The Influence of El Niño Southern Oscillation on Agricultural Production Sustainability in a Tropical Monsoon Region: Case Study in Nganjuk District, East Java, Indonesia

Liyantono[1,2]*, Tasuku Kato[3], Koshi Yoshida[4] and Hisao Kuroda[4]

[1] United Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology,
Saiwai-cho 3−5−8, Fuchu-shi, Tokyo 183−8509, Japan
[2] Faculty of Agricultural Technology, Bogor Agricultural University,
Kampus IPB Darmaga, Bogor 16680, Indonesia
[3] Faculty of Agriculture, Tokyo University of Agriculture and Technology,
Saiwai-cho 3−5−8, Fuchu-shi, Tokyo 183−8509, Japan
[4] Faculty of Agriculture, Ibaraki University, Chuuo 3−21−1,
Ami-machi, Inashiki-gun, Ibaraki 300−0393, Japan

The Nganjuk District experiences a tropical monsoon regime characterized by annual rainy and dry seasons, and the area receives approximately 80% of annual precipitation within the 5 to 6 months of the rainy season. The district has three planting seasons, the wet season (November−February), first dry season (March−June), and second dry season (July−October). A main factor of agricultural production sustainability is managing for climatic variability. The main cause of variability is the El Niño Southern Oscillation, with El Niño years having below-average rainfall and La Niña years having above-average rainfall. Water shortages in the dry season are a problem, especially in El Niño years, whereas flooding occurs in La Niña years. We analyzed trends in agricultural production and the impact of El Niño and La Niña events in a tropical monsoon region by performing a case study of Nganjuk District in eastern Java Island. Groundwater use for conjunctive irrigation in the dry season increased agricultural production by about 0.5 crops yr^{-1}. In El Niño years, groundwater was required for irrigation in the dry season, whereas in La Niña years surface water was almost sufficient or exceeded the demand for irrigation water in the dry season. The harvest index of rice was relatively stable, with a small increasing tendency from 1982 to 2010 (1.22 to 1.82 crops yr^{-1}), and was not influenced by El Niño or La Niña events. Secondary crop production fluctuated, and the failed-harvest index increased in La Niña years. Agricultural production was more secure when farmers applied conjunctive irrigation. Because secondary crops are vulnerable to waterlogging under excess water conditions, early warning of a La Niña year is important so farmers can adopt a farming strategy that will avoid harvest failure in the dry season.

Key words: harvest index, failed-harvest index, La Niña, farming system, conjunctive irrigation

---

Introduction

Grain production in the dry season is important for regional sustainable development in Indonesia. The main production area for grain in Indonesia is Java, where 53% of the country's total paddy rice and 55% of the maize are produced (BPS, 2009). The population growth rate was higher than increasing rate of harvested area, but still lower than increasing rate of agricultural production. However, trend of total agricultural area in Java was decreasing in the last decade. From a long-term environmental and population perspective, agriculture in Java must be managed to achieve sustainable food security in Indonesia. To-

ward that aim, improvements in land use and water management are needed.

The Brantas River basin is one of the most productive and advanced granaries in Indonesia (Usman, 2001). Nearly 84,000 ha of the 387,100 ha being farmed in the Brantas River basin are irrigated using the river, and the rest of the area is irrigated from its tributaries (Ramu, 2004). In recent years, however, there has been a dramatic transformation from low-intensity to high-intensity agriculture within the basin. Cropping intensity increased from around 0.8 crop yr^{-1} in 1960 to 2.2 crops yr^{-1} by 2000, while the area cultivated increased from 247,000 ha to the current 387,100 ha due to improvements in rice varieties, increased agricultural inputs, and establishment of a reliable water supply in the dry season (Bhat *et al.*, 2005).

Nganjuk District lies in the Brantas River basin at Widas tributary basin. The district experiences a tropical monsoon climatic regime characterized by annual rainy and dry seasons, and the area receives roughly 80% of annual precipitation within the 5 to 6 months of the rainy season (December−May). The topography is flat in central and eastern Nganjuk, with elevations ranging from 35 to 100 m above sea level, and mountainous areas are located in the southern and northern parts of the district. In the Nganjuk area, there are three planting seasons: the wet season (WS, November−February), first dry season (DS1, March−June), and second dry season (DS2, July−October). Paddy fields are cultivated in WS and DS1, and secondary crops (maize, soybeans, peanuts, mungbeans, and red onion) are cultivated in DS1 and DS2.

A main factor of agricultural production sustainability in Nganjuk District is managing for climatic variability. The main cause of variability is the El Niño Southern Oscillation (ENSO), with El Niño years having below-average rainfall and La Niña year having above-average rainfall. Under normal conditions, water shortages in the dry season are a problem in Nganjuk District; these shortages are worse in El Niño years and do not occur in La Niña years.

El Niño events were reported to have an impact on health (Franke *et al.*, 2002) and agricultural, fishery, and forestry production (Begeron and Sedjo, 1999; Yokoyama, 2002; Nezlin *et al.*, 2005). Although La Niña events are related to hurricane severity in the southern and eastern United States (Pielke and Landsea, 1999), La Niña events are often beneficial for monsoon regions. El Niño events have been assoc-

iated with drought and harvest failure in Indonesia, whereas La Niña events bring sufficient water for good harvests in the dry season.

It is important to identify the impacts of El Niño and La Niña events on agricultural production at a specific location in the tropical monsoon zone, such as Indonesia, in order to mitigate harvest failure in the future. The objective of this study was to assess trends in agricultural production in Nganjuk District, in the eastern part of Java Island, and to identify the impacts of ENSO (El Niño and La Niña) years on agricultural production in this tropical monsoon region.

Materials and Methods

Study Area

There are four main sub-basins in Nganjuk District: Widas, Kuncir, Bodor, and Warujayeng-Kertosono. The Widas River flows through the Widas sub-basin. The Kuncir River and Bodor River flows through the Kuncir and Bodor sub-basins, respectively, and these two rivers merge to form the Kedungsoko River. The Klinter River feeds the Warujayeng-Kertosono sub-basin, where there is a flat basin in which land use is dominated by agriculture fields (Fig. 1). The lowland area of Nganjuk District is an alluvial plain formed by the Widas and Brantas Rivers. Based on a hydrogeology map (Puspowardoyo, 1984), the area has a good aquifer with moderate to high productivity and a high specific capacity ($>172.8 \, m^2 \, d^{-1}$).

The lowland irrigation area in Nganjuk District is divided into four irrigation blocks: Widas, Mrican-Kiri, Kuncir-Bodor, and Ketandan-Tretes (Fig. 1). There are two main surface irrigation systems in the Widas and Mrican-Kiri blocks and two local surface irrigation systems in the Kuncir-Bodor and Ketandan-Tretes blocks. The characteristics of the blocks differ with regard to water supply system and geomorphology. The Widas block lies in the Widas sub-basin and is supplied water from the Bening Reservoir and small rivers within the block. The Mrican-Kiri block is supplied water from the Mrican barrage on the Brantas River and lies in the Warujayeng-Kertosono and Bodor sub-basins. The Kuncir-Bodor block is supplied water from small rivers from Willis Mountain, has no reservoir, and lies in the Kuncir and Bodor sub-basins. The Ketandan-Tretes block is supplied water from small rivers from the Kendeng Mountains, has small reservoirs, and lies in the Widas sub-basin. All irrigation systems in Nganjuk District are conjunction
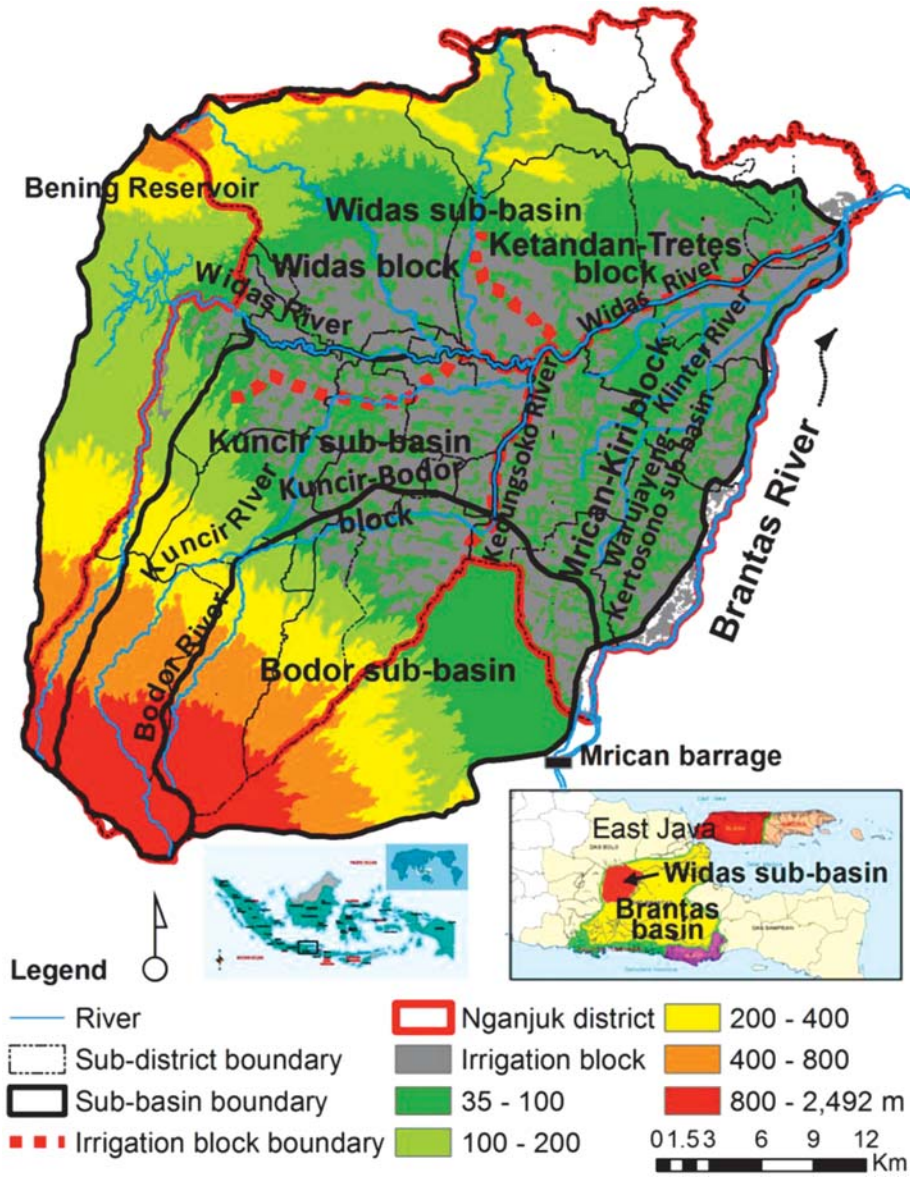
Fig. 1. Map of the study area showing the sub-basins and irrigation blocks.

irrigation of surface water and groundwater and reuse drainage water from the upstream area.

Trends in Agricultural Land Use

The trends in agricultural land use were analyzed using time series statistical data from 1972 to 2010. The yearly cropping indexes (*CI*) of rice, maize, soybeans, peanuts, mungbeans, and red onion were calculated for each lowland irrigation block. Statistical data were in subdistrict units and were obtained from the local branch of Statistics Indonesia (BPS Nganjuk, 1973−2011). The classification of each subdistrict in

an irrigation block was based on weighted agricultural area of the subdistrict in the irrigation block (Table 1). *CI* was calculated as follows:

$$CI_i = \sum_{j=1}^{6} \sum_{k=1}^{n} \frac{CA_{ijk}}{\sum_{k=1}^{n} A_{ik}} \tag{1}$$

where CI_i is yearly cropping index in irrigation block i, CA_{ijk} is total cultivated crop j in subdistrict k in irrigation block i per year, A_{ik} is agricultural area in subdistrict k in irrigation block i, and n is total number of subdidstrict in irrigation block i.

Table 1. Classification of subdistricts in irrigation blocks

Irrigation blocks	Subdistricts	Agricultural area (ha)
Widas	Bagor, Gondang, Nganjuk, Rejoso, Sukomoro, Wilangan	9,889.3
Mrican-Kiri	Baron, Gondang, Jatikalen, Kertosono, Ngronggot, Pace, Patianrowo, Prambon, Sukomoro, Tanjunganom	14,607.5
Kuncir-Bodor	Bagor, Berbek, Gondang, Loceret, Nganjuk, Pace, Sukomoro, Tanjunanom	10,150.9
Ketandan-Tretes	Gondang, Jatikalen, Lengkong, Patianrowo	4,131.0

Irrigation Data and Farming System Analysis

Irrigation systems were investigated based on statistical data from 1972 to 2010. Irrigation intake was obtained from surface irrigation data for 2009. The current irrigation systems were analyzed using average surface irrigation intake data from the four blocks in Nganjuk District and irrigation well density in DS2 in September 2009. Data were obtained from the local government (Irrigation Services of Nganjuk District, 2008; Irrigation Services of Nganjuk District, 2009; BPS Nganjuk, 1973−2011). Each farming system was classified as lowland, upland, and mixed of lowland-upland farming system based on field investigations and interviews.

Harvest Indexes and ENSO Year Analysis

Statistical data regarding areas of successful or failed harvests were collected from the local branch of Statistics Indonesia in a time series from 1982 to 2010 for each subdistrict (BPS Nganjuk, 1973−2011). Yearly harvest index (*HI*) and failed-harvest index (*FHI*) for each lowland irrigation block were calculated from:

$$HI_i = \sum_{j=1}^{6} \sum_{k=1}^{n} \frac{HA_{ijk}}{\sum_{k=1}^{n} A_{ik}} \qquad (2)$$

and

$$FHI_i = \sum_{j=1}^{6} \sum_{k=1}^{n} \frac{FHA_{ijk}}{\sum_{k=1}^{n} A_{ik}}, \qquad (3)$$

where HI_i is yearly harvest index in irrigation block i, HA_{ijk} is total harvested crop j in subdistrict k in irrigation block i per year, FHI_i is yearly failed-harvest index in irrigation block i, and FHA_{ijk} is total failed-harvest crop j in subdistrict k in irrigation block i per year.

El Niño and La Niña events in the dry season (DS1 and DS2) were identified based on Southern Oscilla-tion Index (SOI) data of the U.S. National Oceanic and Atmospheric Administration (NOAA, 2011). Flood and drought events in irrigation blocks were identified based on statistical data obtained from the local branch of Statistics Indonesia (BPS Nganjuk, 1973−2011).

The relationships among cropping index, harvest index, and failed-harvest index and El Niño/La Niña years (SOI) were analyzed using regression analysis and the *P* value considered to be significant by Microsoft Excel 2007.

Results

Trends in Agricultural Land Use

Agricultural land use was analyzed from 1972 to 2010 using the yearly cropping index (*CI*). The cultivated areas of rice, maize, soybeans, peanuts, mungbeans, and red onion were classified for the four irrigation blocks. During this period, total *CI* increased in all lowland irrigation blocks, with the rate of increase of the Widas block being the highest (0.039 crop yr^{-1}) and that of the Kuncir-Bodor block the lowest (0.020 crop yr^{-1}) (Fig. 2). The average rates of increase of *CI* were 0.020 and 0.010 crop yr^{-1} for rice and secondary crops, respectively. The *CI* of rice from the 1980s was higher than total *CI* of secondary crops (maize, soybeans, peanuts, mungbeans, and red onion) in all blocks. However, in some years the *CI* of all secondary crops was slightly higher than the *CI* of rice in the Widas (1986−1998, 1996, and 1997) and Kuncir-Bodor (1982−1985) blocks. Data for 1972−1976 were available only for the Widas block (rice and secondary crops) and all blocks (secondary crops). During this period, the *CI* of rice and *CI* of all secondary crops were both about 1 crop yr^{-1} (Fig. 2). In all blocks, the *CI* of rice showed a steady increase until 2010. However, the *CI* of all secondary crops was stable in the Mrican-Kiri and Kuncir-Bodor blocks and tended to increase in the
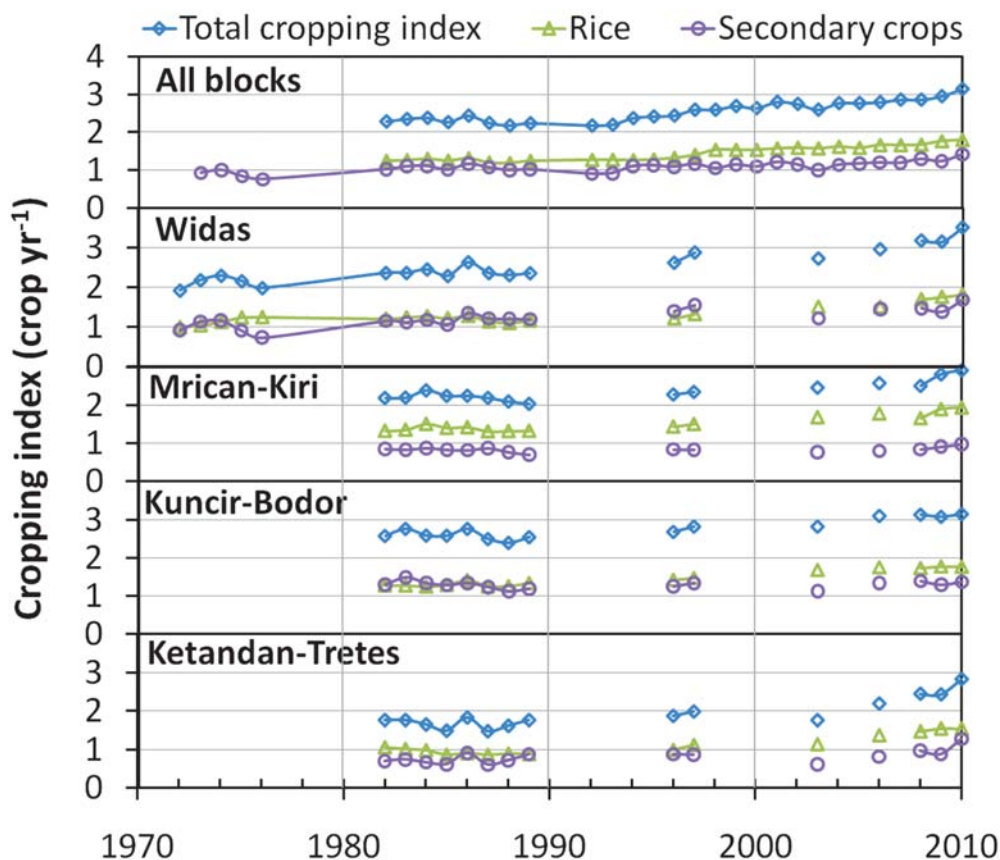
Fig. 2. Land-use trends as illustrated by cropping index (*CI*) in all irrigation blocks and in the Widas, Mrican-Kiri, Kuncir-Bodor, and Ketandan-Tretes blocks, where rice was cultivated in WS and DS1 and secondary crops were cultivated in DS1 and DS2.

Widas and Ketandan-Tretes blocks.

The actual *CI* was higher than the total *CI* for all blocks illustrated in Fig. 2, by about 0.10–0.15 crop yr^{-1}, due to the availability of data for the sugar cane crop in all irrigation blocks. The statistical data for the 1980s, 1990s, and 2003 show that sugar cane was cultivated on about 4000–6000 ha yr^{-1} in all blocks. The *CI* analysis in this study did not include the sugar cane crop because data were not available for the individual blocks.

Agricultural production of rice tended to increase from 1972 to 2010 in all lowland irrigation blocks, with the rate of increase varying from 0.017 to 0.021 crop yr^{-1} (Fig. 3). The increase was caused by an increase in the cultivated area of rice in DS1 in all irrigation blocks. Production of maize tended to increase or was stable because yield was moderate to high, and the rate of increase of *CI* varied from 0.011 to 0.018 crop yr^{-1} in the Mrican-Kiri, Kuncir-Bodor, and Ketandan-Tretes blocks (Fig. 3). The increase in the cultivated

area of rice in DS1 caused the cultivated area of maize to decrease in DS1 and increase in DS2. In contrast, the *CI* of soybean tended to decrease because the price and yield of soybean were low. Soybean was cultivated in DS1 and DS2. The *CI* of red onion remained stable throughout the 1970s and 1980s and then tended to increase in the Widas and Kuncir-Bodor blocks, with the Widas block having the highest rate of increase of *CI* (0.015 crop yr^{-1}). The cultivated area increased because the price and yield of red onion was high. Red onion was cultivated in the early WS, middle DS1, and DS2.

Irrigation and Farming Systems

In all irrigation blocks, most irrigation systems used only surface water before 1990. The Mrican barrage was constructed in 1972, and the Bening Reservoir was built in 1981. Small irrigation systems were also developed in the Kuncir-Bodor and Ketandan-Tretes blocks before 1990. The Indonesian government also
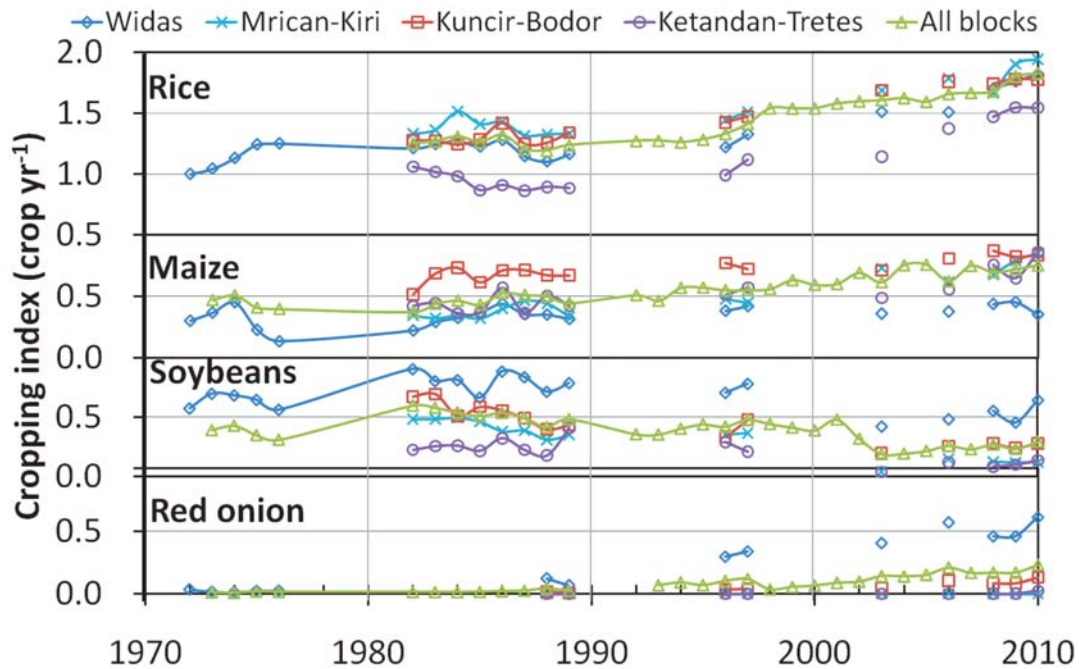
Fig. 3. Land-use trends as illustrated by cropping index (*CI*) of rice, maize, soybeans, and red onion in all irrigation blocks. Rice was cultivated in WS and DS1, maize and soybeans in DS1 and DS2, and red onion in early WS, DS1, and DS2.

Table 2. Number of irrigation wells (NIW) and irrigation well density (IWD) in the four irrigation blocks

Year	NIW	IWD (wells ha^{-1})	Pumps	Pump density (pumps ha^{-1})
1976	238	0.006	438	0.011
1985	292	0.007	3242	0.083
1989	409	0.010	3896	0.099
2009	15,892	0.405	5033*	0.128

*Data for 2003

introduced conjunctive surface water and groundwater irrigation in the 1970s and 1980s through a groundwater development project (P2AT) (Prastowo *et al*. 2007; Stiebel and Suradji 1985; Sudaryanto 1983). Total P2AT and collective wells accounted for 155 wells in 1989 and 77 wells in 2009.

Conjunctive use of surface water and groundwater for irrigation was mostly applied after the 1990. Conjunctive groundwater use by farmers increased rapidly after the 1990. Farmers extracted groundwater using pumps if the surface water was insufficient in DS1 and DS2. The number of irrigation wells increased rapidly after 1990, with the irrigation well density increasing from 0.010 wells ha^{-1} in 1989 to 0.405 wells ha^{-1} in 2009 (Table 2).

During the last decade (2001–2010), conjunctive use was intensively applied in all irrigation blocks. Despite this, the Ketandan-Tretes block still experienced severe water shortages in DS2 due to the small number of irrigation wells (Table 3). Although surface water was sufficient in the Mrican-Kiri block in DS2, the Widas block had insufficient surface water and the Kuncir-Bodor and Ketandan-Tretes blocks did not have surface water toward the end of DS2 (Table 3).

The lowland irrigation blocks are flooded in WS and experience drought in DS2, which has influenced the cultivation system and the selection of suitable crops grown in the area. There are three kinds of cultivation systems. The paddy field system (inundation) is used in WS and DS1 in areas with sufficient surface water. After the rice harvest, paddy fields are converted to an upland system in DS1 or DS2 to cultivate secondary crops. In the *surjan* system, a series of raised beds are constructed in the paddy field (Fig. 4). The width of the lower parts varies from 40 to 200 cm depending on the purpose. Widths of around 40–60 cm are used to drain excess water in WS and to irrigate the secondary crop cultivated in the upper part in DS1 and DS2.

Table 3. Cultivated area, surface water supply, number of irrigation wells (NIW), and irrigation well density (IWD) in DS2 (September 2009) in each irrigation block

Irrigation blocks	Cultivated area (ha)	Surface water supply (mm)	NIW	IWD (wells ha^{-1})
Widas	6348 (64%)	1.1	5594	0.38
Mrican-Kiri	13,635 (93%)	4.7	2059	0.21
Kuncir-Bodor	9351 (92%)	0.3	7884	0.78
Ketandan-Tretes	3486 (84%)	0.0	355	0.09
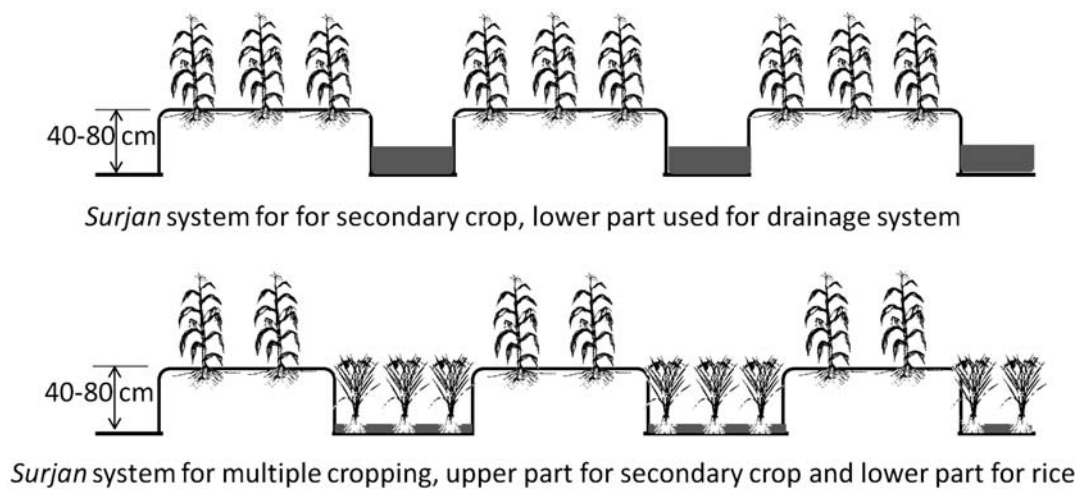
Fig. 4. Cross section of planting areas in the *surjan* farming system.

Widths of about 60–200 cm allow for a multiple cropping system, with the lower part serving as a paddy field and the upper part used to cultivate a secondary crop.

Harvest Index and ENSO Years

Agricultural production was quantified using the harvest index (*HI*) and failed-harvest index (*FHI*) of rice and secondary crops. In 1989 the total *HI* for all blocks was 2.21 crops yr^{-1} (Fig. 5). Between 2001 and 2010 the value showed a stable increase, with an average total *HI* of 2.81 crops yr^{-1}. The *HI* of rice was higher than that of secondary crops. In the 1990s and 2000s the *HI* of rice tended to increase every year, whereas the *HI* of secondary crops fluctuated, although secondary crops showed a long-term increasing trend over the study period. The *HI* of rice in the Mrican-Kiri, and Kuncir-Bodor blocks was higher than total *HI* of rice. The *HI* of secondary crops in the

Widas and Kuncir-Bodor blocks was higher than the total *HI* of secondary crops (Fig. 5), and farmers in the Widas and Kuncir-Bodor blocks intensively used groundwater to supplement surface water irrigation.

Table 4 shows the classification of ENSO events from 1972 to 2010 according to SOI data (NOAA, 2011) from early DS2 to early WS (July–December). The occurrence of flooding and drought was identified from statistical data related to harvest failure events. Flooding was not related to ENSO events, but mostly occurred in WS. Drought was related to strong El Niño events in 1982 and 1987.

The *FHI* of rice in the 1980s was higher than the *FHI* in later decades (Fig. 6). Rice harvest failure was mostly caused by flooding in the late WS, when plants were in the ripening and harvest phase. In the 1980s, secondary crop harvest failure was related to the magnitude of El Niño events (drought) in DS1 and DS2. In that decade, the R^2 values of linear regression of second-
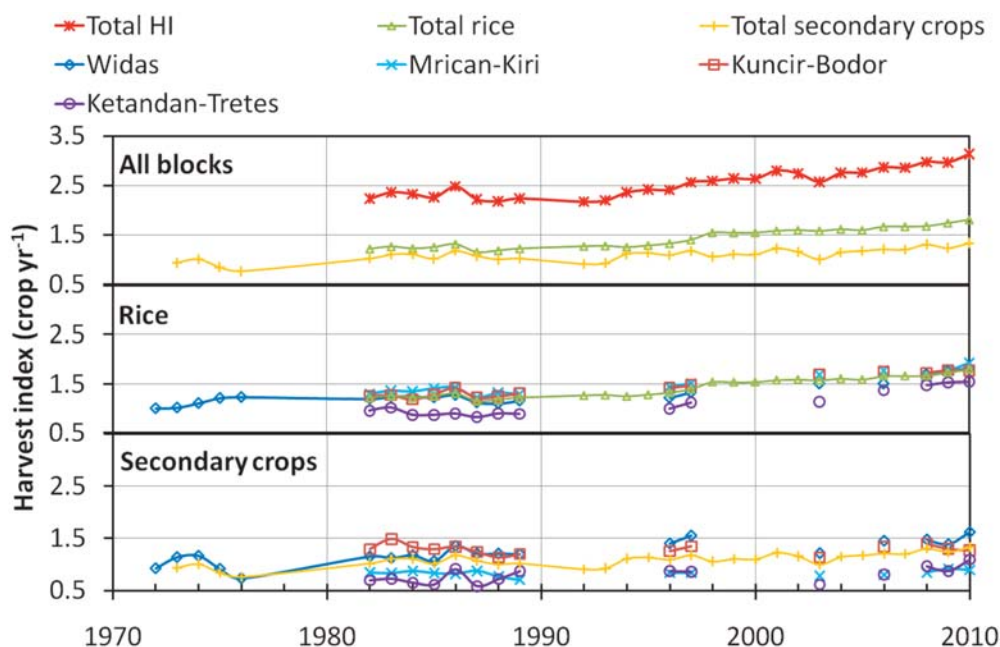
Fig. 5. Harvest index (*HI*) in all irrigation blocks from 1972 to 2010.

Table 4. El Niño/La Niña and flood/drought events in Nganjuk District from 1972 to 2010

Year	Episode	Remark
1972	Strong El Niño	No data
1973	Strong La Niña	No data
1974	Weak La Niña	No data
1975	Strong La Niña	No data
1976	Weak El Niño	No data
1977	Weak El Niño	No data
1982	Strong El Niño	Flood and drought
1983	Weak La Niña	—
1984	Weak La Niña	Flood
1986	Weak El Niño	Flood
1987	Strong El Niño	Flood and drought
1988	Strong La Niña	—
1991	Moderate El Niño	—
1994	Weak El Niño	Flood
1997	Strong El Niño	Flood
1998	Moderate La Niña	—
1999	Moderate La Niña	Flood in DS1
2000	Weak La Niña	—
2002	Moderate El Niño	—
2004	Weak El Niño	—
2006	Weak El Niño	—
2007	Weak La Niña	—
2009	Moderate El Niño	Flood
2010	Moderate La Niña	Flood in DS1and DS2

ary crop *FHI* and SOI were 0.994 and 0.772 in El Niño and La Niña years, respectively. The magnitude of El Niño was positively correlated with secondary crop *FHI*, where the regression coefficients is significantly different from zero at the confident level 0.05 (*P* value ＝0.016). The magnitude of La Niña events showed a negative correlation, and the regression coefficients is not significant. However, harvest failure of secondary crops after the 1980s showed a positive correlation (R^2 ＝0.78) with the magnitude of La Niña events. It suggested that harvest failure was caused by inundation of crops in areas with poor drainage in DS1 and DS2, although the regression coefficients is not significant (*P* value＝0.117). El Niño events did not influence *FHI* after the 1980s.

In the 1980s, El Niño events promoted the failure of rice and secondary crops (Table 4, Fig. 6). Drought increased harvest failure because the conjunctive use of groundwater was not yet widely applied in DS1 and DS2. After the 1980s, however, El Niño events no longer influenced harvest failure of secondary crops because conjunctive irrigation was widely applied by farmers. La Niña events increased the harvest failure of secondary crops because most farming in the dry season used the upland system, and secondary crops in areas with poor drainage were inundated with runoff water. Flooding also affected rice harvest failure in the WS until recently. Rice harvest failure in the down-
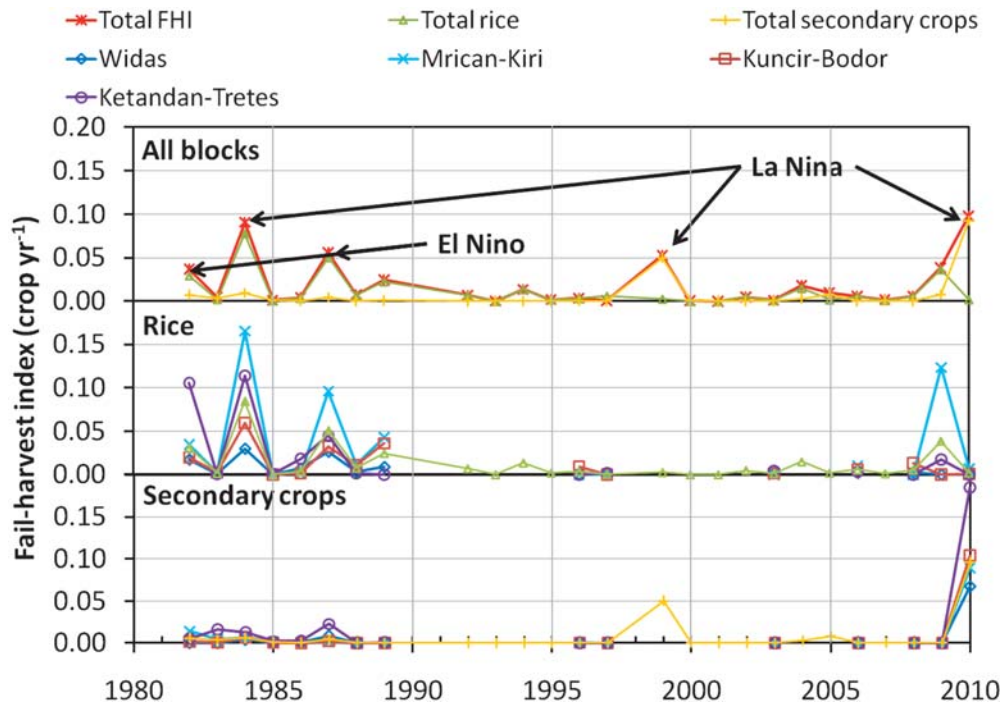
Fig. 6.   Failed-harvest index (*FHI*) and the relationship to El Niño and La Niña events in all irrigation blocks from 1972 to 2010.

stream irrigation blocks (Mrican-Kiri and Ketandan-Tretes) was higher than in the upstream blocks (Widas and Kuncir-Bodor).

Discussion

Irrigation projects in the Nganjuk District in the 1970s and 1980s increased *CI* to 2.21 crops yr^{-1} by 1989. The increasing *CI* helped to raise farmers' income and quality of life. During this period, the Indonesian government also introduced deep-well irrigation using motorized water pumps. Some farmers also applied shallow-well irrigation manually using bucket and dug wells in the middle of their fields. As farmers' income increased in the 1990s and 2000s, they developed and applied conjunctive groundwater use by employing motorized water pumps on shallow wells to irrigate maize, soybeans, mungbeans, and peanuts. Farmers developed deep-well irrigation systems for red onion, a crop with a relatively high economic value. Conjunctive irrigation successfully increased agricultural production in the dry season by about 0.5 crops yr^{-1}. In El Niño years, groundwater was used to supply irrigation water from the end of DS1 through DS2. Groundwater could supply sufficient water for irrigation in the dry season, as indicated by no harvest

failure occurring in the district in El Niño years.

Rice production was relatively stable during the study period, with a small increase from 1.22 to 1.82 crops yr^{-1} between 1982 and 2010, and it was not influenced by ENSO events. In La Niña years, surface water was almost sufficient or exceeded the need for irrigation water in DS1 and DS2. Little groundwater was used in this situation, and in La Niña of 2010 the groundwater level decreased at only 50% the groundwater level of that decreased in a normal year. Secondary crop production fluctuated during the study period. The *CI* of secondary crops decreased by 0.009 crop yr^{-1} in the La Niña of 2007, despite there being sufficient water resources, the *CI* increased by 0.161 crop yr^{-1} in the La Niña of 2010. However, the area experiencing harvest failure grew when the magnitude of La Niña increased, because secondary crops are vulnerable to waterlogging. Thus, if farmers in the district could be provided with clear information regarding ENSO for the coming year, it would help them to choose the best secondary crop to cultivate during the dry season.

Conclusion

The development of irrigation systems in Nganjuk

District increased agricultural production and farmers' income, thus motivating the farmers to achieve further gains by using groundwater resources. Conjunctive groundwater use increased the *CI* by about 0.5 crops yr^{-1} and provided sufficient water for successful harvests in the dry season and El Niño years. Thus, agricultural production was more secure when farmers applied conjunctive irrigation.

Our analyses indicate that El Niño did not influence agricultural production in Nganjuk District, whereas La Niña did have an influence, depending on the magnitude of the event. After the 1980s, the area experiencing harvest failure grew when the magnitude of La Niña increased, although the opposite was seen in the 1980s. Because secondary crops are vulnerable to waterlogging, providing farmers with an early warning of a La Niña year would allow them to choose the best crop and farming system in order to avoid harvest failure in the dry season.

References

Bergeron, N., Sedjo, R., 1999. The Impact of El Niño on Northeastern Forests: A Case Study on Maple Syrup Production. Discussion Paper 99−43. Resources for the Future, Washington, D.C.

Bhat, A., Ramu, K., Kemper, K., 2005. Institutional and Policy Analysis of River Basin Management, the Brantas River Basin, East Java, Indonesia. World Bank Policy Research Working Paper 3611.

BPS (Statistics Indonesia), 2009. Strategic Data of BPS. BPS, Jakarta.

BPS Nganjuk (Central Bureau of Statistics of Nganjuk District), 1973−2011. Nganjuk in Figures. BPS Nganjuk, Nganjuk, Indonesia.

Franke, C.R., Ziller, M., Staubach, C., Latif, M., 2002. Impact of the El Niño/Southern Oscillation on visceral leishmaniasis, Brazil. Emerging Infect. Dis. 8, 914−917.

Irrigation Services of Nganjuk District, 2008. Global annual planting plan (*rencana tata tanam global*) 2008/2009. Irrigation Services of Nganjuk District, Nganjuk, Indonesia.

Irrigation Services of Nganjuk District, 2009. Number of irrigation well in Nganjuk District. Irrigation Services of Nganjuk District, Nganjuk, Indonesia.

Nezlin, N.P., Hammer, W.M., Zeidberg, L.D., 2005. Influence of El Niño 1997−1998 on the pelagic ecosystem off California: remote-sensed analysis. Proceedings of California and the World Ocean 02, pp. 1233−1252; doi: 10.1061/40761(175)110.

NOAA/National Weather Service, 2011. Cold and warm episodes by season. http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml, accessed November 2011.

Pielke Jr., R.A., Landsea, C.W., 1999. La Niña, El Niño, and Atlantic hurricane damages in the United States. Bull. Amer. Meteor. Soc. 80, 2027−2033.

Prastowo, Hardjoamidjojo, S., Pramudya, B., Murtilaksono, K., 2007. Performance of shallow groundwater irrigation schemes in Nganjuk, East Java, Indonesia. CIGR Ejournal Vol. IX. June.

Puspowardoyo, R.S., 1984. Indonesia Hydrogeology Map: Kediri Sheet. Department of Mining and Energy, Bandung.

Ramu, K., 2004. Brantas River Basin Case Study: Indonesia. Background Paper. World Bank, Washington, D.C. Available at http://siteresources.worldbank.org/INTSAREGTOPWATRES/Resources/Indonesia_BrantasBasinFINAL.pdf. Accessed 1 April 2009.

Stiebel, W.H., Suradji, 1985. Groundwater development in the lower Solo River basin. Hydrogeology in the Service of Man: Memoires of the 18th Congress of the International Association of Hydrogeologists, Cambridge, pp. 197−208.

Sudaryanto, T., 1983. Effect of tubewells on income and employment: a case study in three villages in Kediri, East Java, Indonesia. In: Wicks, J.A., Nelson, G., Hettel, J.P.G. W.P.G. (Eds.), Consequences of Small-Farm Mechanization. International Rice Research Institute and Agricultural Development Council, Manila, pp. 107−118.

Usman, R., 2001. Integrated water resource management: lessons from Brantas River Basin in Indonesia. In: Abernathy, C. (Ed.), Intersectoral Management of River Basins: proceedings of an international workshop on "Integrated Water Management in Water-Stressed River Basins in Developing Countries: Strategies for Poverty Alleviation and Agricultural Growth," Loskop Dam, South Africa, 16−21 October 2000. IWMI, Colombo, Sri Lanka, pp. 273−296.

Yokoyama, S., 2002. ENSO Impacts on Food Crop Production and the Role of CGPRT Crops in Asia and the Pacific. Proceeding of a joint workshop on "Coping against El Niño for Stabilizing Rainfed Agriculture: Lessons from Asia and the Pacific," Cebu, the Philippines, 17−19 September 2002. UN-ESCAP CGPRT Centre, Bogor, Indonesia, pp. 79−93.