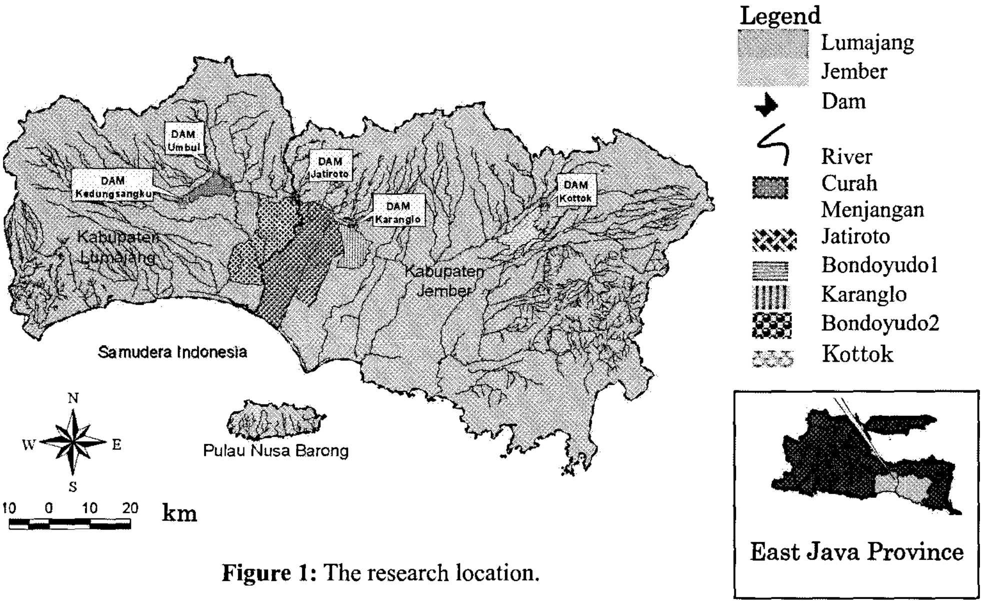


Figure 1: The research location.

The Bondoyudo Mayang Irrigation area has a relatively high precipitation rate in the upper stream but is a short distance to the sea. This condition makes the water flow easily to the sea. In order to utilize the water effectively, several dams and irrigation system were built to intensify the agricultural sector; which supported the wetland rice cultivation (East Java Statistics, 2006).

The Bondoyudo Mayang irrigation system normally applies three times annual rice cultivation with the irrigation water supplied by the Dam system. This system was designed to support three times rice cropping in one year period. However, the system must be maintained from the time a crop is planted especially in the dry season. In areas of irregular rainfall, irrigation is used during dry season to ensure harvests and to increase crop yields (Barmawi et al., 2007).

In many cases, Indonesian irrigation system is mostly surface irrigation in which water is applied and distributed over the soil surface by gravity. It is the most common form of irrigation and it is adapted throughout the world over many years. Surface irrigation is often referred to as flood irrigation, implying that the water distribution is uncontrolled and therefore, inherently inefficient. Furthermore the management of this system is a compulsory requirement to the sustainability of the irrigation system (Andow and Hidaka, 1998).

The Bondoyudo Mayang irrigation system is supported by 13 rivers. The nine rivers are within the Lumajang Regency and the other four are within Jember Regency. The high water velocity is common in those rivers because of the short distance from the upstream to the sea. This short distance causes many flood problems even in a very short period of rain (East Java Statistics, 2006).

The largest catchment of those 13 rivers is the Bondoyudo River which is 1,196 km^2. It is then followed by Mayang (649 km^2), Mujur (240 km^2), Tanggul (213 km^2), Glidig (175 km^2), Bedagung, Rejali, Krai and others which have less than 100 km^2. Those rivers are managed as one Irrigation system with six dams and six irrigation sites under the Bondoyudo Mayang Irrigation Bureau (East Java Statistics, 2006).

3. Methods

3.1. Land use change

Trends of land use change in flooded rice field area were analyzed using East Java Statistical Profile time series data between 2000 and 2005, historical land use maps, the previous studies conducted by local government and digital map interpretation. The land use map in 2005 made by the National Survey Agency (Bakosurtanal) with scale 1/100,000 was digitized. Classification accuracy was assessed by collecting ground truth data on field investigation in 2005.

3.2. Water balance

In this study, the simplification of water balance equation developed by Crowford (1985) was used and described as follows:

$$Q = P - AET + \Delta S \qquad (1)$$

Where:

Q is runoff (mm/month)

P is precipitation (mm/month)

AET is evapotranspiration (mm/month)

ΔS is the change in storage (in soil or the bedrock) (mm/month)

In the specific case of irrigation activity, the Q (runoff) in water balance equation can be defined by irrigation (IR) which is explained in the equation number 2 below. The excel spreadsheet Water Demand Agriculture (WADAG) method was used in this research to measure the irrigation water demand (consumptive uses) which determines two important variables:

1. Water requirement for soil tillage, which was calculated using Van de Goor and Zijlstra's formula (Anonymous, 2003)

$$IR = M \frac{e^k}{(e^k - 1)} \qquad (2)$$

where :

IR is flood capacity rice field water demand (field capacity with 50 mm addition)

M is water demand to replace lost from evaporation and percolation ($M = Eo + P$(mm/day))

Eo is evaporation during the soil tillage (mm/day)

P is percolation (mm/day)

$$k = \frac{M \times T}{S}$$

T is time for soil tillage

S is water demand for soil field capacity with addition of 50 mm layer

2. Plant evapotranspiration, which is calculated using Penman-equation (Anonymous, 2003). It is a term used to describe the sum of evaporation and plant transpiration from the earth's land surface to atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and waterbodies while transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata in leaves. The equation of evapotranspiration number is multiplied the evapotanspiration potential by plant coefficient.

$$ETc = Kc \times ETo \qquad (3)$$

where :

ETc is crop evapotranspiration (mm/day)

Kc is crop coefficient, depend on each crop and its growth stage

ETo is crop potential evapotranspiration (mm/day)

While the crop potential evapotranspiration was calculated by modified Penman equation (Batchelor, 1984) as explain below:

$$ETo = c\,[W.\,Rs\text{-}Rn1 + (1\text{-}W).\,f(u)\,(e_a - e_d)] \qquad (4)$$

where :

ETo is potential evapotranspiration (mm/day)

c is Pennman number (Pennman tabel)

e_a is saturated vapor pressure °C (mbar) (Pennman tabel)

e_d is actual vapour pressure (mbar)

Rs is solar radiation (W/m^2)

$Rn1$ is net short-wave radiation (W/m^2)

$f(u)$ is the wind velocity on the 2 m above the ground (m/s)

W is radiation coefficient i (Penman tabel)

3. In the excel spreadsheet, the irrigation demand was calculated by multiplying the unit area of irrigation area column by the unit of water requirement on the each irrigation system column.

The 5-year time series of data on climate variables from 2000 to 2005 such as precipitation, evaporation, wind velocity, vapor pressure, and solar radiation were collected from conventional equipments (Pluviometer Obs rain gauge, and Hellman model rain gauge, Pan evaporator, Anemometer, Thermo-hygrograph, Barometer, Barograph and Campbell-Stokes Solar Sphere) at five weather stations installed in each dam site of Bondoyudo Mayang irrigation system. The river and dam discharges were measured by AWLR (Automatic Water Level Recorder) and flow meter on each dam.

3.3. Crop-water productivity

According to Phengphaengsy and Okudaira (2006), crop-water productivity is defined by crop yield/water consumptively used. It may be quantified in terms of wet or dry yield, nutritional value or economic return. In this research, crop-water productivity can be assessed as yield per unit of water consumption and yield per water consumption. Data on paddy field's yield were collected from the Water User Organization (WUO) by interviewing the farmers, and also cross-checking the data by unit harvested method. Water consumption values were taken from the spreadsheet water demand agriculture (WADAG).

$$\text{Water Productivity for Command Areas} = \frac{\text{Rice Yield (ton)}}{\text{Water Consumption (liter/sec)}} \tag{5}$$

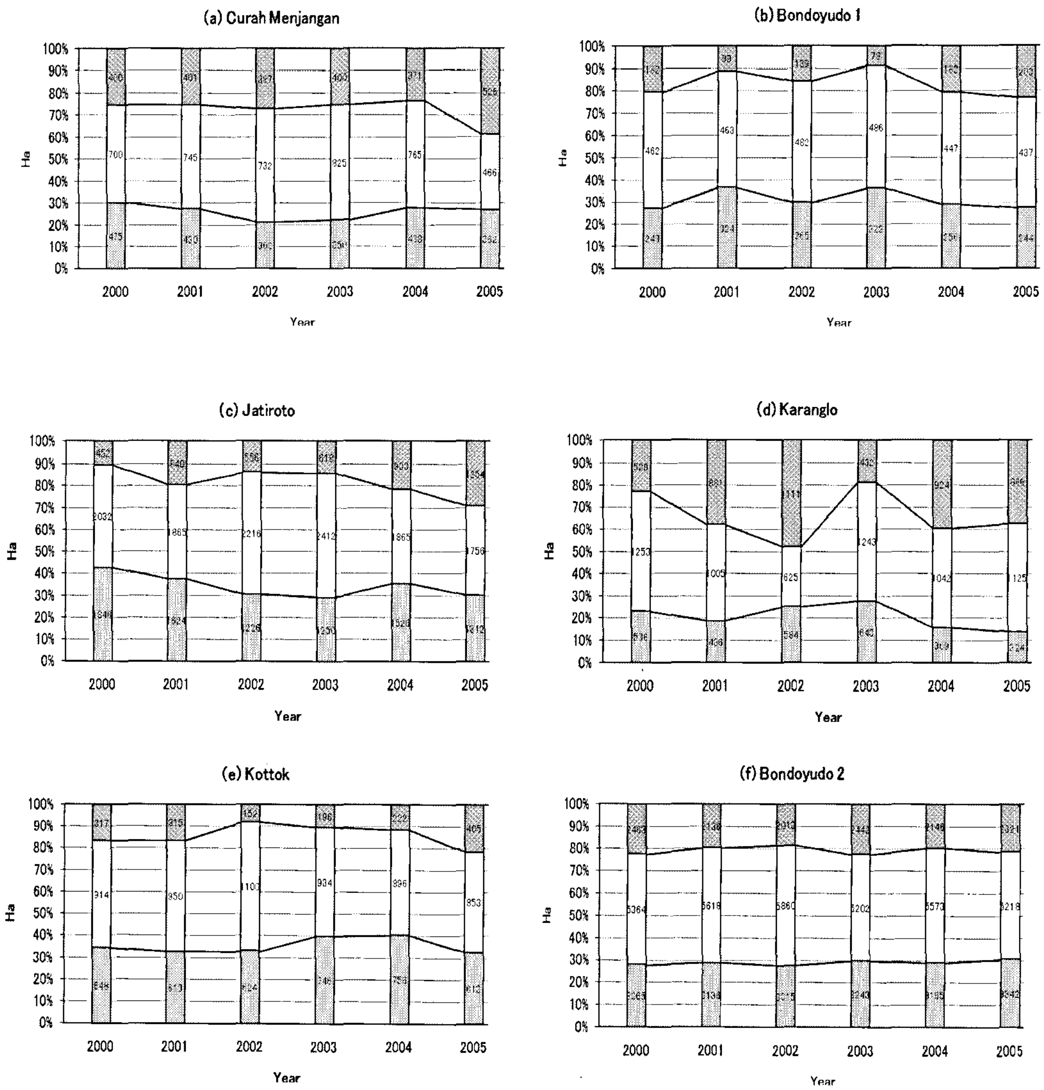
Crop-water productivity was one of irrigation performances which were calculated from the irrigation seasons and the irrigation months of the 2000–2005 hydrological years. This indicator was obtained from the average annual yield and the average annual water consumption irrigation values. The value of productivity close to 1 or equal to 1 indicates that the applied water was able to meet the maximum effectiveness to support crops growth. On the other hand, the lower value of productivity indicates that the applied water was unable to support the growth of the crop or failure of the irrigation system.

4. Results

4.1. Land use change

Figure 2 shows the fluctuation of irrigation land utilization in the three time cropping periods per year due to the failure of the irrigation system to support the three times rice cropping with the same amount of water. Between 2000 and 2005, there was a fluctuating trend of land utilization on the time series data of rice cultivation area. The variation of land utilization only happened temporarily; hence, the land use change in Bondoyudo Mayang irrigation area may not be permanent.

Another phenomenon from 2000 to 2005 was a trend of the low rice area cultivation in the second and the third rice cultivation, compared with the first rice cultivation during three times rice cropping pattern. It was also observed that, the first rice cultivation has the largest area and the third rice cultivation has the smallest area in a year. This phenomenon was the effect of water balance status on the Bondoyudo Mayang irrigation area where there were several months of water supply insufficiency, additionaly the trend of changing rice into more commercialized crops.



Legend :

☐ : First rice

▩ : Second rice

▨ : Third rice

Figure 2: The temporal land use patterns in Bondoyudo Mayang irrigation area.

4.2. Water balance

Figure 3 shows the estimated water demand, availability, and allocation, using water balance model in the Curah Menjangan, Bondoyudo, Jatiroto, Karanglo, Kottok and Bondoyudo. There were several months of insufficient water supply and several periods of water sufficiency which vary for each dam. In the Curah Menjangan irrigation area (Figure 3a), mostly water availability was sufficient except from September to October due to the low precipitation, which directly resulted in the smaller rice cultivation area during the third period of rice cultivation (August until October). The same phenomenon occurred in the second period of rice cultivation which runs from April until July.

In the Bondoyudo Dam (Figure 3b), the insufficient water condition occurred from April until July which was the period of low precipitation, and consequently causing the smaller rice cultivation area in the third period of rice cultivation (August until October). However, since Bondoyudo Dam covered two irrigation areas which were the largest irrigation areas among the six irrigation areas, the water availability was also higher and more stabile compared with other dams.

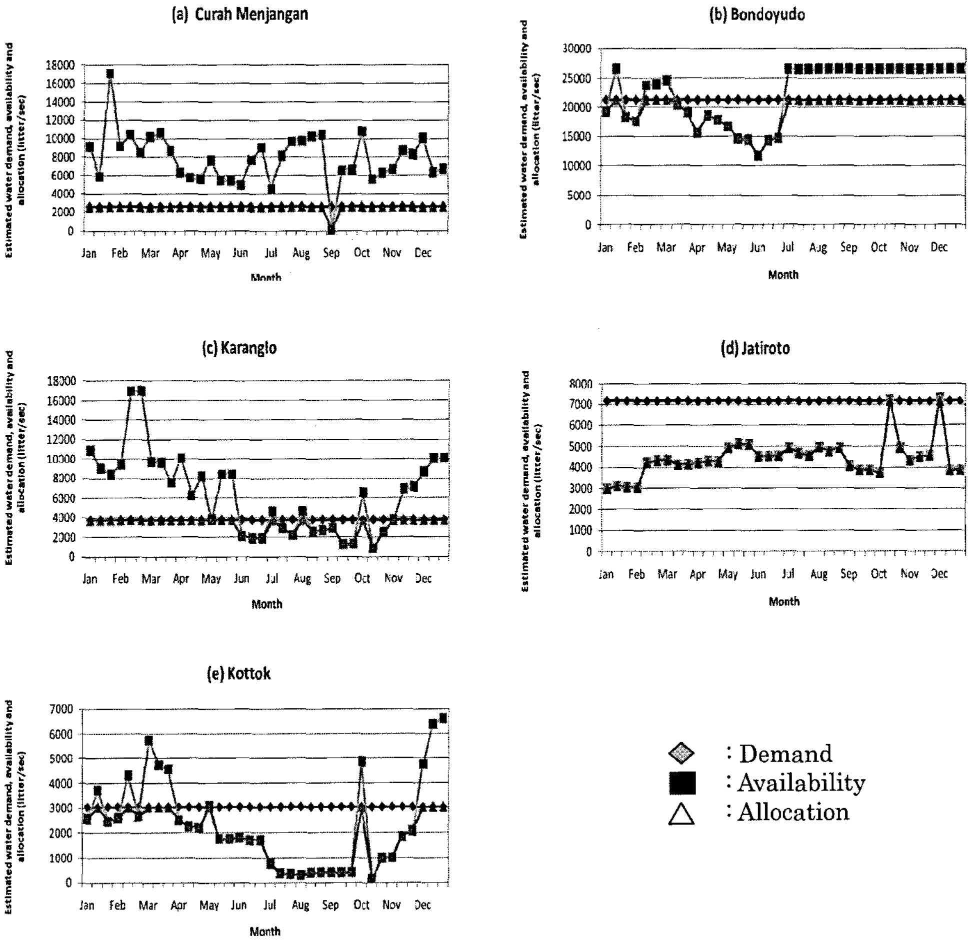


Figure 3: Five years average of water balance in dam sites under Bondoyudo Mayang irrigation area from 2000 - 2005.

Similar trends were observed in the Karanglo Dam (Figure 3c) with the water balance quite fluctuant between sufficient and insufficient, in June and November. This condition created the smaller rice cultivation area during the third period and the second period of rice. On the other hand, the water demand in the Jatiroto dam (Figure 3d) was higher than water supply, and the water allocation was based exactly on water availability; hence, the rice cultivation area followed the pattern of *rain-feed rice-field* area which had larger area in rainy season (October until February).

In the Kottok Dam (Figure 3e) the water sufficient condition was only for several periods which were from January to February, March to April, September to October and December. This fluctuate water availability created the rice cultivation area which was smaller in the Second rice period (April until July) and the third rice period (August until October). However, water outputs and inputs actually were almost in equilibrium between demand and allocation in all years and seasons, which mean that if the performance of the dam and irrigation system was in the good condition, the fluctuation in rice cropping area and alteration of crops on one cultivation year should not have happened.

4.3. Water productivity

After combining water demand analysis with the annual yield data which was obtained by estimated mean value from annual yield year from 2000 until 2005, water productivity ratio of the six irrigation area can be seen in Table 1.

Table 1: Crop-water productivity index analysis of six irrigations area.

	Irrigation area	Annual Yield (ton)	Water consumption m^3/sec	Water productivity
1	Karanglo	20221.92	231540.16	0.09
2	Kottok	74175.50	84780.89	0.87
3&4	Bondoyudo1 and 2	94397.42	809968.72	0.12
5	Curah Menjangan	63890.67	282806.40	0.23
6	Jatiroto	162257.83	159918.56	1.01

Based on the water productivity, it is suggested that the Jatiroto irrigation area was the most productive and efficient irrigation area. This indicates that Jatiroto irrigation area had good maintenance practices for the irrigation system and had better management in the irrigation system and crop management conducted by the farmer; Water User Organization (WUO), which simultaneously results in the stable harvest. On the other hand, the lowest irrigation productivity was observed in Karanglo irrigation area, which only scored 0.09.

The temporal land-use change, water balance analysis and water productivity, showed that the irrigation performance in the study area was rather poor, mostly due to the lack of maintenance of the network and poor irrigation management. In consequently, from the estimated result on the yield of six irrigation areas, there was a significant reduction in crop production due to water insufficiencies in each year as shown in Figure 4.

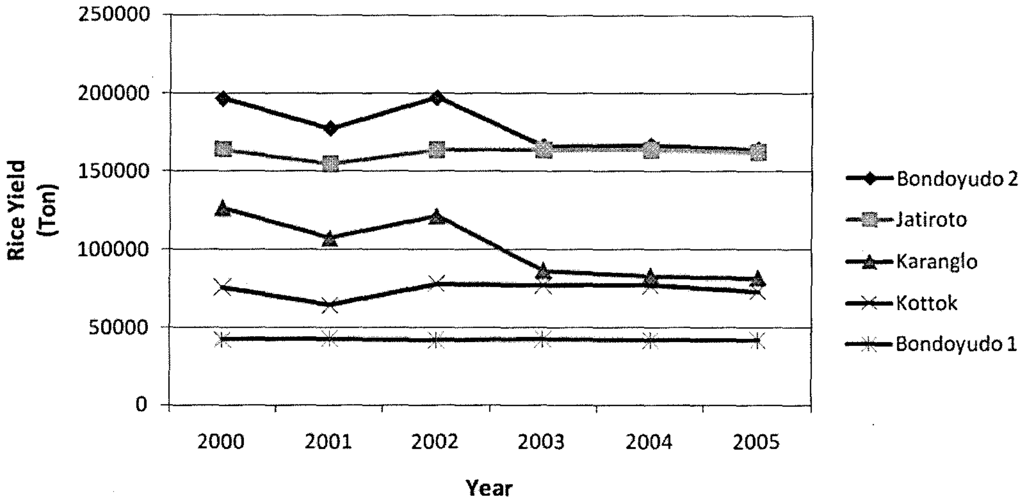


Figure 4: Yearly changes of estimated annual rice yield between 2000 and 2005.

5. Discussion

According to Veldkamp and Lambin (2001), Minimum maintenance on old irrigation network, inadequate management and over intensive cropping system often results in the continuing stagnancy and yield reduction, which has also happened in Bondoyudo-Mayang Irrigation system since it was installed in 1935. Further, land quality degradation and changes in land–labor ratios were worsened the condition of many old irrigation areas.

Changing rice to other commodities which have lower water demand and higher value can be a temporal solution, but they tend to negatively cause in economic differentiation, wage labor, farming system and market adjustment which lead to unsustainable agriculture practices in this area (Verbit et al., 2005). However, in the minimum water supply third period of rice cultivation, the alteration of commodities should be put into important consideration.

The continuously high pressure from other commodities which have higher values is still the main factor cropping pattern change. This phenomenon occurred mainly at time of third rice cultivation when water is scarce. Industrial crops such as tobacco (*Nicotina tabacum*) and sugar cane (*Sacharum officinarum*) are the major crop instead of rice in the third rice period. Third rice cultivation has the smallest area in a year. This might be the effect of water balance status on the Bondoyudo Mayang irrigation area where there were several months of water supply insufficiency, and also the trends of changing rice into more commercialized crops.

In Bondoyudo Mayang irrigation area, the water scarcity for several months (in the dry season) would not necessary happen if the irrigation performance worked well. The irrigation performance itself was not only dependant on the physical and infrastructure condition of the network, but also on farmers' ability to utilize the water.

However, the poor maintenance practices in the irrigation network facilities contributed to the decreasing of cropping area in the dry season. Hence, it is already a major problem and is seriously limiting the agricultural development. Farmers are under pressure to grow more crops with less water. Therefore, there is an urgent need to find ways to cultivate more rice with less water. To achieve this, efficient and appropriate irrigation technologies are needed (Boling et al., 2004).

The rehabilitation of Bondoyudo Mayang irrigation system should focus on physical rehabilitation of irrigation facilities. It is also possible to change the irrigation management (i.e., decreased irrigation intervals and irrigation depths, especially in the shallow, coarse-texture, high infiltration-rate soils of the platforms) and irrigation systems (i.e., pressurized system where irrigation depths and water infiltration are controlled by the irrigation system rather than by the soil) (Barmawi et al., 2007). However, total rehabilitation and improving physical condition of irrigation facilities are not feasible in the short term considering the social-economic constraints. The better choice is the modernization of the organization with the goal of improving the farmer's skill of irrigation management and efficiency in order to conserve water yet maintaining the present crop yields.

6. Conclusion

In the aging irrigation system, the main problem is the unefficiency of the network due to the minimum maintenance and the low skill of farmer in managing the available water. This phenomenon resulted in the fluctuation of cultivation area in the three times rice cropping system. The ideal function of irrigation area which has to collect the water during the rainy season and distribute during the dry season is not working well. Hence, the cropping pattern follows similar pattern to the rain-field rice cultivation system which uses more area in the rainy season compared to the dry season.

The higher availability of water status on each irrigation area does not necessarily indicate higher productivity of irrigation area, which was shown in the case of Karanglo which showed lower water productivity compared to other irrigation ares. On the other hand, the Jatiroto irrigation area recorded the higher water productivity compared to the others, even though the water availability is not sufficient enough to support the rice cultivation.

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