Influence of global climate indices and rainfall on rain-fed crop yield in highland of South-Central Java, Indonesia

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Chapter 1. Introduction

1. Background

1.1. Performance of agriculture in Indonesia

The Indonesian archipelago has about 17,508 islands straddling the equator, 6,000 of which are inhabited (Indonesia Statistic Bureau, 2008). The country lies at the edges of the Pacific, Eurasian, and Australian tectonic plates and thus an active site for volcanic eruptions, earthquakes, and tsunamis. Indonesia's tropical climate, geography, large forested areas, and extensive coastline (~80,000 km) have created in Indonesia to the world's second highest biodiversity after Brazil. Morever, Indonesia is one of the most culturally diverse countries in the world with around 300 distinct native ethnic groups, 742 different languages and 8 dialects, thus all make indonesia to become an interesting country to study and also an excellent model for assessing the risks of climate variability on agriculture.

In agriculture, Indonesia has many cropping systems such as a manicured irrigated rice system in Bali, a system based on rain-fed corn and sorghum in Nusa Tenggara Timur, a dry land cassava system in Maluku, a system of oil palm plantation in Kalimantan, and a system of sago palm and sweet potato in Papua. Rice is the main staple food in most areas and the rice sector is the largest employer in the agricultural economy overall. The islands of Java and Bali, which contain over half of Indonesia's population and account for roughly 55 % of the nation's rice production, are dominated by rice agriculture, particularly in the monsoon season.

Rice is not just a staple food in Indonesia but it is an agricultural product for international trading as well. As with the population growth rate of 1.18% (CIA World Fact Book, 2008), the need of rice is becoming a great issue in Indonesia. Although there are other main crops, which are available in some areas, such as corn and sago palm in the eastern part of Indonesia, rice is still the number one choice. According to FAO report in 2007, Indonesia has the third highest consumption of rice. The harvested rice area was 12,147,637 ha in 2007 with more than 50% located in Java Island (Indonesian Statistic Bureau, 2008) and a total population of more than 230 million inhabitants (CIA World Fact Book, 2008), rice availability is becoming a major priority.

Agricultural sector is still considered to be the most important part of the overall economic development and the structure of Gross Domestic Product (GDP) is the commonly used indicator. Based on data from Indonesia Statistic Bureau (2008), the agricultural sector contributed 33% of total GDP in 1970, the highest compared to other contributing sectors such as industry, trade, oil and gas sectors, which ranged from 8% to 16%. Most of the agricultural GDP came from the food crop sector, which contributed 58% of agricultural GDP (Table 1). This reveals that the food crop sector had an important role in the national economy. Since the agricultural sector played an important role in food security, most of the income obtained from oil exports was allocated to support agricultural development, particularly the food crop sub-sector, which was realized in terms of irrigation network development, agricultural credit subsidy and agricultural input price subsidy (Irawan, 2002). With the support of the green revolution, which enabled yield to increase, government policy increased food crop contribution to GDP from 58% in 1970 to 60% in 1980. Another important impact was the achievement of rice self-sufficiency in 1984.

As reported by Tambunan (1999), Irawan and Sutanto (1999), the achievement of rice self-sufficiency in 1984 motivated the government to reorient development of the national economy. Since foreign revenue continuously decreased due to decreasing oil prices, while the government had to pay foreign debts, since 1985 development of the economic sector was focused more intensively to increasing income from exports. The reorientation of development policy caused a decrease of government support to the agricultural sector, because the export value of the agricultural sector was relatively low compared to other economic sectors. Since that year, many kinds of subsidies in the agricultural sector began to be reduced; just the opposite occurred in the industrial sector, excluding oil and gas, since the industrial sector was capable of producing higher export income than the agricultural sector. The reduction of government subsidies decreased in the agricultural sector growth rate, from 3.6 % in 1970-1980 to 3.2 % in 1980-1990.

Table 1. Gross Domestic Product (GDP) for Indonesia during the period from 1970 to 2000.

Year	Non-agriculture	Agriculture	Sub-sector of Agriculture				
			Food Crops	Estate Crops	Livestock	Fishery	Forestry
1970	67.0	33.0	58.3	14.9	9.6	6.8	10.4
1980	77.3	22.7	60.2	14.0	9.8	6.5	9.5
1990	82.4	17.6	58.4	17.7	11.3	7.9	4.5
1995	83.9	16.1	52.7	16.2	11.0	9.8	10.3
1996	84.6	15.4	52.2	16.5	11.3	9.9	10.1
1997	85.2	14.8	50.4	16.5	11.8	10.4	11.0
1998	82.7	17.3	51.2	16.7	10.7	10.6	10.8
1999	82.7	17.3	51.2	17.8	10.6	11.1	9.4
2000	82.9	17.1	59.4	12.6	10.7	9.4	7.8
Growth of GDP (%)							
1970-1980	9.92	3.6	3.8	3.4	2,8	3,5	2.9
1980-1990	6.31	3.2	3.1	5.0	4,4	5,3	1.3
1996:							
-quarter I	6.9	5.5	6.3	5.6	6,2	4,5	1.3
-quarter II	8.2	4.5	4.8	3.7	6,1	4,5	1.2
-quarter III	9.5	2.2	0.6	3.0	6,1	4,6	1.3
-quarter IV	12.0	0.9	-3.9	5.3	6,1	4,7	1.3
Average 1997	9.2	3.3	2.0	4.4	6,1	4,6	1.3
-quarter I	9.1	-0.6	-1.3	9.0	4,9	3,8	-13.2
-quarter II	8.4	2.0	-2.9	4.4	4,9	3,8	33.0
-quarter III	3.7	1.6	-3.7	0.8	4,9	8,7	15.8
-quarter IV	4.2	0.4	-3.2	-4.1	4,9	6,5	9.4
Average 1998	6.4	0.8	-2.8	2.5	4,9	5,7	11.2
-quarter I	-5.7	4.5	-1.6	12.9	3,3	9,5	31.8
-quarter II	-18.0	-10.1	-14.0	-8.0	-6,3	3,1	-7.1
-quarter III	-19.0	3.3	7.0	6.0	-10,8	2,8	-0.9
-quarter IV	-24.6	8.8	29.8	3.4	-13,0	1,8	-15.7
Average 1999	-16.8	1.6	5.3	3.6	-6,7	4,3	2.0
-quarter I	-10.6	5.2	8.2	21.5	-1,0	-1,5	-12.2
-quarter II	3.7	6.2	3.9	25.8	-2,0	4,7	-0.5
-quarter III	2.2	-5.5	-1.5	-8.3	-2,1	3,3	-26.7
-quarter IV	7.7	-3.9	-8.1	-0.8	0,1	7,9	-8.7
Average 2000	0.7	0.5	0.6	9.5	-1,2	3,6	-12.1
-quarter I	5.9	-8.5	-8.0	-5.6	0,8	-1,4	-29.5

Source: Computerized database, Central Bureau of statistics, Indonesia.

The political crisis of 1997 in Indonesia caused a sharp drop in GDP. According to Tambunan (1999), Irawan and Sutanto (1999), all sectors of the economy were affected except agriculture, since those sectors were relatively intensive in using imported materials. Meanwhile, the agricultural sector was still capable of growing to 1.6%, which made the contribution of the agricultural sector to total GDP increase from 14.8% in 1997 to 17.3% in 1998 (Table 2). This reveals that the agricultural sector had higher resistance than other sectors in facing the economic crisis.

Table 2. Gross Domestic Product (GDP) of Indonesia during the period from 1996 to 1999

Variable	1996	1997	1998	1999
Number of workers (million)				
1. Rural area	58.0	57.5	57.4	56.5
- Agiculture	35.4	33.5	36.1	34.9
- Non-agiculture	22.6	24.0	21.3	21.6
2. Urban area	27.7	29.6	30.3	32.3
- Agiculture	2.3	2.4	3.4	3.5
- Non-agiculture	25.3	27.2	27.0	28.8
3. Rural + urban area	85.7	87.0	87.7	88.8
- Agiculture	37.7	35.8	39.4	38.4
- Non-agiculture	48.0	51.2	48.3	50.4
Annual growth (%/ year)				
1. Rural area	-	-1.0	-0.2	-1.5
- Agiculture	-	-5.4	7.6	-3.3
- Non-agiculture	-	5.9	-11.1	1.5
2. Urban area	-	7.0	2.5	6.7
- Agiculture	-	1.8	42.7	4.9
- Non-agiculture	-	7.4	-1.0	6.9
3. Rural + urban area	-	1.6	0.7	1.3
- Agiculture	-	-5.0	9.9	-2.6
- Non-agiculture	-	6.7	-5.7	4.5

Source: Computerized database, Central Bureau of Statistics, Indonesia.

1.2. The effects of climate variability

Climate impacts on agricultural product supply at various stages of the market system, such as production, storage and distribution activities. Climate also influences agricultural production capacity, through the generative and vegetative growth of each plant. Therefore, agricultural product prices usually fluctuate by season; during favorable climate or high production capacity, the price of an agricultural product drops due to supply increase, while the opposite occurs during bad weather conditions.

In tropical regions, where rainfall is relatively high and fluctuating, production capacity and pattern of agricultural production in a year are highly affected by rainfall conditions. This is particularly true for food crops or seasonal crops, and according to Bottema (1995) there are two variables of rainfall, which relate to food supply or food security problems in every region; they are monthly quantity and distribution of rainfall. Rainfall quantity will determine the amount of food that can be produced or food production capacity in each region, while monthly rainfall distribution plays a role in food production/supply continuity over the year.

Climate variability encompasses inter-annual or decadal fluctuations in rainfall and temperature patterns driven by coupled ocean-atmosphere circulation dynamics. An important climate variability, which influences crops production is El Niño (or El

Niño Southern Oscillation, ENSO), can briefly be defined as the anomalous appearance of warm surface temperatures in the central and eastern equatorial Pacific Ocean. ENSO is a dominant and recurring pattern of climate variability in the eastern equatorial Pacific that is characterized by anomalies in sea-surface temperature (referred to as El Niño and La Niña for warming and cooling periods, respectively), and by seasonal fluctuations in sea level pressure between Tahiti and Darwin, Australia (Southern Oscillation) (Pauly and Tukayama, 1987). Neutral ENSO conditions are characterized by a moderate strong eastern wind and a deep thermo cline in the western Pacific, causing convection over the western portion of the Pacific and the onset of normal monsoon rains over the Indonesian archipelago. During El Niño (warm mode) periods of the cycle, the easterly winds slacken and sometimes even reverse direction, shifting the concentration of warm water from the western to the central Pacific Ocean. As a result, convection occurs over the central Pacific, and dry conditions tend to prevail in the western Pacific. In extreme El Niño years, warm water is concentrated in the eastern Pacific where there is also a deeper thermocline and reduced upwelling near the surface—and thus lower productivity of pelagic fisheries such as Peruvian anchoveta (Pauly and Tukayama, 1987).

In neutral ENSO years, according to De Datta (1981), the main planting season occurs before the peak of the winter monsoon (December-January), because excessive water at the vegetative growth stage hampers rooting and decreases tiller production. Then the International Rice Research Institute or IRRI (2004) investigated that during the 90-120 days grow-out period from transplanting to harvest, at least 20 cm of cumulative rainfall is needed to moisten the ground sufficiently for planting, and about 100 cm of rainfall is needed throughout the season for cultivation. A smaller dry season planting takes place in April-May after the wet season crop is harvested. Indonesian agricultural statistics are available by trimesters (January – April, May – August, and September – December) as illustrated in Figure 1. These trimesters correspond closely with rice production and ENSO cycles.

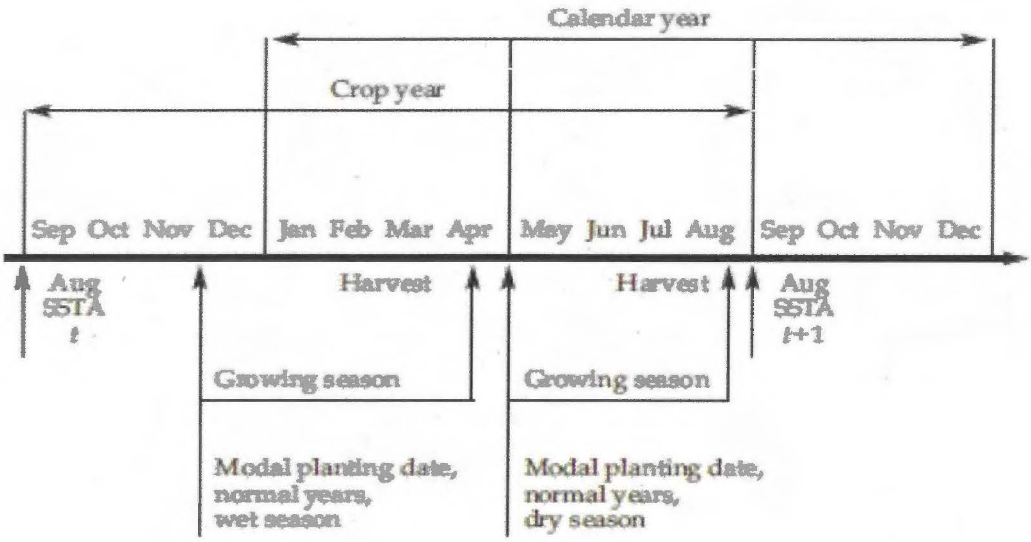


Figure 1. Crop calendar for Indonesian rice production (Falcon *et al.*, 2004)

Strong El Niño events can cause a delay in monsoon onset by as much as two months, thus delaying rice planting or causing farmers to switch to crops that require less moisture early in the production cycle, such as maize (Naylor *et al.*, 2001; Falcon *et al.*, 2004). Since the rains eventually do come, there is little impact of ENSO on rice yields. A delay in planting in turn extends the "hungry season" (the season of scarcity) before the main rice harvest. In addition, delayed planting of the main wet season crop may not be compensated by increased planting later in the crop year, leaving Indonesia with reduced rice area and a larger than normal annual rice deficit. In the absence of policy intervention, these two effects can drive prices up in domestic and international markets—with disproportionate impacts on poor net consumers of rice (Falcon *et al.*, 2004). During La Niña years, rains typically arrive earlier than normal, allowing for early planting and harvesting of rice.

However, the current climatic condition has become a constraint for rice production and limits the capacity of farmers to grow rice. The changes in atmospheric condition due to anthropogenic activities accelerate the fragile balance between demographic condition and food production. Meanwhile, Naylor *et al.*, (2007) stated that the agricultural production in Indonesia is influenced strongly by annual and inter annual variations in precipitation which is caused by the Austral-Asia monsoon and ENSO dynamics, with significant consequences for agricultural output, rural incomes and staple food prices.

Also, climate change will affect the progress of plant growth, and according to Adam *et al.* (1998), climate change is expected to influence the production of crops and livestock as a component of agriculture. These biophysical parameters are directly affected by changes in climate variability, especially precipitation, and the frequency and severity of extreme events like droughts, floods and windstorms. Rainfall variability will create additional impacts on Indonesian agriculture in a long period. During the years of El Niño, rice production in Indonesia is affected by delayed rainfall and reduction of rice crop area, resulting in an annual rice deficit larger than normal.

Understanding the seasonality of rainfall and rice production is important because Naylor (2007) stated that rice planting follows the rain in the "run-of-the-river" irrigated systems and rain-fed systems that are typical in Java. According to IRRI report in 2005, Indonesia has 23.5% rain-fed area, where the farmer still depends on rain-fed systems. During the normal years, the farmers plant the crops between October and early December, when there is sufficient moisture to prepare land for cultivation and to facilitate the early rooting of transplanted seedling. A delay of monsoon due to variations of climate will lead to postponement of main rice harvest, which often drives up prices in domestic and international markets. Meanwhile the amount of water received during the dry season is usually insufficient to grow rice crop without irrigation.

The decisions concerning the suitability of cropping systems, agricultural technologies and practices should be considered. According to Huang (2003), many selections may take several agricultural technologies or practices, including 1) land preparations, crop residues management and tillage, 2) choosing crops and varieties, 3) growing period and types of planting, 4) fertilizer and their application, and 5) pest controlling. However, combinations between microclimates and agricultural technologies factors will influence the success of crop production.

1.3. Problem on agriculture in South-Central Java

Many studies have shown the relationship between climate indices and crops production in Indonesia (Naylor *et al.*, 2002; Irawan, 2002; Kirono and Khakim, 1998; Amien *et al.*, 1996). Indonesia consistently experiences dry climatic conditions and droughts during the warm phase of the El Niño–Southern Oscillation (ENSO) cycle (Naylor *et al.*, 2001). The decrease of rainfall during the growing season, mostly lead by El Niño, critically affects the rain-fed agriculture. El Niño events which delay the beginning of the rainy season are threatening the stability of food security (Hamada *et al*., 2002; McPhaden, 1999). During previous two events (1982-1983 and 1997-1998), harvest areas for paddy have decreased to approximately 670 and 700 thousand hectares, respectively. These numbers gave the total loss to the Indonesian economy of about US$ 2.75 billions (BAPPENAS, 1999). Naylor *et al.* (2007) shows a marked increase in the probability of a 30-day delay in monsoon onset in 2050, as a result of changes in the mean climate. Therefore, reliable studies on the relationship between climate indices and crops remain one of the foremost tasks to secure the food production in the country.

The island of Java produces more rice than 50% of the total amount of national production (Central Bureau of Statistic, 2008), making this area the biggest contribution of rice production in Indonesia. Compared to other places, Java has an intensive agriculture and a well-developed irrigation system. Around 50% of farmlands in this area are irrigated. However, the dryland agriculture, mostly in the southern highland of the island still remains 41%. Irawan (2002) indicated that the El Niño events had dramatically decreased the crop yields for this area. An effort to cope with the threat of food insecurity for highland areas is considered to play an important role to the food security under climate change.

In the normal year, rice is planted early in the 'wet season' between September and December, when there is sufficient moisture to prepare the land for cultivation and to facilitate early rooting of rice seedlings (Naylor *et al.*, 2002). The decrease in rainfall is threatening the production of rice in rain-fed agriculture at dry land fields in Indonesia. In 1997, about 52% of dryland rice-producing sub district in Java Island could not produce rice. These areas are mostly located at southern Java (Irawan, 2002). The average production loss was about 19% where mostly suffered in the highland fields.

The main problem of agriculture in highland fields is water scarcity due to less amount of rainfall (Hoogenboom, 2000). Irawan (2002) indicated that the El Nino had dramatically decreased the crop yields for this area. An effort to cope with the threat of food insecurity for areas of highland is considered to play an important role for food security, not only under climatic factor but also non-climatic factor.

Within this context, an effort in non-climatic factor is improving cropping system in those areas. Mostly, farmers in the areas of highland are using multiple cropping systems (MCS) in their cropping pattern. MCS refers to multiple crops that are planted on the same field, but not simultaneously, during a season (Beets, 1975). Many studies show that MCS is better than the monoculture in dryland because it may minimalize chemical fertilizer, pesticides and farm machinery (Huang, 2003). On the other hand, the advantages of MCS depend on the plant population density (Herbert *et al.*, 1984; Putnam *et al.*, 1985; Putnam *et al.*, 1986), and plant spacing (Sharma and Thakur, 1993; Nakano and Mizushima, 1994; Hasanuzzaman *et al.*, 2009). The growth of rice, especially the height and number of tillers using System of Rice Intensification (SRI) has been reported by Murtiningrum *et al.* (2011), where the number of tillers in conventional crops has more and relatively higher than SRI.

In this study, we investigate the highland agricultural issues in Gunungkidul, South Central of Java at a large- and micro-scale levels, and reveal the influences of climate indices and the cropping patterns in this area.

2. Study area

Gunungkidul district was selected as a study area (Fig. 2). Based on its topography, Gunungkidul is divided into three zones: North Zone (Patuk, Gedangsari, Nglipar, Ngawen, Semin, and northern part of Ponjong sub-district), Central Zone (Playen, Wonosari, Karangmojo, central part of Ponjong, and northern part of Semanu), and South Zone (Panggang, Tepus, Paliyan, Rongkop, southern part of Semanu, and southern part of Ponjong). These zones have elevation ranging 200 - 700 m, 150 – 200 m and 0 - 300 m above sea-level, respectively. Based on the data from Badan Pusat Statistik (BPS) or Central Bureau of Statistic, Gunungkidul district (2003), the amount of sub-districts was increased from 15 to 18 sub-districts due to the expansion of sub-district. Three of the sub-districts are Purwosari, formerly a part of Panggang, Tanjungsari, formerly a part of Tepus and Girisubo, formerly a part of Rongkop (Fig. 3).

Gunungkidul is characterized by its karst that is not suitable for farming due to lack of water during dry season. The average annual rainfall is 2,500 mm. Most of the farmers in this area practice rain-fed agriculture and cultivate multiple cropping systems. They use *pranata mangsa*, a worldview based on the Javanese lunar cyclical calendar, to decide their planting schedule. Major agricultural product is cassava that once established can endure drought and heat effectively. Other products include corn, soybean, upland (dryland) rice and legumes. Figure 4 shows rainfall distribution and cropping patterns in various land types in Gunungkidul (Falcon *et al.*, 1984). Corn is planted first at the beginning of the rainy season, and the cassava that follows about a month later is left for up to 20 months before harvest. Legumes are interplanted with the cassava and corn.

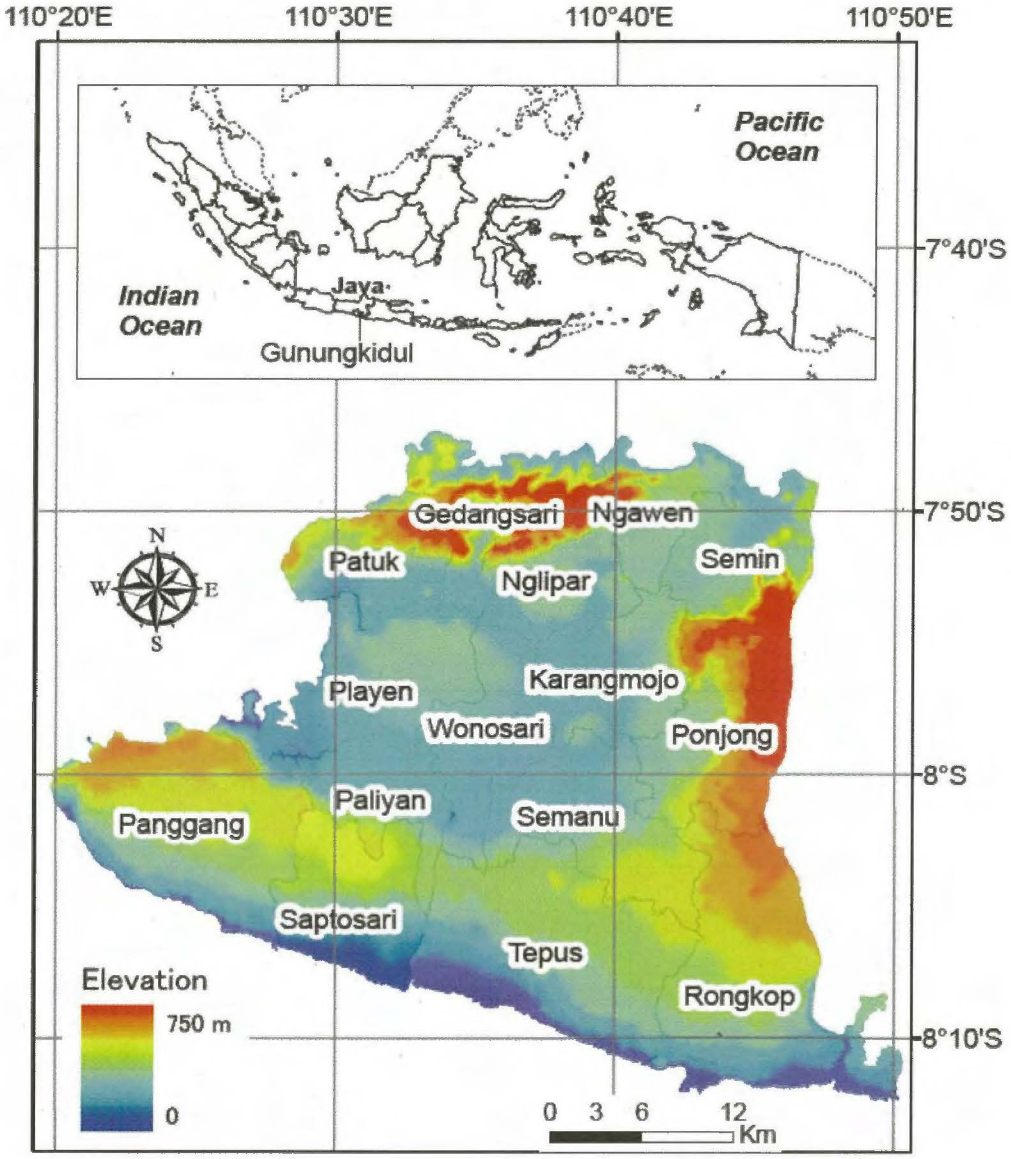


Figure 2. The 18 sub-districts of Gunungkidul and its topography. The variations in elevations show distinct landscape characteristics of each district (before 2002).

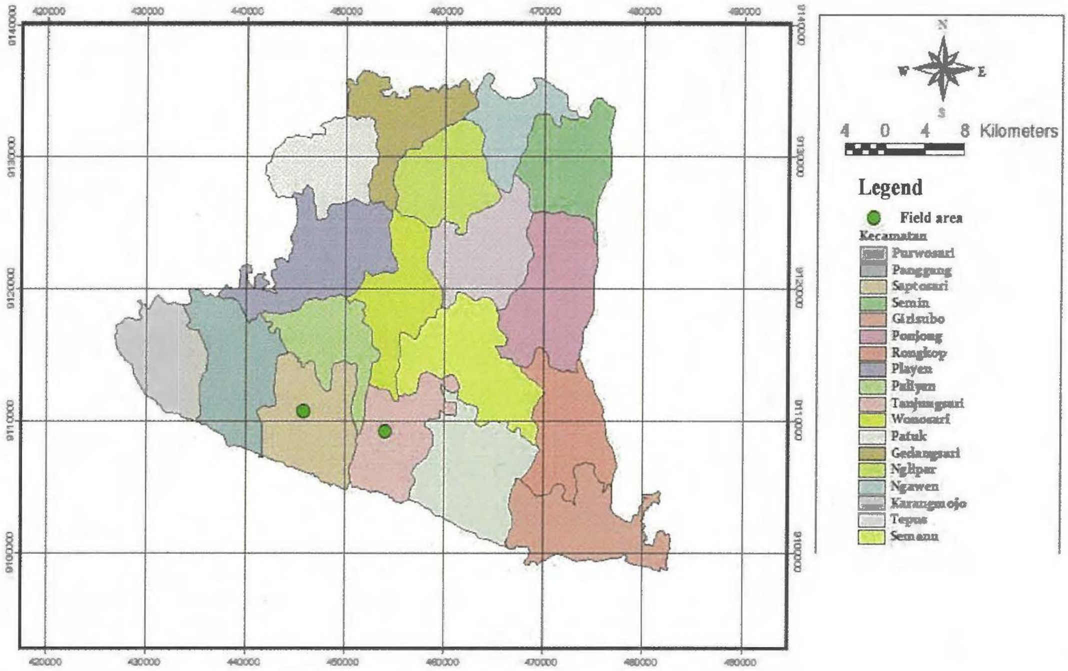


Figure 3. The sub-districts after expansion in 2002

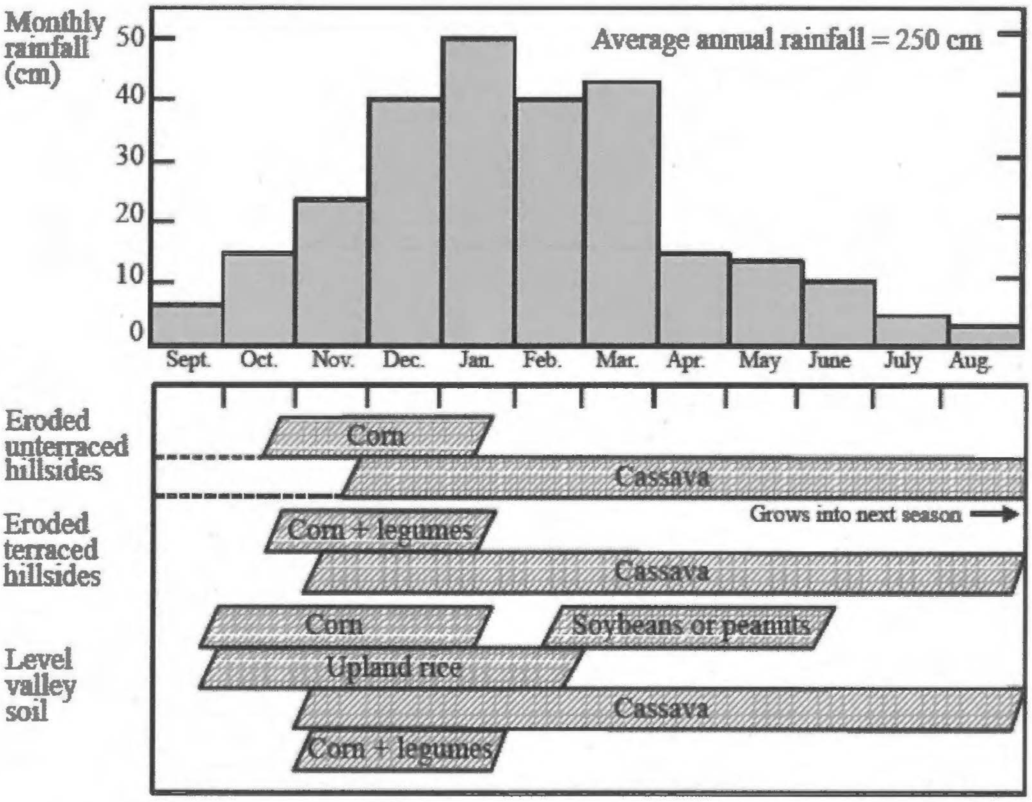


Figure 4. Monthly rainfall distribution and cropping patterns based on three landform types (level valley soil, eroded terrace and unterraced hillsides) in Gunungkidul (Falcon *et al.*, 1984)

In micro-scale, Observations were conducted at Saptosari and Tanjungsari sub-districts, and they are located at highland agriculture; with 93% of them 185 to 500 above sea-level and high proportion of multiple cropping systems based on Agricultural Service for Food Crops and Horticulture (ASFCH), Gunungkidul district (2009). The mean rainfall is 1400 mm for Saptosari and 1700 mm for Tanjungsari during rainy season based on the record data from 1989-1998. On average, the wet period lasts for about 4 to 6 months (November to April) and the dry period lasts also for 4 to 6 months (May to October), respectively (ASFCH, 2006).

Most of the farmers in this area practice rain-fed agricultures and cultivate multiple cropping systems. They also use *pranata mangsa*, a worldview based on the Javanese lunar cyclical calendar, to decide their planting schedule. Figure 5 shows the cropping patterns in Saptosari and Tanjungsari (ASFCH, 2009). Combination of maize – dryland rice - cassava and maize – peanut - cassava are planted first at the beginning of the rainy season, and combination of peanut – cassava and soybean – cassava follows the next planting season.

<table>
<tr><td colspan="6">Rainy season</td><td colspan="6">Dry season</td></tr>
<tr><td>Nov</td><td>Dec</td><td>Jan</td><td>Feb</td><td>Mar</td><td>Apr</td><td>May</td><td>Jun</td><td>Jul</td><td>Aug</td><td>Sep</td><td>Oct</td></tr>
<tr><td colspan="3">Maize</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Dryland rice</td><td colspan="4">Peanut</td><td colspan="4">Peanut</td></tr>
<tr><td colspan="12">Cassava</td></tr>
<tr><td colspan="12">Cropping pattern A</td></tr>
<tr><td colspan="4">Maize</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Peanut</td><td colspan="3">Soybean</td><td colspan="4">Peanut</td></tr>
<tr><td colspan="12">Cassava</td></tr>
<tr><td colspan="12">Cropping pattern B</td></tr>
</table>

Figure 5. Cropping patterns at Saptosari and Tanjungsari during one year (ASFCH, 2009)

3. Aim of study

This study seeks to explain the influence of global climate, local rainfall and cropping pattern on crop yield in highland of South-Central Java, Indonesia at macro- and micro-scales. The analysis of macro-scale includes the relationships between global climate indices and crops yield while the micro-scale the influence of local climate indices and cropping patterns to the height and tillers of rice based on multiple cropping systems. The analysis at macro-scale will describe about the kind of crops and planting areas are sensitive to the changes of global climate indices. It may contribute to a better understanding of spatial and temporal variability of the global climate indices against small regions of the study area. On the other hand, the analysis at micro-scale will describe the suitability of cropping systems in highland areas. Overall, this study will provide valuable information to policy makers in agricultural sector in this area, not only for the estimation of crop yield but also for deciding the starting date of planting season and suitable plants for the cropping systems.

Explanation about relationships among global climate indices, local rainfall and rain-fed crop yields can be seen at Fig. 6 below.

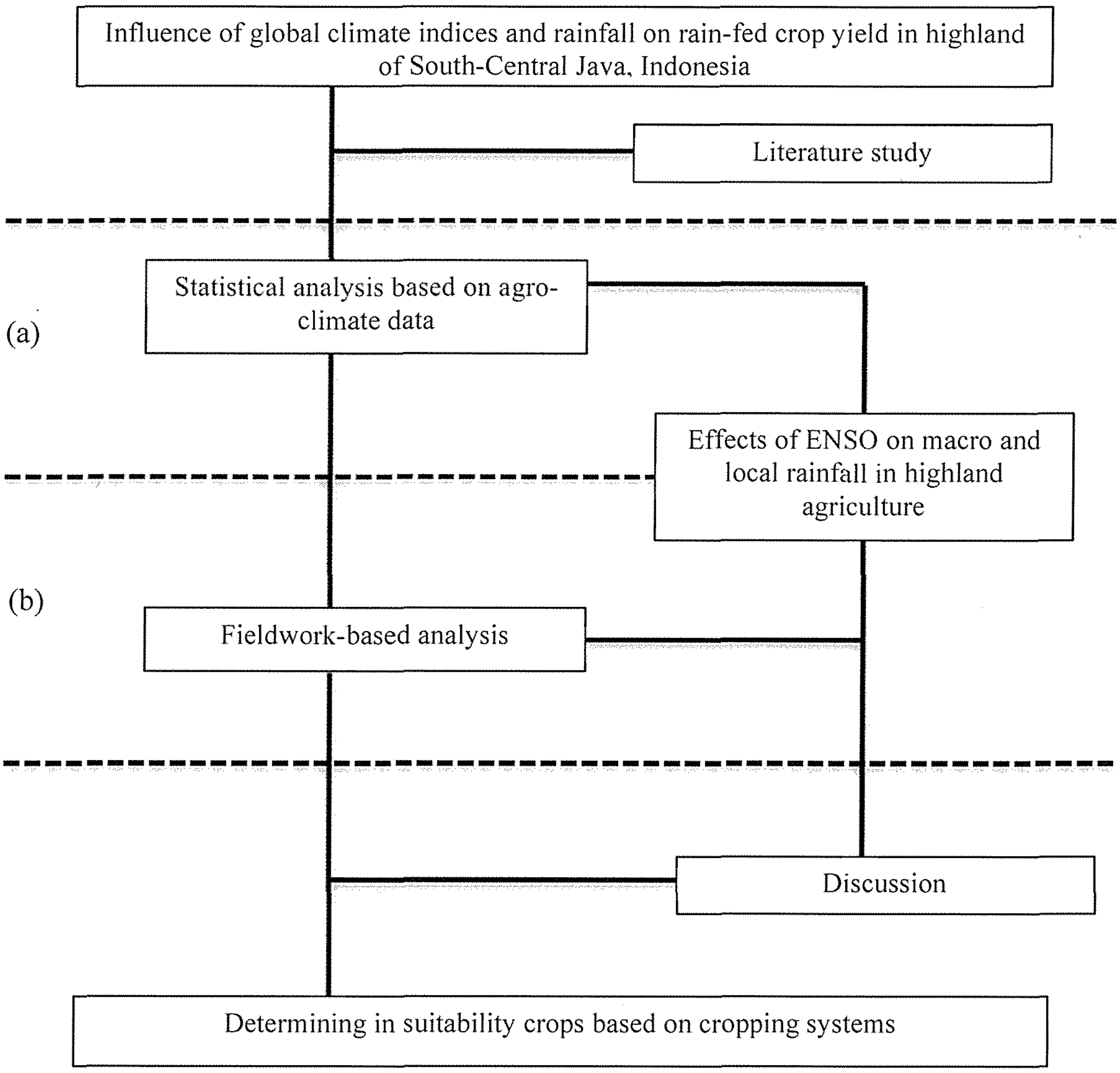


Figure 6. Flowchart: this study is divided into two main objectives: (a) relationships between rain-fed crop yield and global climate indices based on statistical data, (b) field-work research in the influences of cropping systems on the height and tillers of rice.

Chapter two will describe previous studies related to global climate indices, local rainfall, soil characteristics in, multiple cropping systems, and other factors of highland agriculture. In Chapter three, we examine the relationships between global climate indices and rain-fed crop yields, and validate the model crop yields based on global climate indices in the South-Central Java. In Chapter four, we examine influences of cropping systems on the height and tillers of rice based on fieldwork analysis. In Chapter five, we provide a discussion of the relationship among global, local climate indices, and rain-fed crop yields. In Chapter six, conclusions of this study are given.

Chapter 2. Preliminary studies

1. Relationships among global climate indices, rainfall and crop yields

References in global climate indices and crop yields, local climates (rainfall, temperature, relative humidity, solar radiation) and crop yields were documented (Naylor *et al.* 2002; Irawan, 2002; Naylor *et al.*, 2001). In Indonesia, variable rainfall during the growing season, mostly due to El Niño and La Niña events, critically affects rain-fed agriculture. Hamada *et al.* (2002) indicated that El Niño events affect delaying the beginning of the rainy season (typically, October–March) and thereby negatively affecting agricultural production. During the past 20 years, several El Niño events (McPhaden, 1999) delayed the paddy harvest in Indonesia and threatened the stability of food security (Harger 1995; Amien *et al.*, 1996). Irawan (2002), Kirono and Tapper (1999) stated that the delayed start of the rainy season due to El Niño events has a greater effect on crop yields in highland areas, where agriculture is rain-fed.

At present, about 40 % of total rice area is classified as rain-fed (lowland or upland), while about 3.5 million ha of rice-land are still being classified as deep-water of flood-prone (Maclean *et al.*, 2002). Variability in the amount and distribution of rainfall is the most important factor that limits yield of rain-fed rice. Variability in the onset of the rainy season leads to variation of the start of the planting season in rain-fed rice areas. Moreover, in drained upland, moisture stress severely damages or even kills rice plant in an area that receives as much as 200 mm of precipitation in one day and then receives no rainfall for the next 20 days. Complete crop failure usually occurs when severe drought stress take place during the reproductive stages.

Rain-fed agriculture in highland areas is more affected by rainfall variability because of the topographical characteristics of these areas (Haylock and McBride, 2001). According to Anders *et al.* (2006), precipitation patterns are affected by both topography and air mass conditions on the windward side of mountains. Many studies have investigated the relationship between rainfall variability and topography in Indonesia. Nitta *et al.* (1992) reported that the blocking effects of Sumatera topography weaken tropical convective systems moving eastward from the Indian Ocean to the Western Pacific. Hamada *et al.* (2008) showed that rainfall and wind speed are greater on the windward side than on leeward side of the mountains of western Sumatera and suggested that surface topography plays a role in determining the rainfall distribution not only in Sumatera but also in and around the entire Indonesian archipelago.

Rainfall variability in Indonesia also correlates with global climate indices, such as the Southern Oscillation Index (SOI) and sea surface temperature (SST) (Saji *et al.*, 1999). SST fluctuations are the most pronounced around Indonesia and in the nearby tropical Pacific (Trenberth and Shea, 1987; Trenberth and Hoar, 1996). Nicholls (1981, 1984) showed that surface pressure at Darwin, northern Australia and SST around Indonesia could be used to predict Indonesian climate variations and Indonesian rainfall. Kirono and Tapper (1999) found that rainfall from June to November was positively correlated with the SOI from 1951 to 1997, and that the relationship was particularly strong in southern Java, including Yogyakarta Special Province. Thus, rain-fed crop production in highland areas of Indonesia is simultaneously influenced by rainfall variability, global climate as reflected by the SOI and SST indices, and the highland topography. Naylor *et al.* (2001, 2002) quantified the relationships among El Niño-Southern Oscillation (ENSO), rainfall variability, and Indonesian rice and corn production from 1971 to 1998, and Naylor *et al.* (2007) assessed the possible effects of climate variability and change on food security in 2050. As shown in Kirono *et al.* (1999), there are clear spatial and seasonal variations in ENSO influence on rainfall in Indonesia, which may be evident in crop production, as it was the case for negative growth rates for rice production during the 1982, 1991 and 1994 El Nino events. Kirono *et al.* (1999) has indicated that in June to November rainfall is positively correlated with SOI and the relationship is particularly strong for southern Indonesia. In fact, almost all the provinces indicated negative growth rate. It means that during El Niño years, the dry-season rainfall tends to decrease so the only land that can be cultivated at these times is irrigated rice field. Consequently, total dry-season rice production for some provinces is reduced. Considering seasonal effects, rice production appears most strongly affected by ENSO in May to August (dry-season transition) and September to December (wet-season transition) periods, and for some provinces, it is possible to predict rice production a few months in advance using the antecedent value of SOI.

In correlations with plant, rainfall is a particularly important driving variable in the semi-arid and sub-humid tropics, but it is also important in temperate zones during in dry periods. Its value can change more from day to day than any other meteorological variable. Hoogenboom (2000) indicated that normally, on the wet days its value is often 2-20 mm, but can reach 100 mm or more in intensive tropical storms, but if the rainfall is insufficient, it causes drought. Drought occurs during periods of insufficient rainfall, while water logging occurs during periods of extensive rainfall. Drought can cause an increase or decrease in developmental rates, depending on the stage of development, and also reduce gross carbon assimilation through stomata closure, causing a modification of biomass partitioning to the different plant components. The other cases, flooding causes water logging stress, and it can cause a lack of oxygen in the rooting zone, which is required for root growth and respiration. In some cases, extreme rainfall can make a crop unharvestable, when farmers are unable to enter the field due to saturation of the topsoil.

2. Relationships between local climates and crop yields

Rainfall is an important factor in the plant growth and agricultural production, which amount of rainfall influences the agricultural production in the field area. Lack of rainfall, it will disturb in the plant growth and developmental process. For rice, it needs a high amount of water and sufficient moisture in the early stage, thus it will be highly affected by the change of growing season due to the amount of rainfall.

The vegetative and reproductive development phases are influenced by temperature, as the main weather variable (Hodges, 1991). In most cases, an increase in temperature causes an increase in developmental rates, the respiration rate of plants, reduce net photosynthesis and hence eventually reduce plant yield. As reported by Sasendran *et al.* (2000), an increase of temperature can lead to a decrease in the length of the growing season and the yield of most crops.

Solar radiation is also an important factor in the effect of crops production, which provides energy for the processes that drive photosynthesis, affecting carbohydrate partitioning and biomass growth of the individual plant components (Boote and Loomis, 1991). Other weather factors that can affect crop production include soil temperature, wind and relative humidity.

In most cases, during the early part of growing season, soil temperature is an important factor, as it affects planting and germination. Relative humidity (RH) expresses the amount of water present in the air, and it affects transpiration and the amount of water loss by the canopy, causing drought stress water-limiting conditions. RH can also influence biotic stresses, such as the presence as well as the activity of pest and disease. Wind can also have a multiple impact on crop production, which can affect the rate of transpirational water loss by the leaves. Also, wind can affect the transport and the distribution of insects and diseases in the atmosphere, and subsequent presence in the plant canopy (Hoogenboom, 2000).

3. Multiple cropping systems

The important stage during the planting season is cropping pattern and this is a decisive factor on the success of cultivation and productivity yields. The meaning of cropping pattern is the yearly sequence and spatial arrangement of crops, and cropping system is the cropping patterns used on a farm their interactions with farm resources, and available technology that determine their make up. There are many cropping pattern practice in the world, but two of famous cropping pattern are monoculture and multiple cropping.

Monoculture is the repetitive growing of the same crop on the same piece of land, while multiple cropping is the intensification of cropping in time and space dimensions, growing two or more crops on the same field in a year. Strategies in multiple cropping emphases on time and space arrangement to maximize crop productivity due to many factors, for example limiting-water and farmland, so multiple cropping systems provide high efficiency in farmland use (Howard and Lessman, 1991). According to Gliemann and Amador (1979), that in areas of the world where multiple cropping is a common aspect of agro-ecosystem management, productivity generally is more stable and constant in long-term. Comparison between monoculture and multiple cropping systems with implications for crop improvement can be seen at Table 3.

Table 3. Comparison of monoculture and multiple cropping systems with implications for crop improvement (Adapted from Altieri *et al.*, 1978; Dickinson, 1972)

Characteristic	Monoculture	Multiple crop	Breeding implication for multiple crop genotype
Net production	High (with fossil fuel)	Moderate (near monoculture)	Specific cultivars may be needed for some multiple cropping systems
Species diversity	Low	Moderate-high	System approximates native vegetation and crop variability may be desirable
Nutrient/light use	Poor-moderate	Moderate-high	Component crops may complement each other in light interception and rooting pattern
Nutrient cycles	Open (leaching losses)	Closed (with perennials)	More efficient use of lower levels of applied fertilizer desirable
Weed competition	Intense	Moderate	Crop competition suppresses some weed; more difficult to use herbicide mixes
Insect/disease	Severe	Moderate	Some insect control from system; less difference in disease incidence
Labor requirements	Seasonal	Distributed	More operations possible by hand on small areas; multiple hand harvests possible
Diet distributions	Low	High	Nutritional quality a desirable trait for most consumed crops
Economic stability	Low	High	Risk reduced by diversity, range of crop maturities to spread income
Social variability	Volatile	Stable	Different client groups and levels of technology generally involved

The other stated in the advantages and disadvantages of multiple cropping systems was investigated by Huang (2003) The advantages of multiple cropping are summarized as follow: 1) reduce the risk of field losses to drought, insects and disease, 2) obtain a better use of vertical space and time in limited farmland, 3) legumes (as well as a few other plant families) are able to fix and incorporate nitrogen into the system, 4) diversified products contribute to a better balance diet for farmers, 5) higher planting density and heavier much cover aids in weed control, avoidance or reduction of surface erosion, 6) improved soil structure, avoiding the formation of a "hard pan" and promoting better aeration and filtration, and 7) better opportunities for biological control of insects and diseases.

The disadvantages of multiple cropping systems are 1) competition between plants for light, soil nutrients and water, 2) it is difficult to harvest one crop without damage the other, mechanize and incorporate a fallow period in or into the systems, 3) possible over-extraction and loss of nutrients and allelopathic influence between different crop plants.

From the point view of producer, multiple cropping systems increase the value and income of agricultural production (Beuerlein, 2001; Cramer and Cucero, 1992), and some economic analyses of multiple cropping were carried out by a group of scientists at the University of Georgia (Anon., 1980; 1981). In 1980, the study showed that most irrigated multiple cropping productions was profitable on well-drained, sandy soil. Further analyses in 1981 indicated that irrigated crops were generally profitable on a first-crop basis, but in the second-crop the profit was limited to sorghum and soybean. These results suggested that the economics of multiple cropping systems differ significantly from that of a single, full season mono-crop.

4. Highland agriculture and soil characteristics

In rain-fed highland agriculture, water scarcity is a major factor limiting agricultural production for millions of resource-poor dryland farmers. The small total amount of rain combined with its erratic and unreliable occurrence constraint the achievement of stable, sustainable production systems providing satisfactory, low-risk livelihoods. The occurrence of periods of water deficit for crop production, referred to as 'climatic drought', is commonly observed and leads to low water availability to crops (Hoogenboom, 2000). Besides climatic drought, crop water stress may also result from low levels of plant available water in the soil profile due either to the existence of physical barriers to water infiltration (e.g. surface sealing) or to soil chemical or physical limitation to plant root growth and root water uptake.

Mostly, rain-fed highland agriculture is located in highland topography, where soils are characterized by sandy loam with low surface porosity, poor structure, susceptibility to crust formation, and low water-holding capacity. The other soil characteristic in highland is karst topography. Karst is the term given to geographical regions characterized by the presence of carbonate rock (limestone and dolomite), and where drainage mainly occurs via an underground river system. A mild carbonic acid produced from carbon dioxide (CO_2) in the atmosphere is responsible for the solvent nature of groundwater on carbonate rocks. Over a period of millions of year, groundwater dissolves limestone and enlarges drainage routes. This creates topography by caves, sinkholes, mogotes, and underground rivers (Waltham *et al.*, 1983).

In Indonesia, most of the karst is found along the south of Java Island, especially at South-Central Java. The karst surface within the valleys and depression is mantled by deeply weathered clays, up to 10 m in thickness, which are remands of volcanic as intermixed with weathering residue from the limestones (Waltham *et al.*, 1983). On the hills, soil are shallow, patchy redzinas or vertisols, but the karst is intensively cultivated, particularly the red-brown clays in the valleys and depressions, with terracing, irrigation and sophisticated manipulation of available water resources (Uhlig, 1980; Urushibara and Yoshino, 1993). Karst development in the South-Central Java has been influenced by paleoclimatic conditions (Urushibara and Yoshino, and Yoshino, 1997).

5. Growth stages of crops

According to Stansel (1975), the crop growth is the multiple assimilates used for growth and the efficiency of the process, but, in this study, we consider the growth of rice as the height of rice and number of tillers.

The development stage of crops cannot be expressed simply as chronological age, because any related with several environmental factors, such as temperature and water stress, and they can speed up or reduce the rate of phenological development. The concept of development stage is used to illustrate the whole crop and it is not appropriate for individual organs. According to Stansel (1975), the development stage has the value of 0.0 at emergence, 1.0 at anthesis and 2.0 at maturation and its value increases gradually.

Commonly, the development stage is divided into two main phases:

a. Vegetative phase

In this phase, temperature and day length are main factors. The temperature that affects the phenological development process can be taken as equal to the daily average air temperature at the height of the shoot's growing point. Only when day or night temperature regularly reach values where the response is non-linear, is another procedure of weighing temperatures required. Some plants require a certain minimum or maximum night length before flowering is triggered, but in most cultivars phenological development is continuous process slowed by unfavourable day lengths.

In this phase, from emergence to flowering around 62 to 109 days is required and the height of rice is around 1.0 meter. The longest duration occurs during the third tiller to panicle initiation with 24 to 42 days.

b. Reproductive phase

The reproductive period is the period after flowering until maturity. In this phase, the development rate is constant and it is different with vegetative period, which is the development rate that gradually increases.

In the reproductive phase, especially from flowering to maturation, it more days are needed than the other stages, around 30 to 42 days with the height of rice around 1.0 meter.

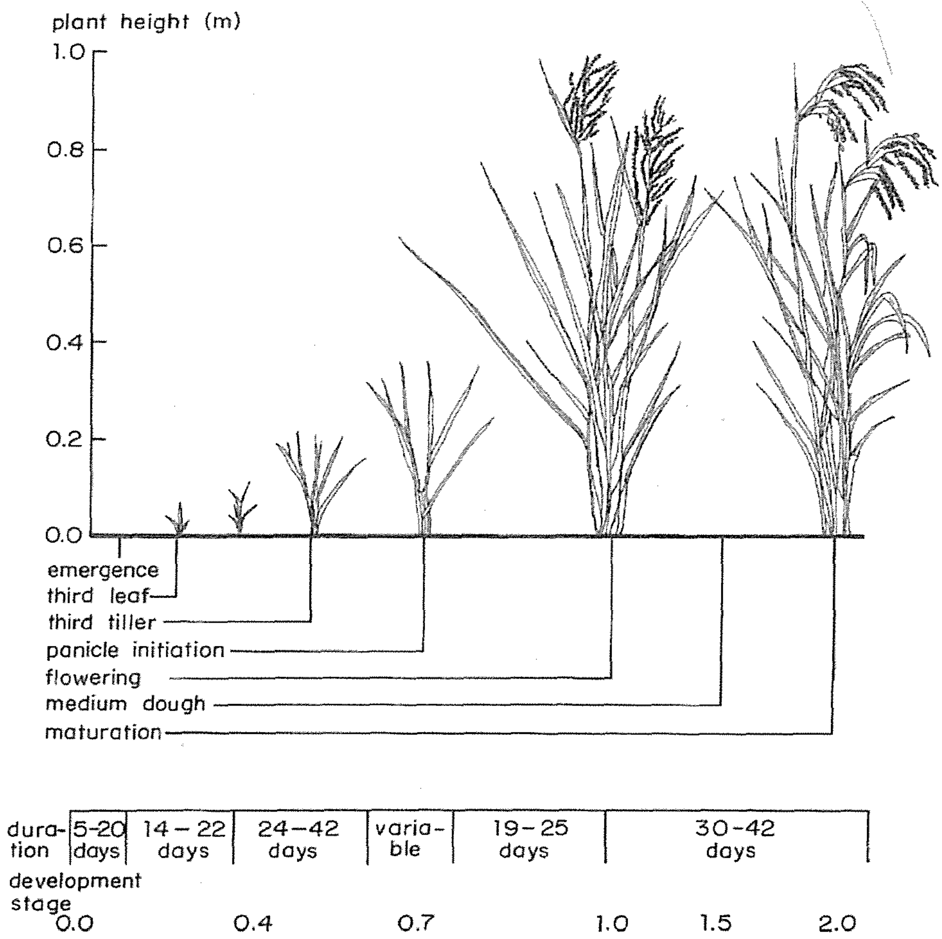


Figure 7. Development stages of rice crop (Source: Stansel, 1975)

Figure 7 shows the development stage begins at 0.0 when plantation starts at seedling emergence. Often, however, plantation starts when young plants are already well established. Value of 0.1-0.25 for the initial development stage of field crops are common, and as high as 0.5 for transplanted rice. Stansel (1975) stated that from the planting until maturation needs 95 – 150 days and the height of rice is around 1.0 meter.

Chapter 3. Relationships between global climate indices and rain-fed crop yields in highland of South-Central Java, Indonesia

In this study, we analyze the relationship between global climate indices and rain-fed crop yields in Gunungkidul district, highland of South-Central Java, Indonesia and global climate indices represented by the Southern Oscillation Index (SOI) and sea surface temperature (SST). This work aims to describe which crops and which parts of the study area are sensitive to the changes of global climate indices. The results may contribute to a better understanding of spatial and temporal variability of the global climate indices against small regions of the study area.

1. Data and Methods

1.1. Crops yield

Data of annual crop yields (dryland paddy, corn, cassava and soybean) from 1994 to 2009 were collected from twelve sub-districts of Gunungkidul: Panggang, Paliyan, Tepus, Rongkop, Nglipar, Semanu, Playen, Patuk, Ngawen, Wonosari, Karangmojo, and Ponjong (Fig. 2). Data for the remaining three sub-districts: Gedangsari, Semin, and Saptosari were unable to qualify for this study. Figure 8 shows boxplots of annual crop yields for each sub-district. The yield of cassava accounted for four times greater than any other crop. Moreover, it is approximately normally distributed as indicated from the location of the medium values on the plot, showing its high level of resistance to climate constraints. On the contrary, the boxplot indicates skewed distribution for yields of paddy and soybean.

We assumed that climatic influences on crops yields generally occurred at a higher frequency than that of non-climatic. However, in order to avoid reliability issues and errors associated with the data, the observed crop yields were detrended using a low-pass spectral smoothing filter (Press *et al.*, 1989) with a 5-year moving average. For the analysis, we calculated crop yield residuals (Martinez *et al.*, 2009) as follows:

$$y_{\text{residual}} = \frac{y_{\text{observed}}}{y_{\text{smoothed}}} - 1 \qquad (1)$$

While the residuals maintain the trend of each data set, each was regularized (mean=0) to enable direct observation of statistical fluctuation of the crop yields for each sub-district.

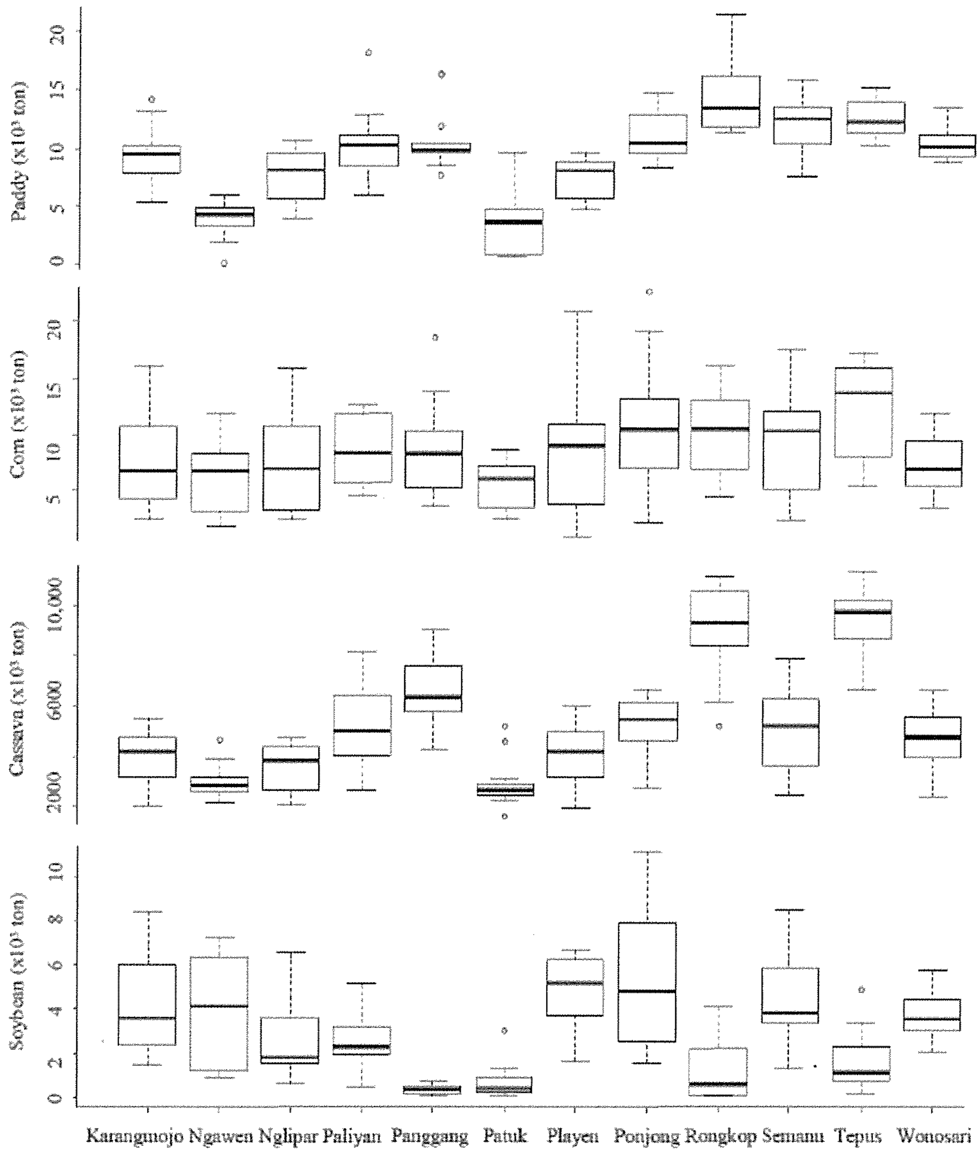


Figure 8. Boxplot showing the statistical distributions of annual crop yields (paddy, corn, cassava and soybean) for each sub –district from 1984 to 2009. Circles show outliners in the data.

1.2. Global climate indices

SOI and SSTs from 1994 to 2009 were used to represent global climate indices for this study. Monthly averaged SOI from 1994 to 2009 was acquired from the Australian Bureau of Meteorology (BOM). The method used by BOM to calculate the SOI is the Troup SOI, which is the standardized anomaly of the mean sea level pressure difference between Tahiti and Darwin. Monthly averaged SSTs of the El Niño monitoring region (Fig. 9): Niño.3 (5°N–5°S, 150°W–90°W), Niño.West (0°–15°N, 130°E–150°E), and the Indian Ocean Basin-Wide, IOBW (20°S–20°N, 40°E–100°E) were acquired from the Japan Meteorological Agency (2012).

For the analysis, at first, we re-calculated the values of SOI and SSTs by averaging their 6-month values for each rainy season (October-March). Here, October is the onset of the rainy and the beginning of the planting season in Gunungkidul (Sardjiman and Mulyadi, 2005). The SSTs from Niño.3, Niño.West and IOBW were integrated using Principal Component Analysis (PCA) to enable direct comparisons between SST and each crop yield residual. For this study, only principal components (PCs) having at least 70% of cumulative proportion of variances were used in correlation analysis with other data. Finally, we performed linear correlation analyses to identify significant relationships between the crop yield residual of each sub-district with the associated SOI and PCs. Using the resulted significant indices, linear regression was performed to evaluate the potential predictability of yield residuals with those combinations of the indices.

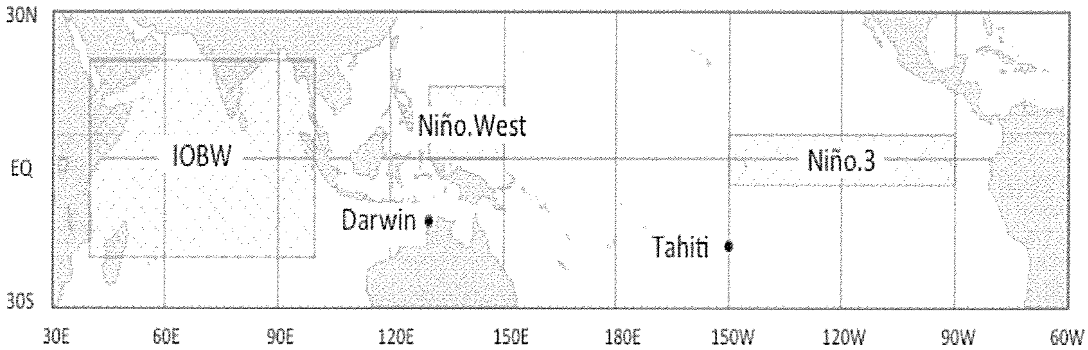


Figure 9. The three El Niño monitoring regions (shaded regions) used to observe the relationships among SSTs in the eastern (Niño.3), the western Pacific (Niño.West), and Indian Ocean (IOBW).

1.3. Local rainfall data

Although the main purpose of this study is to analyze the relationship between global climate indices and rain-fed crop yields, we collected monthly cumulative rainfall data during the rainy season (October–March) from 1994 to 2009 for each sub-district to interpret the analysis results of this study. Figure 10 shows the distribution of averaged annual rainfall during the rainy season. The rainfall was relatively low for Karangmojo, Paliyan, Ponjong, Semanu, and Wonosari. These areas correspond to the basin as shown in Fig. 2. Here we considered that the topography essentially affects the rainfall distribution in Gunungkidul.

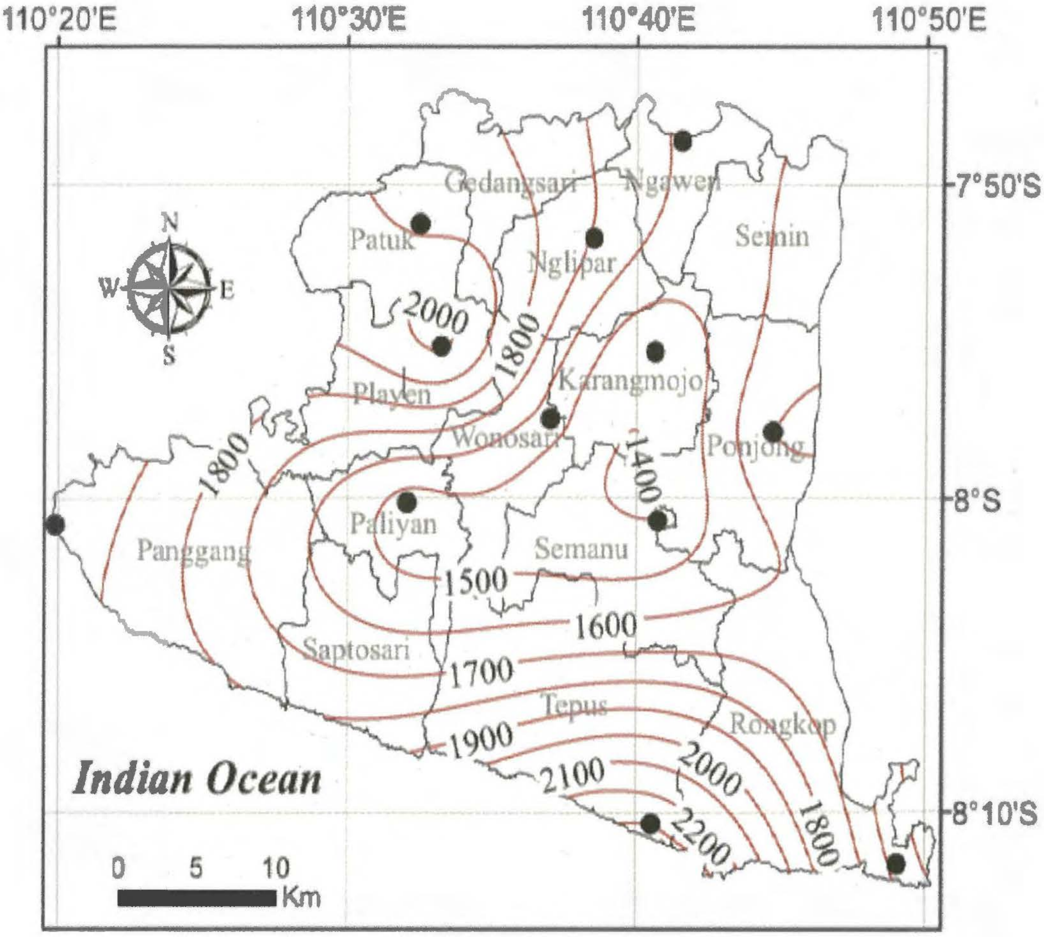


Figure 10. Distribution of averaged annual rainfall during the rainy season based on 1994-2009 rainfalls in Gunungkidul district (dot show rain gauges used in this study). High rainfalls were observed for districts in western and southern parts of the area.

2. Results

2.1. Principal Components for the SSTs

Table 4 shows PC loadings and its statistical variances. The first PC (PC1) of IOBW and Niño.3 shows positive loadings meaning that the SSTs from those two regions were in phase. The contrast between Niño.3 and Niño.West shows that the PC1 strongly links with El Niño and/or La Niña events. For this study, only PC1 was used to represent the SSTs for the three regions as its cumulative proportion exceeded 70% of the total variance (value in bold). Figure 11 shows the original global climate indices and the resulted PC1 from the SSTs. The El Niño in 1998 was distinctly indicated in this figure.

Table 4. Principal components loadings and their importance of components for each PC against the SSTs (Niño.3, Niño.West and IOBW)

	PC1	PC2	PC3
Regions of SST			
IOBW	0.533	0.699	-0.476
Niño.West	-0.527	0.715	0.460
Niño.3	0.662	0.005	0.749
Importance of components			
Stdev	1.485	0.859	0.243
Proportion of variance	0.735	0.246	0.020
Cumulative proportion	**0.735**	0.980	1.000

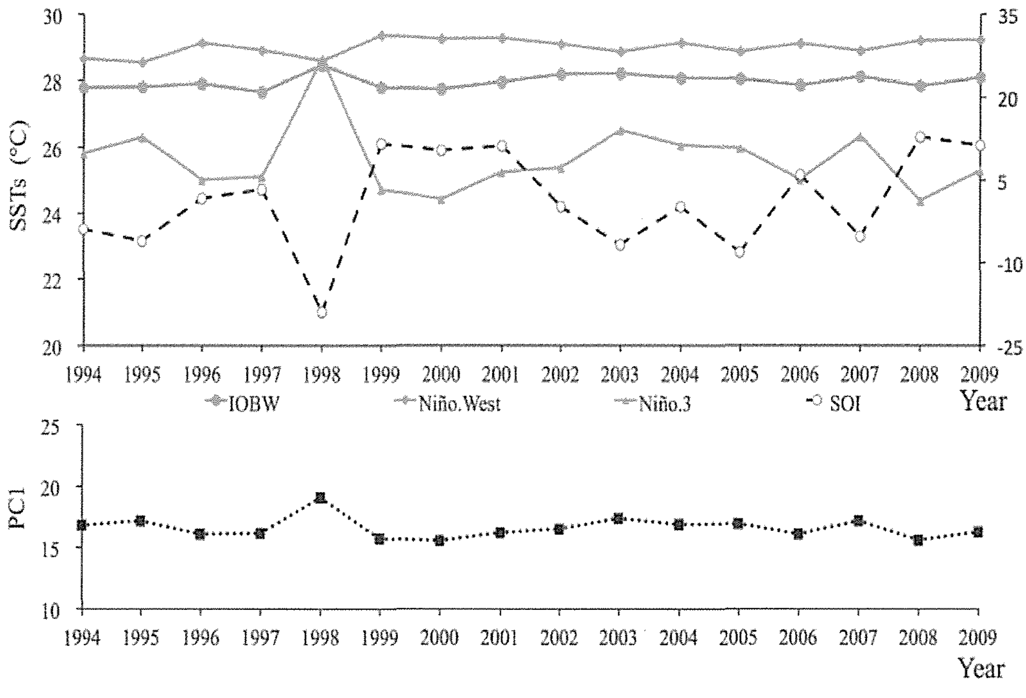


Figure 11. The original global climate indices (top) and the resulted PC1 of SSTs (bottom). Niño.3 shows the most similar trend with PC1 as indicated by its high loadings in PC1.

2.2. Association of global climate indices and crop yield residuals

Correlation of global climate indices with crop yield residuals is shown in Table 7. SOI was negatively correlated with crop yield residuals of dryland paddy in Patuk and Panggang, and of corn in Wonosari. The relationships between these residuals and SOI were as follows:

$$y_p\,(i) = 0.0131*SOI(i) + 0.0171 \quad (2)$$

for dryland paddy (y_p), and as

$$y_c\,(i) = 0.0138*SOI + 0.0204 \quad (3)$$

for corn (y_c), respectively, where i represents the observation year. On the other hand, PC1 shows negative correlation with crop yield residuals of corn in Wonosari and of soybean in Rongkop, Semanu and Patuk. The relationships between these residuals and PC1 were found as

$$y_c\,(i) = -0.1472*PC1(i) + 2.4429 \quad (4)$$

for corn (y_c), and as

$$y_s\,(i) = -0.2543*PC1(i) + 4.1834 \quad (5)$$

for soybean (y_s).

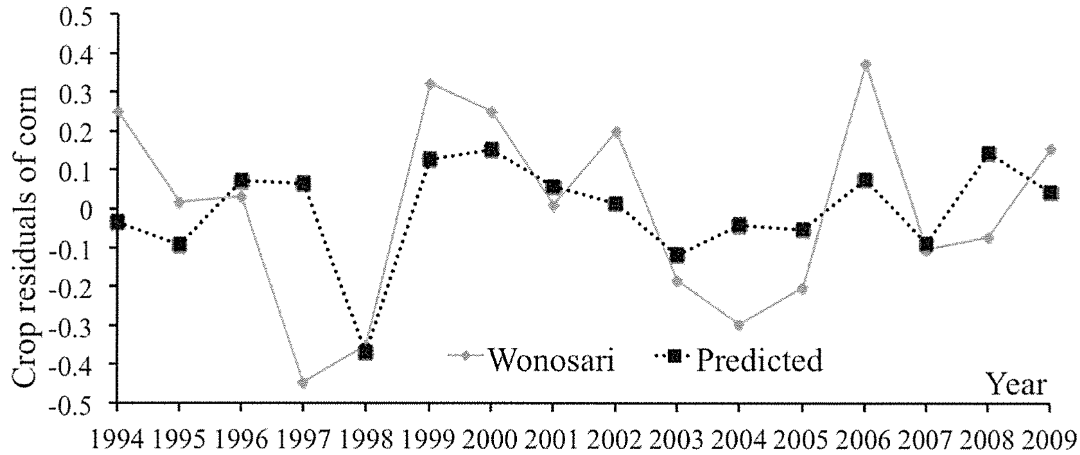
Figure 12 shows these crop yield residuals (solid lines) and their predicted values (dashed lines) for the sub-districts mentioned above. Overall, the predicted values resulted from the regression analyses show a good resemblance to the residuals. This observation indicates that the global climate indices were associated with corn, soybean, and paddy to some sub-districts.

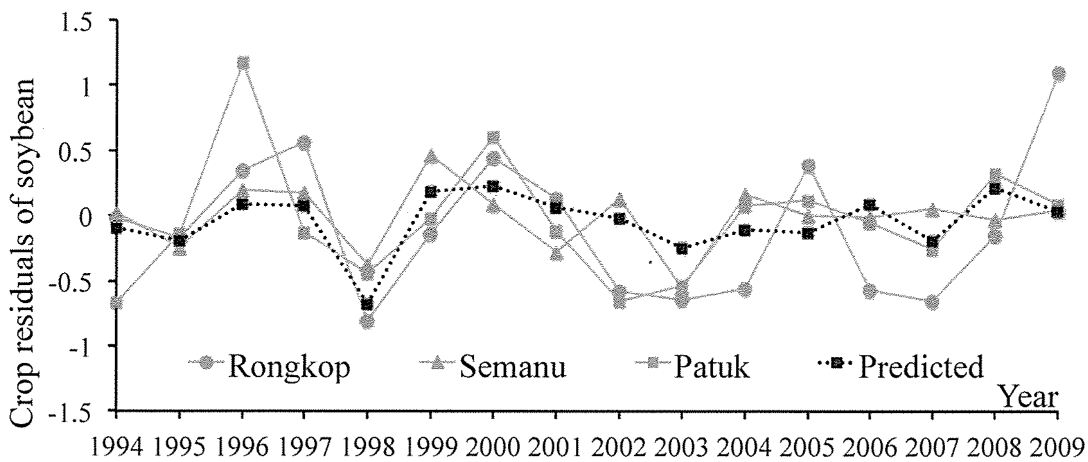
To assess the advantage of using global climate indices in crop yield prediction, we correlated directly the amount of crop yields with the average rainfall data of October to December (OND) for those sub-districts (Fig. 13). Significant relationships were not found in successive analyses with the annual rainfall data for January to March (JFM) and will not be addressed further. Here, crop yields and rainfall data were previously smoothed using 5-year moving average to show their long trends. Strong correlations were found at Patuk and Wonosari (Figs. 13(a), (e)-(f)) but not at Panggang, Rongkop, and Semanu (Figs. 13(b), (c)-(d)). The former are areas of the North and the Central Zones relatively distant from the sea while the latter are areas of the South Zone. Based on this observation, the global climate indices used in this study show better representation to the crop yields than the locally measured rainfall. Significant relationships were not found in successive analyses with the annual rainfall data for January to March (JFM) and will not be addressed further in this paper.

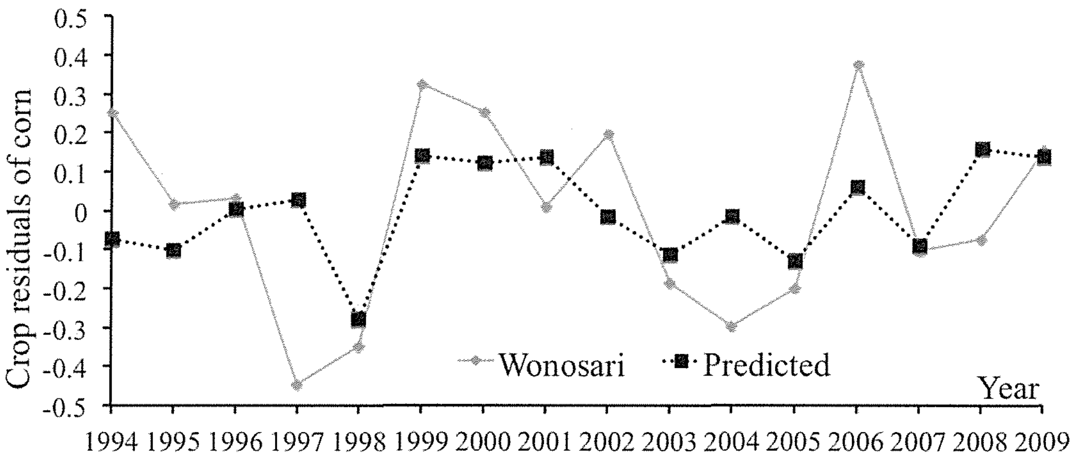
Table 5. Pearson's correlation between the global climate indices (PC1 and SOI) and crop yield residuals (dry paddy, corn, cassava and soybean) for each district of the study area.

	Panggang	Paliyan	Tepus	Rongkop	Nglipar	Semanu	Playen	Patuk	Ngawen	Wonosari	KarangMojo	Ponjong
PC1 vs crop residuals												
Dry	-0.434	-0.262	0.311	-0.163	-0.321	0.121	-0.411	-0.422	0.009	-0.153	-0.111	-0.277
Corn	-0.368	-0.196	-0.192	-0.293	0.030	-0.390	0.203	-0.339	0.023	**-0.519***	0.058	-0.223
Cassava	0.416	-0.306	0.307	-0.030	0.282	0.339	0.458	-0.019	0.110	0.266	-0.011	0.225
Soybean	-0.311	-0.396	-0.358	**-0.510***	0.072	**-0.607***	-0.313	**-0.513***	-0.223	-0.424	-0.363	-0.408
SOI vs crop residuals												
Dry	**0.512***	0.223	-0.126	0.093	0.364	-0.078	0.406	**0.528***	0.154	0.211	0.186	0.267
Corn	0.444	0.125	0.217	0.322	-0.130	0.305	-0.181	0.365	-0.203	**0.500***	-0.015	0.298
Cassava	-0.149	0.293	-0.227	0.205	-0.230	-0.228	-0.334	0.083	-0.137	-0.192	0.086	-0.117
Soybean	0.387	0.328	0.345	0.494	-0.057	0.487	0.417	0.432	0.227	0.231	0.310	0.197

* Significant at $p < 0.05$







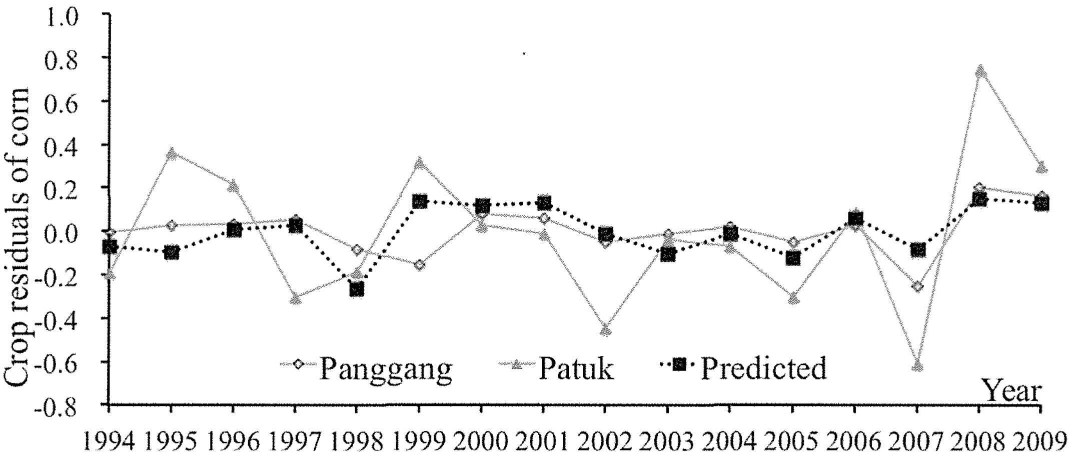
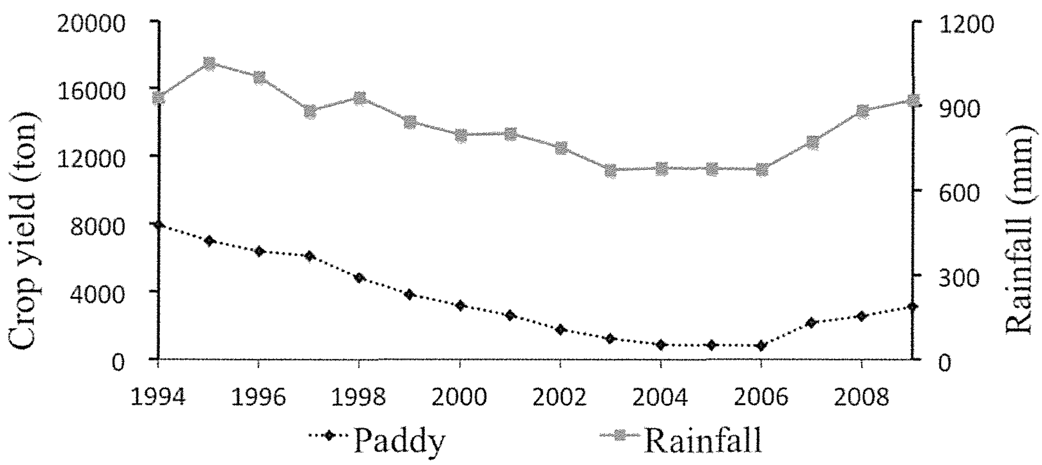
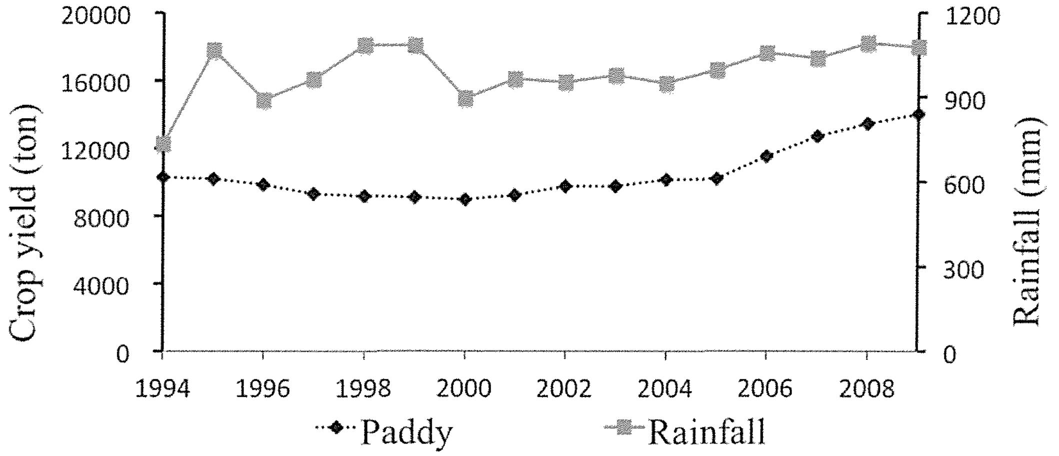


Figure 12. Crop yield residuals and their predicted values for some sub-districts having significant correlations with the global climate indices as shown in Table 5. (a) Crop yield residuals of corn and its predicted values from SOI, (b) Crop yield residuals of paddy and its predicted valued from SOI, (c) Crop yield residuals of corn and its predicted values from PC1, and (d) Crop yield residuals of soybean and its predicted values from PC1.

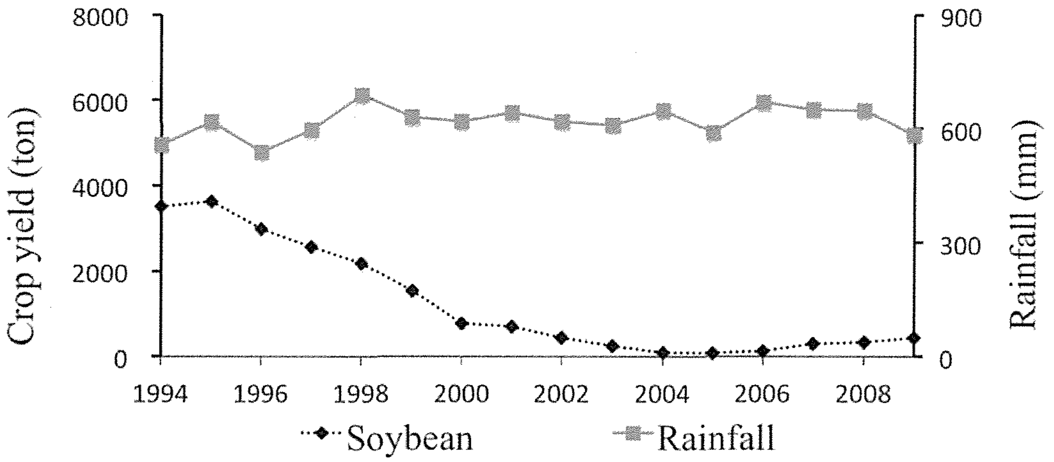


(a)



20000
16000
12000
8000
4000
0
1200
900
600
300
0
Crop yield (ton)
Rainfall (mm)
1994
1996
1998
2000
2002
2004
2006
2008
Paddy
Rainfall

(b)



8000
6000
4000
2000
0
900
600
300
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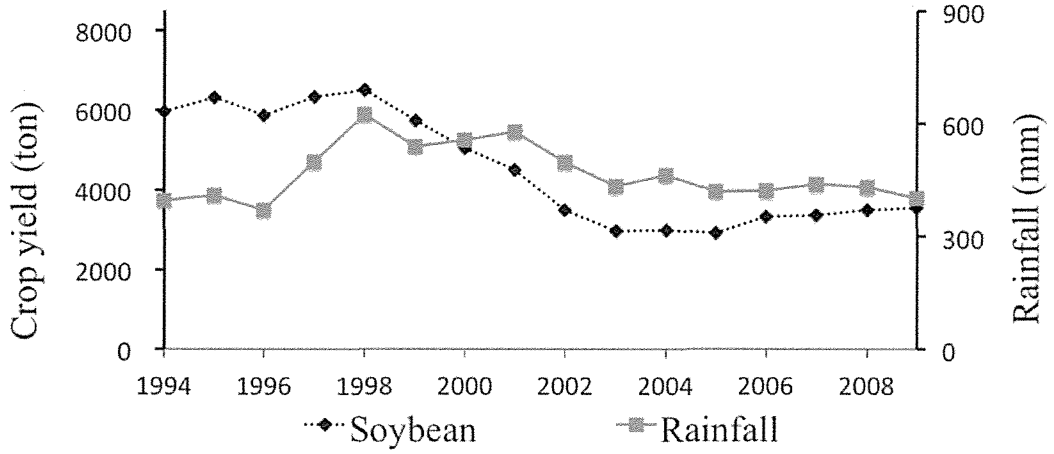
Crop yield (ton)
Rainfall (mm)
1994
1996
1998
2000
2002
2004
2006
2008
Soybean
Rainfall

(c)



8000
6000
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900
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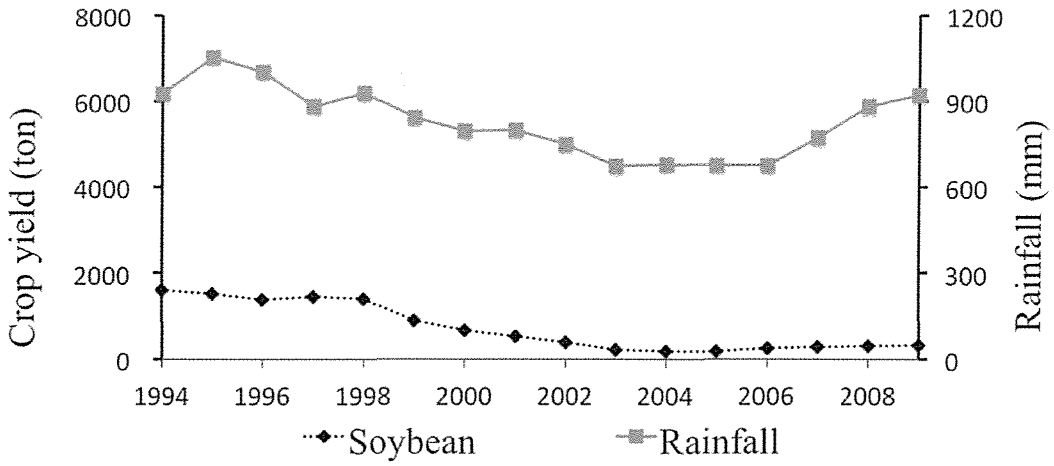
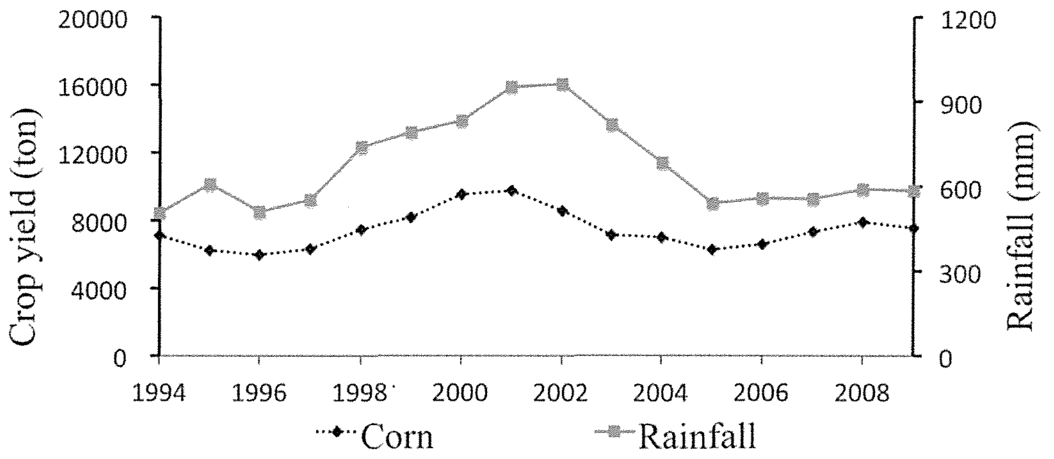
Crop yield (ton)
Rainfall (mm)
1994
1996
1998
2000
2002
2004
2006
2008
Soybean
Rainfall

(d)



(e)



(f)

Figure 13. Variability of crop yields and annual rainfall (OND) from 1994 to 2009 (**Significant at $p < 0.01$) (a) Paddy and rainfall for Patuk (r = 0.88**), (b) Paddy and rainfall for Panggang (r = 0.38), (c) Soybean and rainfall for Rongkop (r = -0.42), (d) Soybean and rainfall for Semanu (r = 0.29), (e) Soybean and rainfall for Patuk (r = 0.80**), and (f) Corn and rainfall for Wonosari (r = 0.78**).

Chapter 4. Influence of cropping pattern on the height and tillers of rice

As stated chapter three, those global climate indices show better representation to the crops yield (dryland paddy, corn and soybean) than locally measured rainfall. The correlation occurs in many crops, and to observe the crops and local agriculture, we have selected dryland paddy or rice, which is a staple food in South Central Java. In this study, we observe the growth of rice, the height and number of tillers and its relationships with cropping pattern in those areas.

In this study, we have analyzed the influence of cropping pattern on the height and tillers of rice. The aim of this study is to observe the height and tillers of rice its influence by combining crops at the rain-fed highland.

1. Data and methods

1.1. Observation design

The observation design is applied based on cropping pattern at Saptosari and Tanjungsari, and it is arranged in a Randomized Completely Block Design (RCBD). RCBD is a suitable design for small observations, where each plot has the same size, and all observations are contained in each plot. This design minimizes heterogeneity in the field as stated by Gomez (1984). Observations were repeated three times, so there are 3 x 4 = 12 plots with the following details (Fig. 14):

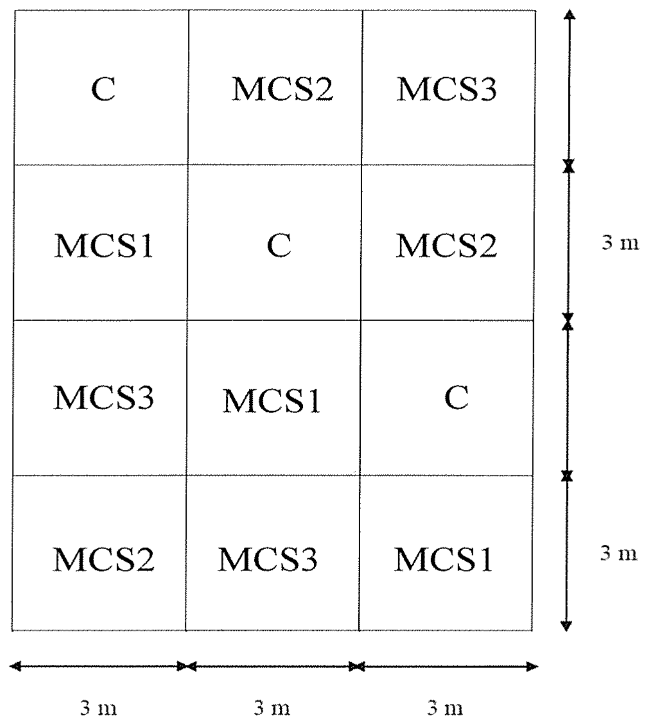


Figure 14. Layout of observation at Saptosari and Tanjungsari

The combination of crops as follows:

1. Rice monoculture: control (C)
2. Rice – multiple cropping: rice + maize (MCS1)
3. Rice – multiple cropping: rice + cassava (MCS2)
4. Rice – multiple cropping: rice + maize + cassava (MCS3)

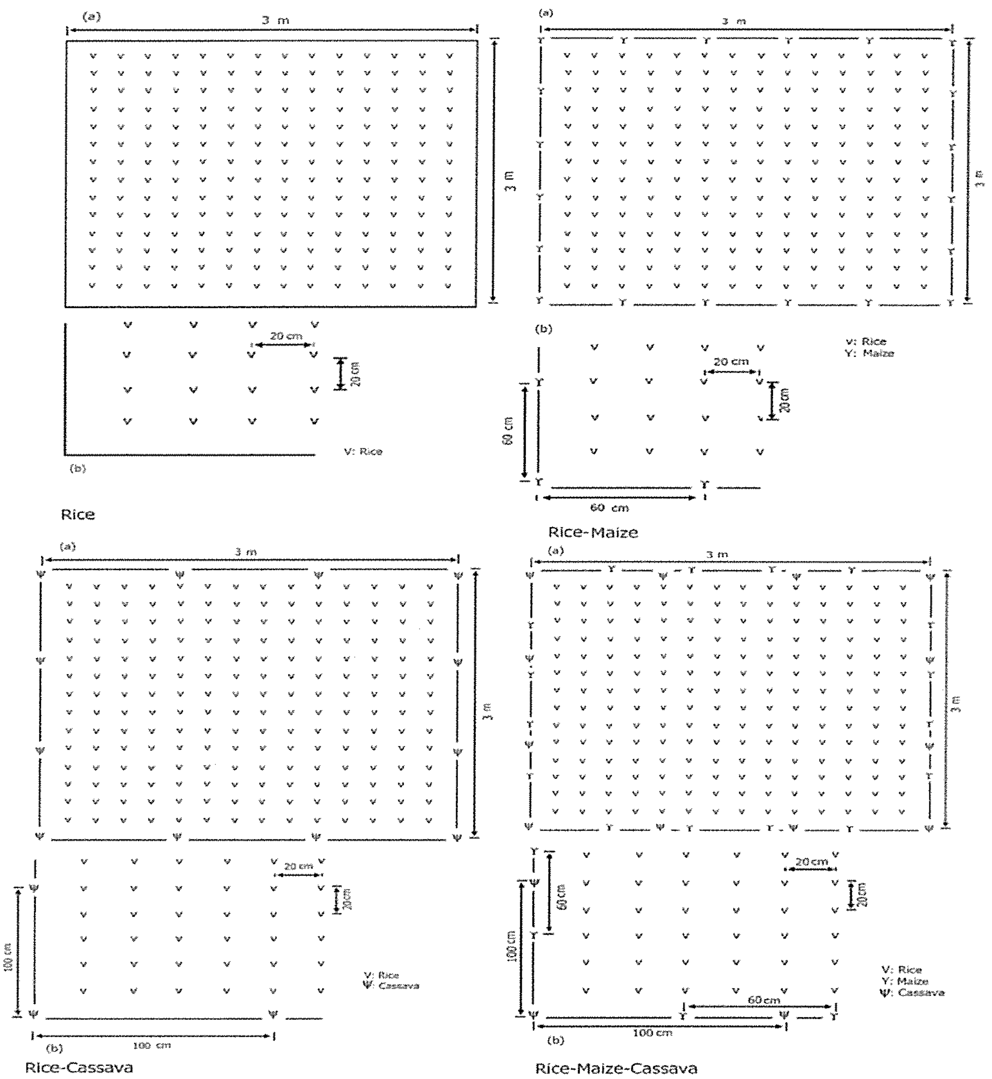


Figure 15. Spacing of each plant in C, MCS1, MCS2 and MCS3

The seeds of rice, maize and cassava were planted together in each plot with different planting dates during planting season from September to February, where the spacing of each plant can be seen in Figure 15. The difference of planting date is caused by local tradition and decision of farmers in each field area. Crop samples (five samples in each plot) were taken periodically every 10-days during the plant growth. Fertilizer and organic nutrients were used in this study by referring local schedule of the farmers in each field areas.

The growth of rice can be analyzed from the height and number of tillers during the plant growth. Mathematical model is providing devices to explore the characteristics of rice growth. If the height of rice is plotted in the graph, it will follow a monomolecular function, and for the number of tillers, it will follow an exponential polynomial function (Murtiningrum *et al.*, 2011). The function is shown below:

$$ln = \left(\frac{Tf-To}{Tf-T}\right) = kt \quad (1)$$

While,

T_f = the height of rice in the harvesting,

T_o = the height of rice seed in the beginning of planting, and

T = the height of rice at day of observation,

and for the number of tillers, using exponential polynomial function as below:

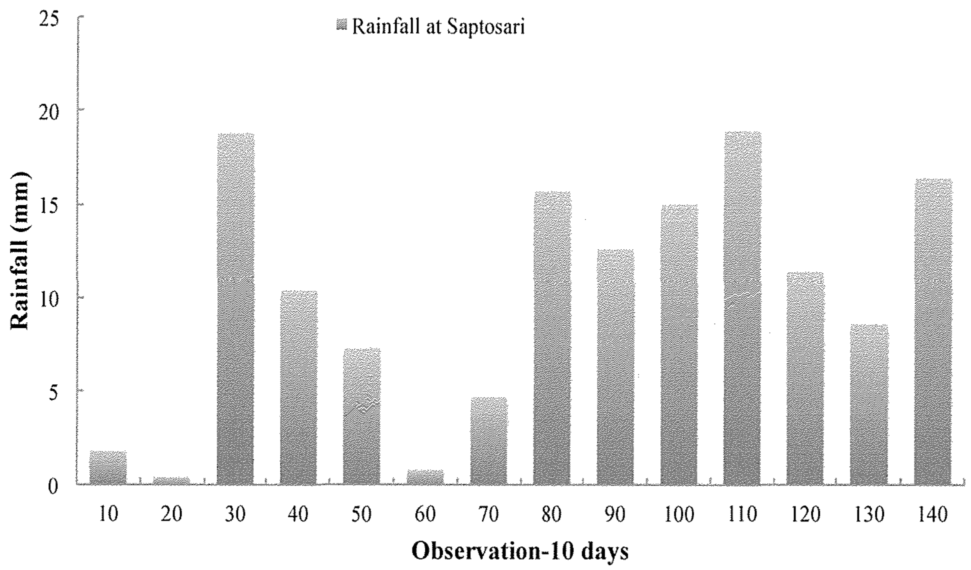
$$A = exp(a_0 + a_1 t + a_2 t^2) \quad (2)$$

While,

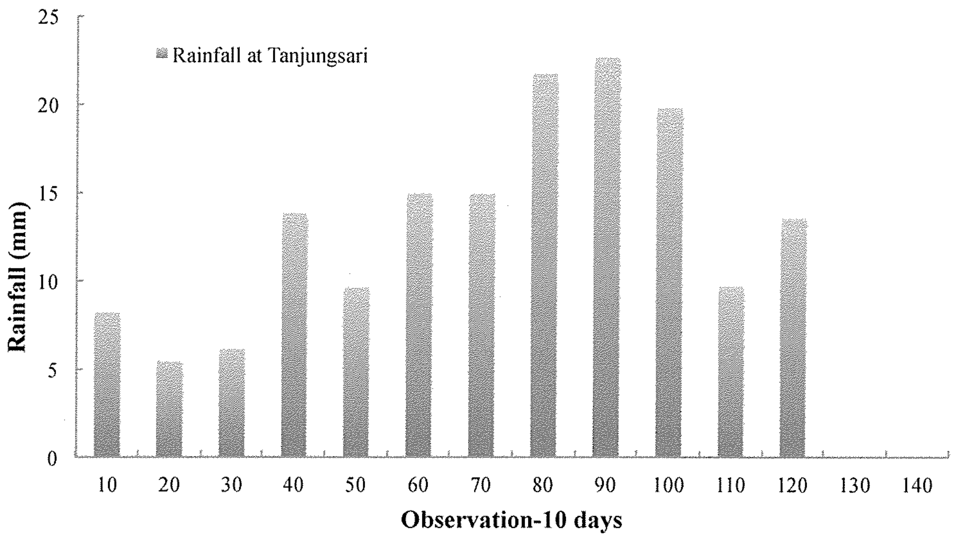
A = the number of tillers.

1.2. Rainfall data

Although the main purpose of this study is to observe the height and tillers of rice at rain-fed agriculture, we collected 10-days cumulative rainfall data during the planting season for two field areas to interpret the analysis result of this study. Figure 16 shows 10-days rainfall data during the planting season. The rainfall was relatively low at the beginning of seeding at both field areas. The amount of rainfall during planting season was also different between both areas, and these corresponded to the topography in those areas.



(a)



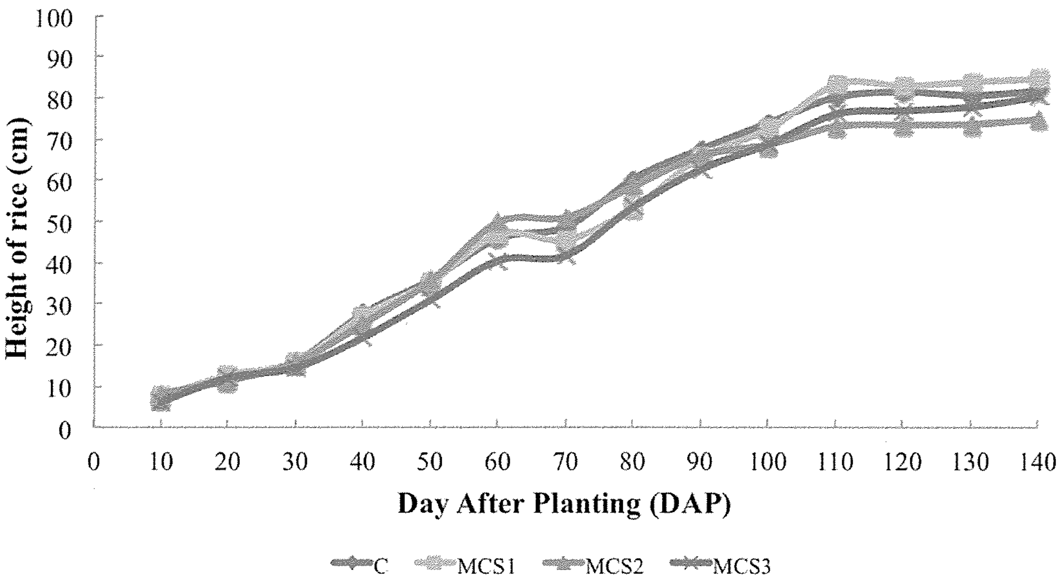
(b)

Figure 16. Rainfall data during observation at Saptosari (a) and Tanjungsari (b)

2. Result

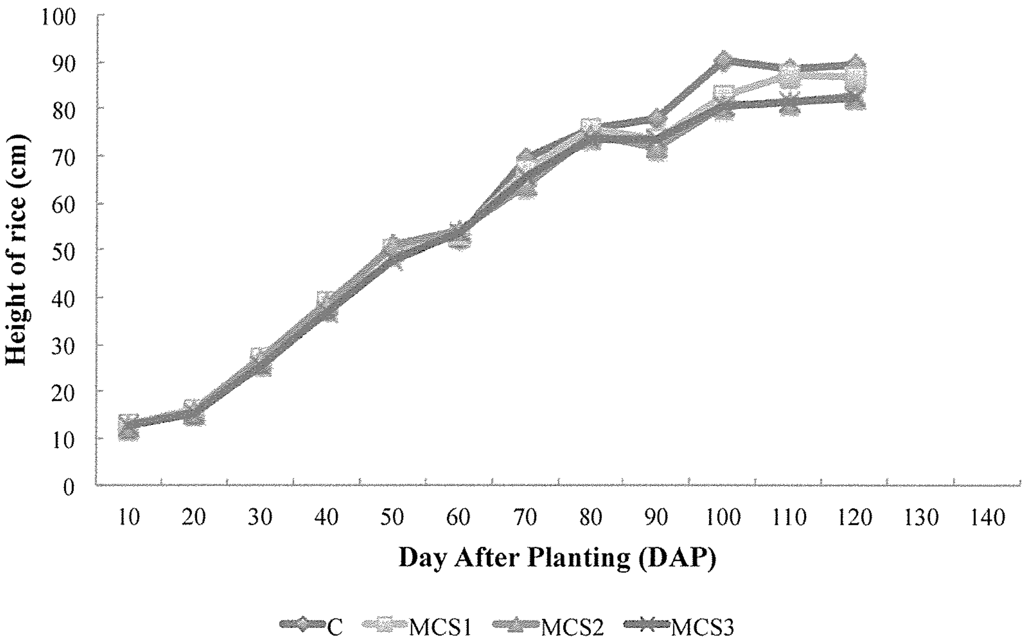
2.1. Observation of the height and number of tillers in rice

Observation data of the height and number of tillers were collected every 10-days during plantings season at Saptosari and Tanjungsari. Figure 17 shows that the highest growth in rice at the age of 140 days is in MCS2 (84.53 cm) and the lowest growth is in MCS1 (74.80 cm), with C (81.70 cm) and MCS3 (80.33 cm) in the middle. At Tanjungsari, the highest growth in rice at the age of 120 days is C (89.20 cm), with MCS2 (82.73 cm), MCS1 (86.73 cm), and MCS3 (82.20 cm) showing closely lower values. Figure 16 shows the highest number of tillers is in C, while the least number is in MCS3 at both field areas.



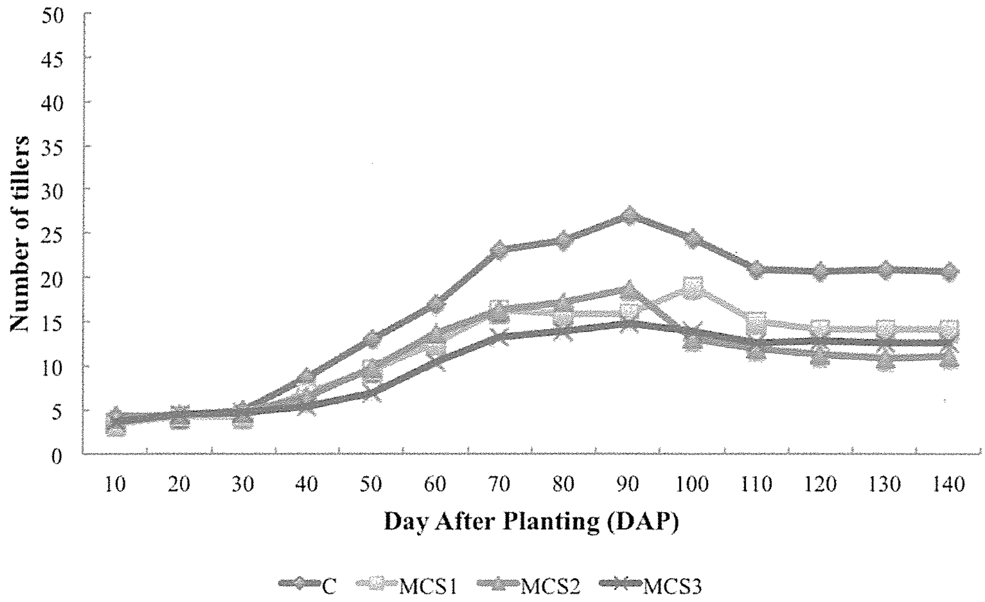
Height of rice (cm)
Day After Planting (DAP)
C
MCS1
MCS2
MCS3

(a)

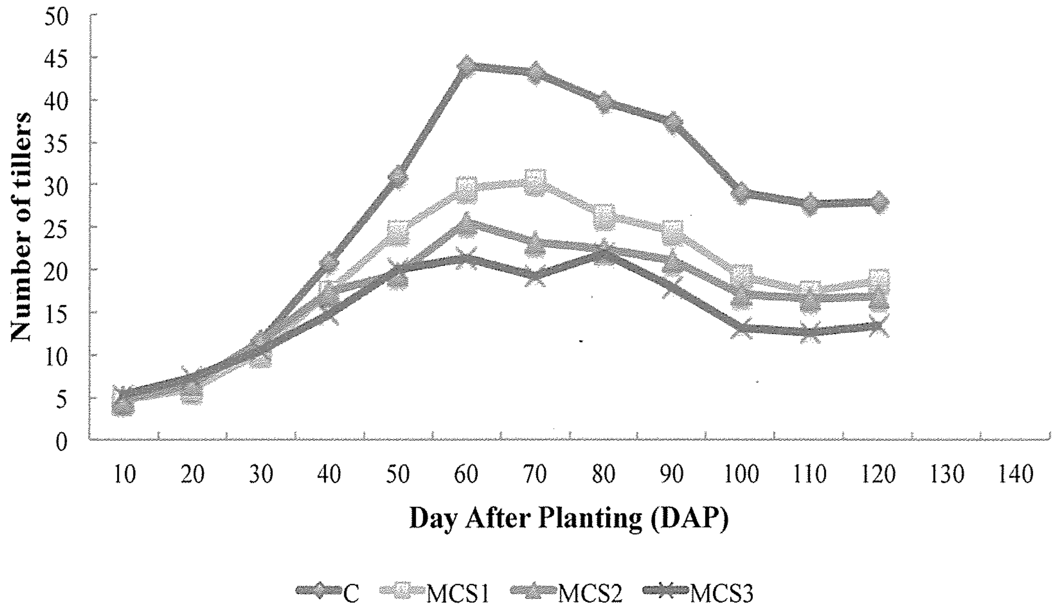


Height of rice (cm)
Day After Planting (DAP)
C
MCS1
MCS2
MCS3

(b)



(c)



(d)

Figure 17. Height of rice and number of tillers in rice monoculture (C), rice - maize (MCS1), paddy - cassava (MCS2), and paddy - maize - cassava (MCS3) at Saptosari (a, c) and Tanjungsari (b, d).

2.2. Model of the height and tillers of rice

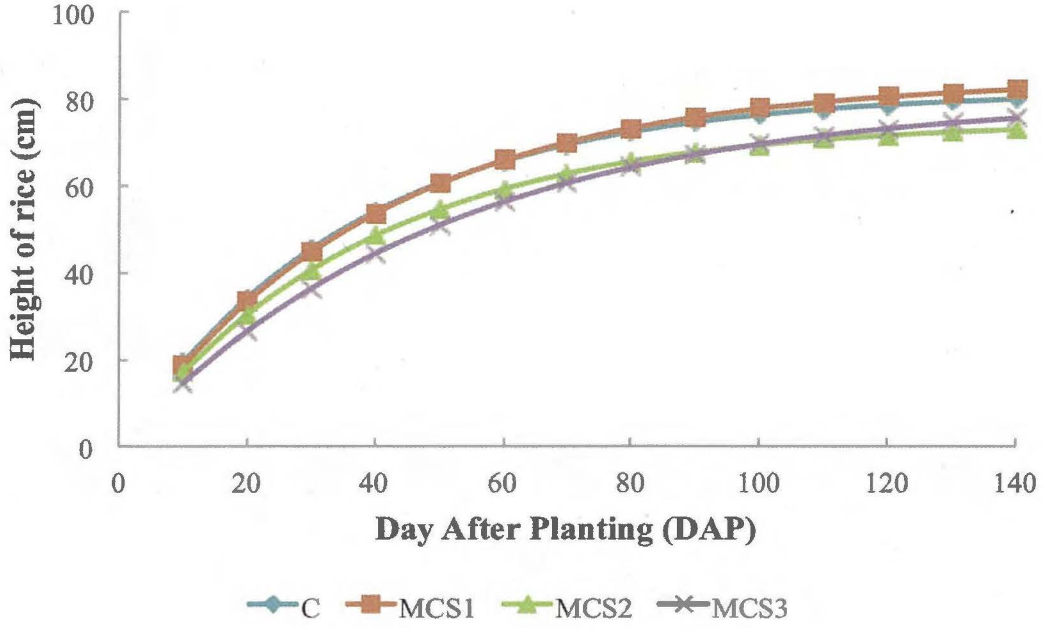
Tables 6 and 7 show coefficient and R^2 for the height of rice using monomolecular function [1] and exponential polynomial function [2]. The model is fit and represents the growth of rice based on height and number of tillers (p<0.05).

Table 6. Models of monomolecular function in the height of rice

Field Area	Combinations	Coefficient (k)	R^2
Saptosari	C	0.027	0.687
	MCS1	0.025	0.681
	MCS2	0.026	0.819
	MCS3	0.020	0.782
Tanjungsari	C	0.027	0.665
	MCS1	0.028	0.811
	MCS2	0.023	0.840
	MCS3	0.036	0.759

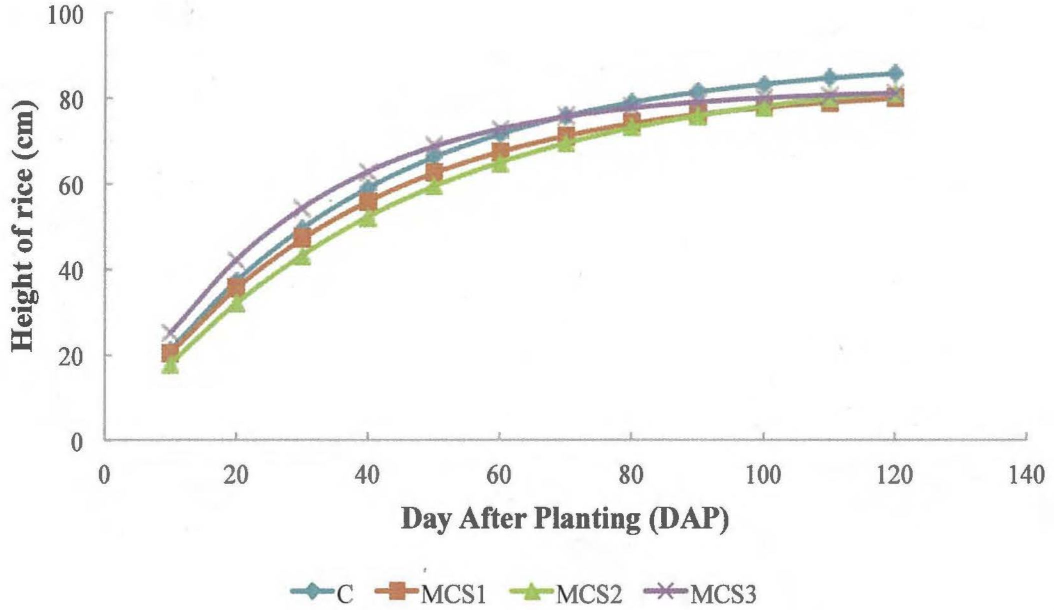
Table 7. Models of exponential polynomial function in number of tillers

Field Area	Combinations	Coefficient a_0	Coefficient a_1	Coefficient a_2	R^2
Saptosari	C	-0.003	0.549	-5.545	0.885
	MCS1	-0.002	0.356	-2.459	0.896
	MCS2	-0.002	0.383	-2.361	0.774
	MCS3	-0.001	0.256	-0.660	0.884
Tanjungsari	C	-0.009	1.423	-21.062	0.866
	MCS1	-0.005	0.726	-6.756	0.899
	MCS2	-0.006	0.966	-11.998	0.865
	MCS3	-0.004	0.631	-4.653	0.857



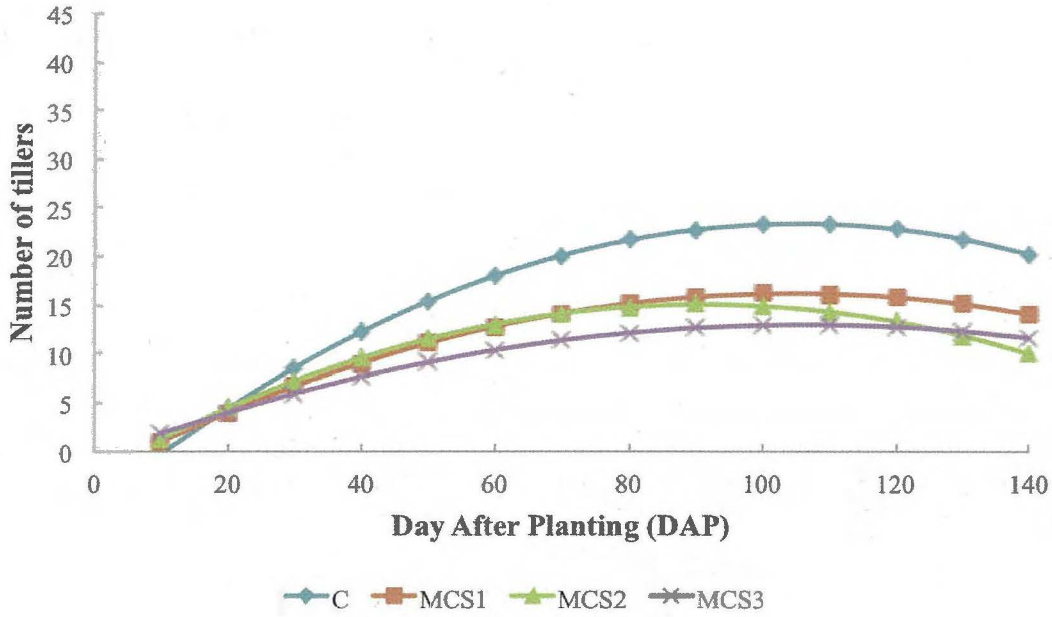
Height of rice (cm)
Day After Planting (DAP)
100
80
60
40
20
0
0
20
40
60
80
100
120
140
C
MCS1
MCS2
MCS3

(a)

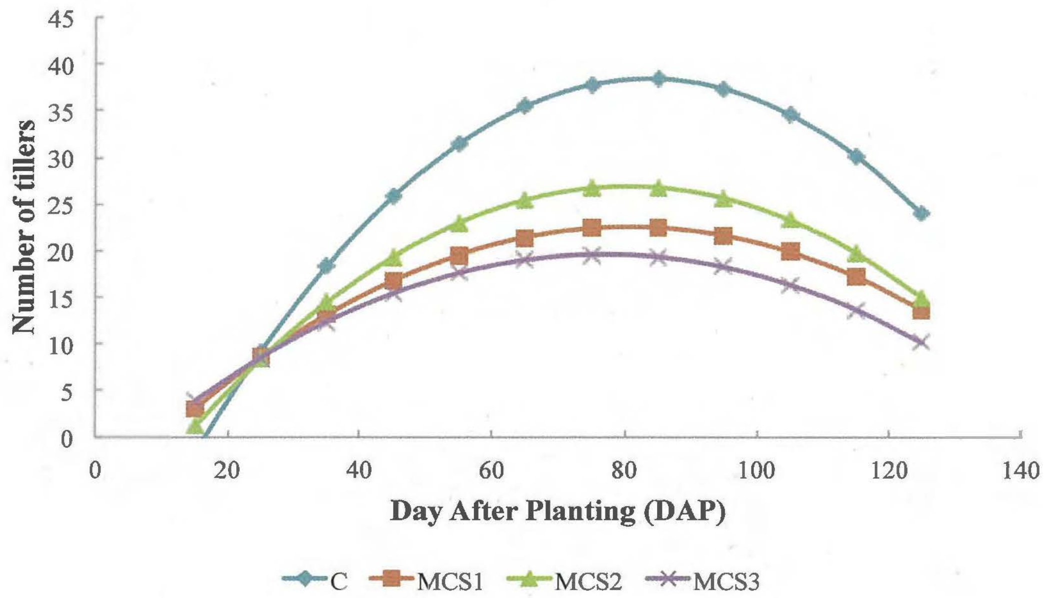


Height of rice (cm)
Day After Planting (DAP)
100
80
60
40
20
0
0
20
40
60
80
100
120
140
C
MCS1
MCS2
MCS3

(b)



(c)



(d)

Figure 18. Height of rice using monomolecular function at Saptosari (a) and Tanjungsari (b), and number of tillers using exponential polynomial function at Saptosari (c) and Tanjungsari (d).

Figures 18a and 18b show that the growth of rice is faster at the beginning of planting (10-40 DAP), and then the growth of rice slows and becomes constant until cultivation. It is indicated that the height of rice is higher in the vegetative phase and slowly in the generative phase. The height of rice is not significantly different between monoculture and all combinations in multiple cropping systems (MCS1, MCS2 and MCS3). Figures 18c and 18d show the most optimum tillers formation is in monoculture, because there is no competition in obtaining solar radiation or soil moisture. The maximum tillers are formed during the growth phase, which revolves around the age of 93 and 65 days after planting. The growth of tillers number in Saptosari and Tanjungsari show the similar results in each treatment. Rice, which is growing in monoculture have more tillers rather than in multiple cropping patterns.

Chapter 5. Discussion

In chapter three, we have revealed significant relationships among rain-fed crop yield residual in highland and global climate indices. While some studies have reported that the variability of temperature, rainfall, and extreme events are forecast to have profound effects on crop yields for arid areas including highlands (Adams and others, 1998; Burton, 2001), these climate indices are difficult to be predicted at inter-annual time scales. Our results open the possibility to predict long-term crop yields to some extent because methods to predict seasonal SOI and SST have been well developed. Future SOI can be effectively predicted using a polynomial function applied to the time series of the past SOI with the aid of Hilbert transform and empirical mode decomposition (EMD) procedure (Salisbury and Wimbush, 2002). On the other hand, SSTs can be predicted using JMA's (Japan Meteorological Agency) El Niño prediction model (Ishikawa *et al.*, 2005), a coupled atmosphere-ocean model that consists of an atmospheric general circulation model (AGCM) and an ocean general circulation model (OGCM).

The results of this study may be used to select suitable crops in multiple cropping systems with higher resistance to the extreme changes of the global indices. Our methods to analyze the relationships between global climate indices and rain-fed crop yields in highland may apply to areas with similar topography and climate field in Indonesia and to other areas over the semi-arid zone. Forecasting global climate indices will become important materials for the improvement of agriculture in the semi-arid areas by using our proposed methods.

Future research must deal with the variation of rainfall distribution pattern in the South-Central Java. Our pre-research shows that during the rainy season from 1981 to 2009, rainfall ranged from 1800 to 2200 mm in the southern coastal and western inland areas, and around 1500 – 1600 mm of the rain fell in the central lowland and northern areas (Fig. 19). During the early season October-November-December (OND), rainfall was 750-900 mm in the southern coastal areas and 500 – 600 mm in the central lowland area (Fig. 20), and the highest amounts of rainfall occurred during the late rainy season at January-February-March (JMF) (Fig. 21).

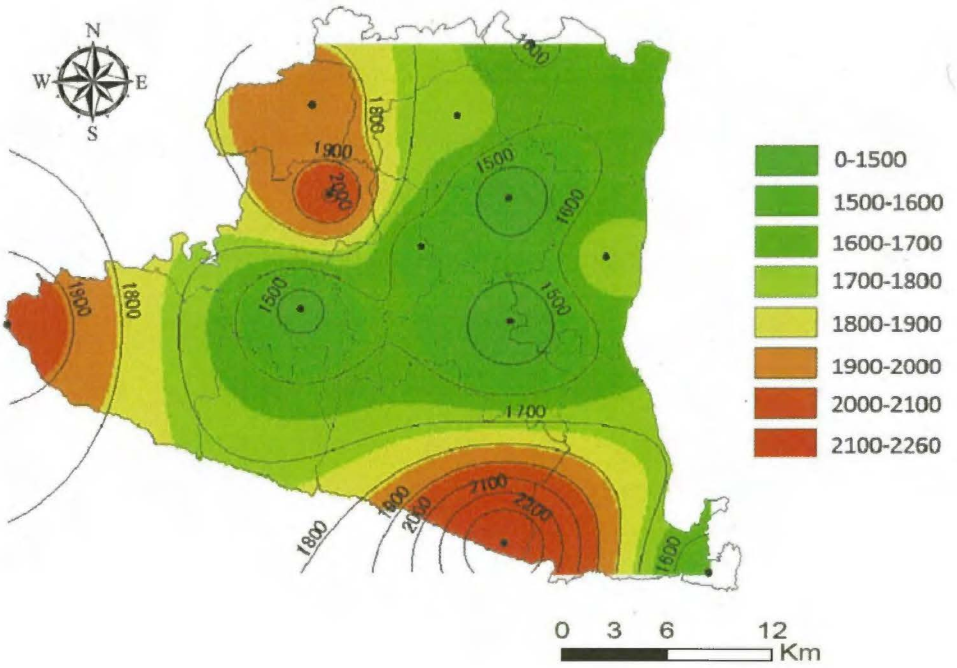


Figure 19. Rainfall distribution pattern of GunungKidul district during the rainy season (October-March) from 1981 to 2009.

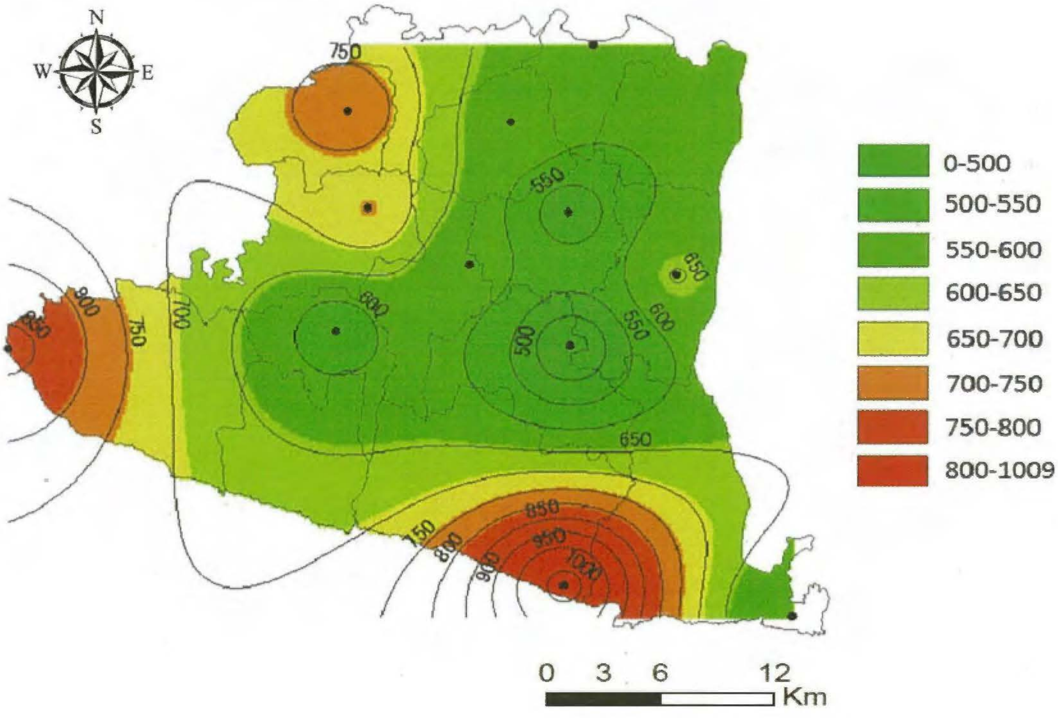


Figure 20. Rainfall distribution pattern of GunungKidul district during the period October-November-December (OND) from 1981 to 2009

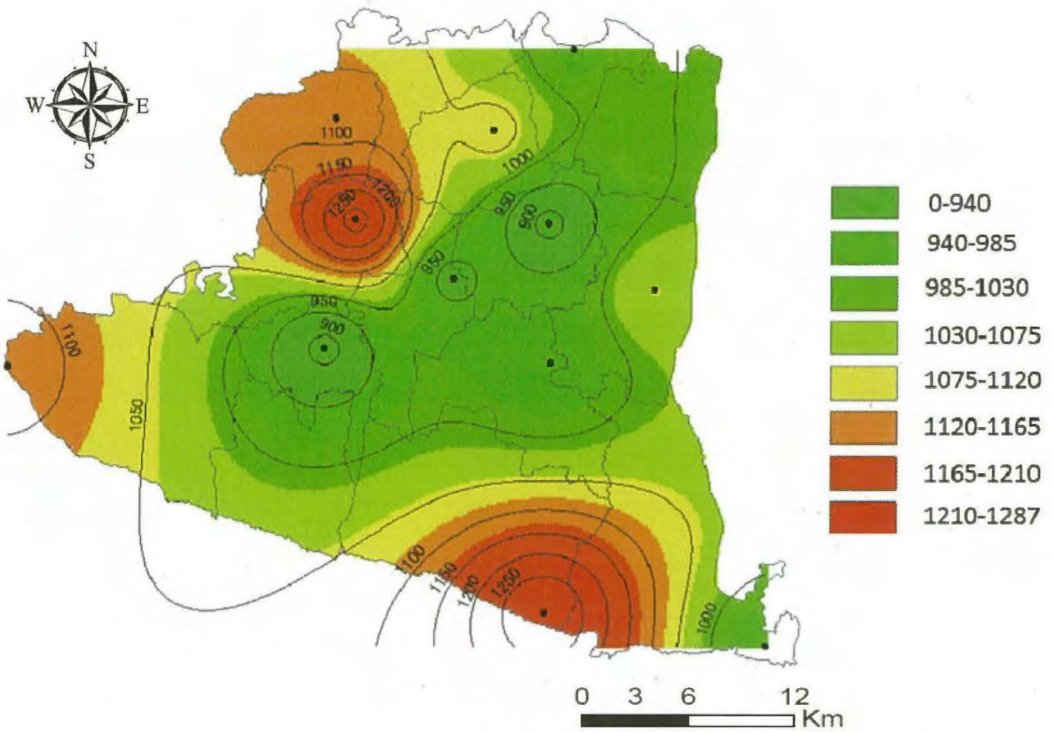


Figure 21. Rainfall distribution pattern of GunungKidul district during the period January-February-March (JFM) from 1981 to 2009

In monsoon areas, the direction of prevailing winds may have a pronounced effect on the distribution of very high amounts of rainfall (Singh and Kumar, 1997), causing the spatial distribution of rainfall to vary seasonally. During the rainy season, especially at its peak in January, westerly winds bring moisture from the Indian Ocean to Java (Fig. 22), and this moisture carried by the winds produces dense clouds and orographic precipitation (Roe, 2005) along the mountain ranges of southern and western Java. As a result, the windward side of mountains in Gunungkidul district receives much more precipitation than the leeward side.

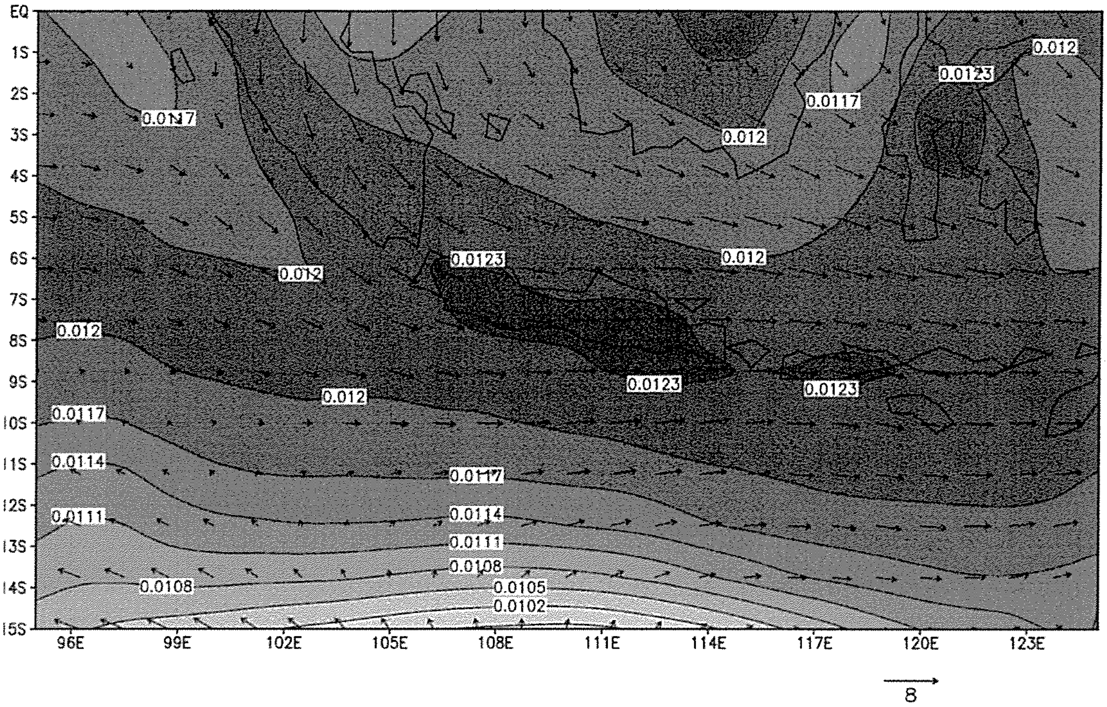


Figure 22. Humidity, wind direction and wind speed in January from 1979 to 2004 at 850hPa.

After we got the result about relationships between global climate indices and crop yield, which is of global scale, we explored Gunungkidul in a small scale. Our research used three areas: Saptosari, Tanjungsari and Rongkop, but in this study, only two field areas were used. The reason is the difference of observation design at Rongkop, and it is difficult to get maximize result in that design.

The height of rice in monoculture and multiple cropping systems is not significantly different. Small design of plots and closest row spacing caused the competitions among plants for nutrients, water and light for their growth and development. Basically, multiple cropping patterns will affect the speed of plant growth among the plant species due to competition for solar radiation. Multiple cropping patterns require more soil moisture than monoculture systems. In addition, the suitability of crops in multiple cropping systems is not only dependent on the height of crops but also on other factors, such as soil conditions, water needed and productivity, but in this study those other factors are not discussed.

The result in the number of tillers shows any difference between monoculture and multiple cropping systems. Rice in MCS tends to form less tillers and it indicates that the cropping pattern will affect the growth of plants during the vegetative phase.

More tillers were observed in monoculture systems because they get more solar radiation to grow and no competition with each crop.

We also have explained the result at Rongkop sub-district. The field design in Rongkop can be seen below:

Block A	Block B
1	
MCS (Rice-Maize-Cassava)	(Maize Monoculture)
2	
MCS (Rice-Maize-Cassava)	(Cassava-monoculture)
3	
MCS (Rice-Maize-Cassava)	C (Rice-monoculture)

Figure 23. Field design at Rongkop

The observation design was divided into two plots with 4.5 m x 3 m with the following details (Fig. 23):

a. Block A: monoculture of rice, maize and cassava with each plot 4.5 x 4 m.

b. Block B: multiple cropping rice-maize-cassava with each plot 4.5 x 4 m.

The result in the height of crops in all combinations at Rongkop can be seen at (Table 8).

Table 8. Height of crops in all combinations at Rongkop

Obs.	Plant	Date of observations									
		10Oct	20Oct	30Oct	9Nov	19Nov	29Nov	9Des	19Des	29Des	8Jan
		10	20	30	40	50	60	70	80	90	100
MCS (A1)	**Rice**	**8.2**	**11.8**	**23.0**	**33.2**	**41.4**	**44.8**	**45.0**	**58.8**	**53.4**	**53.8**
	Maize	5.0	13.6	28.6	51.8	75.6	97.0	118.4	118.8	96.8	-
	Cassava	31.4	37.6	50.2	58.2	67.8	70.8	79.2	87.4	121.3	137.5
MCS (A2)	**Rice**	**7.0**	**12.4**	**23.2**	**33.5**	**39.0**	**40.6**	**42.0**	**56.2**	**55.0**	**55.6**
	Maize	4.8	12.2	27.0	52.0	72.2	95.2	115.4	115.2	114.4	-
	Cassava	26.3	35.0	43.8	49.7	61.5	65.5	81.8	98.5	101.3	109.3
MCS (A3)	**Rice**	**8.2**	**14.0**	**24.4**	**32.8**	**39.0**	**41.6**	**47.2**	**55.8**	**51.0**	**52.5**
	Maize	5.3	13.2	28.4	56.8	82.6	103.3	132.0	124.0	135.4	-
	Cassava	28.2	32.8	42.0	52.8	63.2	67.0	84.2	98.2	105.8	114.8
C	**Rice**	**6.8**	**11.4**	**21.8**	**29.0**	**38.2**	**41.8**	**42.0**	**44.2**	**50.8**	**51.6**

Table 8. Number in bold shows the maximum height of rice at the age of 100 days at MCS (54 cm) and C (51.6 cm). This result indicates that rice growth in MCS is higher than in monoculture systems. It due to local micro-climates, that the solar radiation does not fully reach plants in monoculture systems, and which influences in photosynthesic process. The result of the height of rice at Rongkop can be seen at Fig. 24.

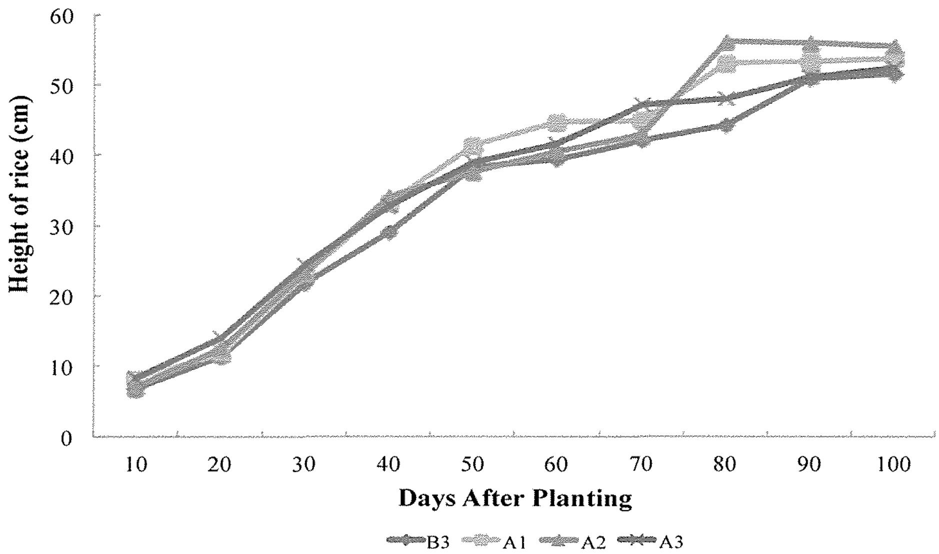


Figure 24. The height of rice in all combinations at Rongkop

Height of rice in Rongkop shows only at the beginning of planting, there is significant difference between monoculture and MCS (Fig. 24). But in the mid of planting season and harvesting time, the difference was not significant between monoculture system and MCS.

The result in number of tillers in Rongkop shows the highest number of tillers is in MCS1 or in block A1 and the least of tiller numbers is in C. The maximum formation of tillers occurs during the growing phase, at the age of 60 days after planting (Fig. 25).

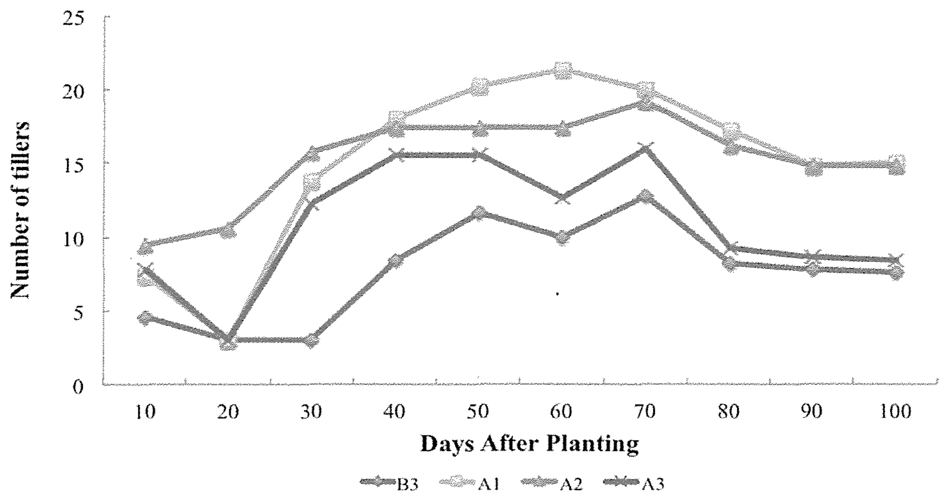


Figure 25. Number of tillers in rice monoculture (B), rice – maize - cassava (A1), rice – maize - cassava (A2), and rice - maize - cassava (A3) at Rongkop.

In this study, the authors also analyzed the productivity of rice in each field area, but more detailed analyzing is needed. The result of the productivity of rice as follows:

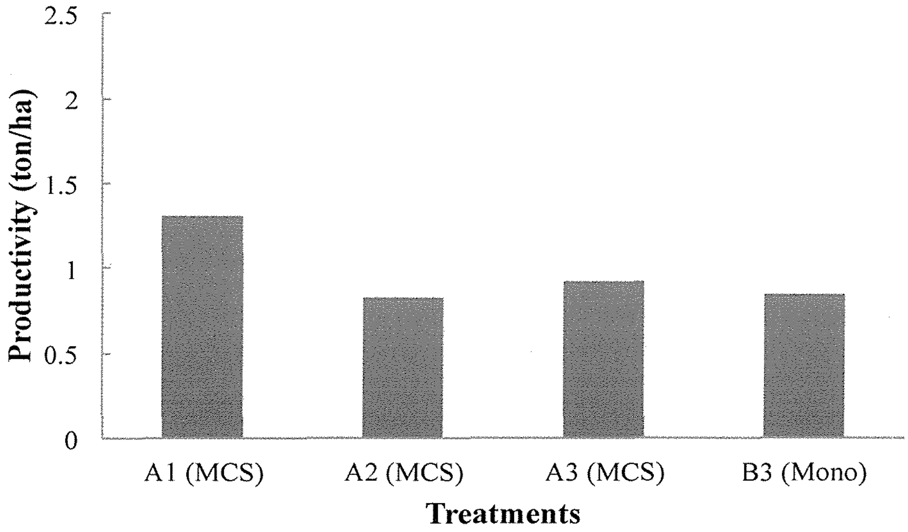


Figure 26. Productivity of rice at Rongkop

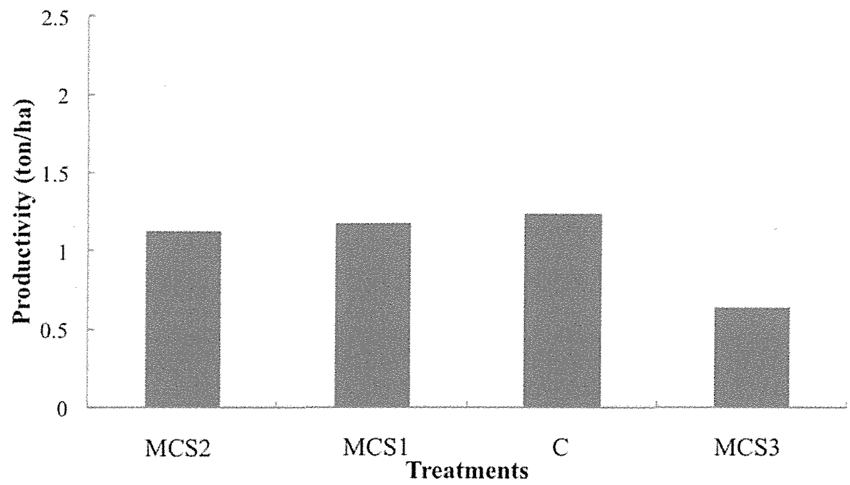


Figure 27. Productivity of rice at Tanjungsari

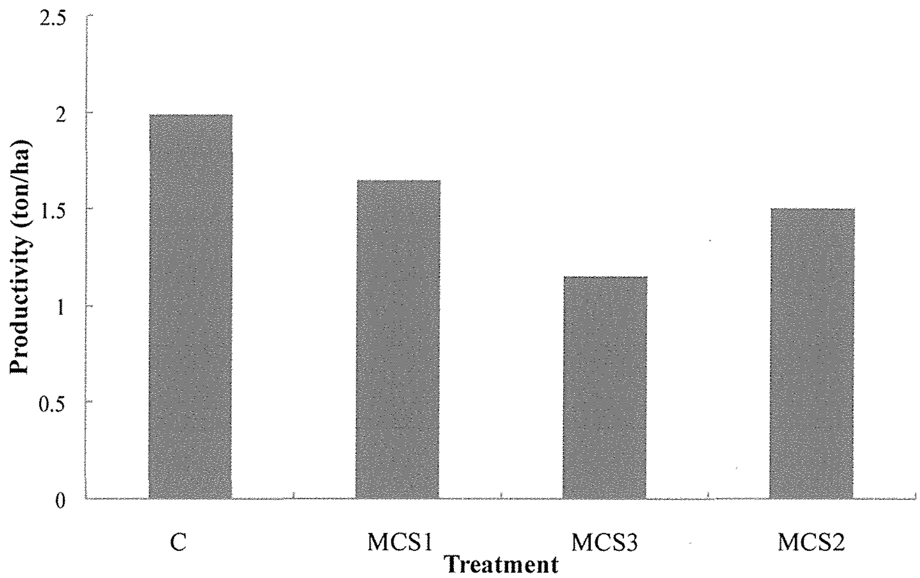


Figure 28. Productivity of rice at Saptosari

The productivity of rice at Saptosari and Tanjungsari (Fig. 27 and Fig. 28) in monoculture is higher than multiple cropping systems. Rice in monoculture system is more productive than all combinations because the plants in the monoculture system have sufficient space to absorb solar radiation and nutrients than in MCS. But at Rongkop (Fig. 26), rice in MCS has a high productivity with 1.02 ton/ha, while the rice in monoculture system only produce biomass 0.85 ton/ha. It indicates that the microclimates do not significantly affect the cropping system at Rongkop.

The decisions concerning the suitability of cropping systems, agricultural technologies and practices should be considered. Determining cropping pattern at rain-fed highland agriculture is not only based on the height and tillers of rice. Many factors are influenced on these decisions, for example soil and climate conditions at those areas. But our result can be used as valuable information to decide the suitability crops in the cropping systems.

Our study found that global climate indices can be used to predict crop yields in the highland agriculture for this area, this achievement provides valuable information to the policymaker in agriculture for this area, not only to estimate crop yield but also to decide the starting date of planting season and suitable plants for the cropping systems. Although as already stated above, climatic factors influence the multiple crop system in this area and further analyses will be conducted to reveal non-climatic factors in order to enhance our understanding.

Chapter 6. Conclusion

In the first research, we have investigated the relationship between global climate indices and crop yields in highland of South-Central Java, Indonesia. The analyses were effectively conducted by summarizing the SSTs using PCA and by calculating the residuals of crop yields for each sub-district of the study area. For some districts, the first principal component of the SSTs was negatively correlated to crop yield residuals of corn and soybean while SOI was positively correlated to that of corn and dryland paddy. Using these relationships, linear regressions were successfully constructed to predict crop yields.

In the second research (micro-scale), we have investigated the influence of cropping patterns on the height and tillers of rice. This study observes the growth of rice cultivated with multiple cropping systems in rain-fed highland. Ten-day data of rice height and tillers were collected from every plot containing rice (C), rice-maize (MCS1), rice-cassava (MCS2), and rice-maize-cassava (MCS3). We used monomolecular and exponential polynomial functions to model the height of rice and the number of tillers, respectively. The results show no significant differences in the height of rice in monoculture and multiple cropping systems. On the other hand, rice in monoculture has more tillers than that in multiple cropping systems.

Finally, using our methods in this study, global climate indices can be used to predict the crop yields than precipitation in the highland agriculture of South Central Java. It will become important information for the improvement of agriculture in the semi-arid areas.

References

Adams, R.M., B.A. McCarl and others. 1998. Climate Change and U.S Agriculture: some futher evidence. Report prepared for the Electric Power Research Institute as part of the Agricultural Impacts Project of the Climate Change (CCIP).

Adams. R.M., Hurd. B.H., Lenhart. S., Leary. S. 1998. Effects of global climate change on agriculture: an interpretative review. *Inter-Research* 11, pp.19-30.

Agricultural Service for Food Crops and Horticulture, Gunungkidul district. 2006. *Profil Tanaman Pangan Kabupaten Gunungkidul* (In Indonesian), pp. 5 –34.

Agricultural Service for Food Crops and Horticulture, Gunungkidul district. 2009. *Rainfall database in Gunungkidul district*, pp. 10-130.

Altieri M.A., C.A. Francis, A. van Schoonhoven, J. D Doll. 1978. A review of insect prevalence in maize (*Zea mays L*) and bean (*Phaseolus vulgaris L.*) polycultural systems. *Field Crop Res* 1, pp. 33-49.

Amien, I., Rejekiningrum, P., Pramudia, A., and Susanti, E. 1996. Effects of interannual climate variability and climate change on rice yield in Java, Indonesia. *Water Air and Soil Pollution* 92, pp. 29-39.

Anders, A.M., Roe, G.H., Hallet, B., Montgomery D.R., Finnegan, N.J., and Putkonen J. 2006. Spatial patterns of precipitation and topography in the Himalaya. *Geological Society of America* 398, pp. 39-53.

Andrews, D.J. 1972b. Intercropping with sorghum in Nigeria. *Exp. Agric.* 8, pp. 139-150.

Anon. (1980; 1981). Irrigated multiple cropping production systems: A summary of progress. Coastal Plain Exp. Stn. College of Agric. Univ. Georgia, Tifton. GA.

Australian Government Bureau of Meteology. 2010. Southern Oscillation Index (SOI) data, retrieved from the statistical climate service at http://www.bom.gov.au/climate/current/soihtm1.shtml

BAPPENAS. 1999. Planning for Fire Prevention and Drought Management Project. Final Report of TA-2999-INO. Asian Development Bank and BAPPENAS (Indonesian National Development Planning Agency). Jakarta, Indonesia. April 1999.

Beets W.C., 1975. Multiple-cropping practices in Asia and the Far East. *Agriculture and Environment* 2, pp. 219-228.

Boote KJ, Loomis RS (1991) Modeling crop photosynthesis—from biochemistry to canopy. In: Boote KJ, Loomis RS (eds) CSSA Special Publication No 19. Crop Science Society of America, Madison, WI

Bottema, J.W.T. 1995. Market Formation and Agriculture in Indonesia from the Mid 19th Century to 1990. Thesis (Dr)-Katholieke Universiteit Nijmegen.

BPS (Badan Pusat Statistik). 2000. *Statistik Indonesia 1999* [Statistical Yearbook of Indonesia, 1999], Jakarta.

Buerlein J. 2001. Relay cropping wheat and soybeans. *Ohio State University Extension Fact Sheet*. AGF-106-01. 1-2.

Burton, I. 2001. Vulnerability and Adaption to Climate Change in the Drylands: The Global Drylands Partnerships, Washington D.C.

CIA World Fact Book. 2008. Access from https://www.cia.gov/library/publications/theworld-factbook/print/id.html on 21 December 2010.

Central Bureau of Statistic. 2003. Statistik Gunungkidul district 2002 [Statistical Yearbook of Gunungkidul, 2002], Yogyakarta.

Central Bureau of Statistics, Republic of Indonesia. 2007. Key indicators of Indonesia. Booklet Indicator Kunci. BPS-Indonesia.

Central Bureau of Statistic, Republic of Indonesia. 2008. Access from http://www.bps.go.id/sector/agri/pangan/table9.shtml on 21 December 2010.

Cramer C., K. Cicero. 1992. 2 crops or the price of 1. *The New farm*. 14(2), pp. 14-17.

Dickinson, J. C. 1972. Alternatives to monoculture in the humid tropics of Latin America. *Prof. Georgr*. 24, pp. 217-232.

De Datta, S. K. 1981. Principles and practices of rice production. *John Wiley and Sons*, New York.

Fageria, N.K., 1992. Maximizing Crop Yields. *Marcel Dekker*, New York.

Falcon W.P, Naylor R.L., Smith W.L., Burke M.B., McCullough E.B. 2004. Using climate models to improve Indonesian food security. *Bulletin of Indonesian Economic Studies* 40 (3), pp. 357-359.

Falcon W.P, William O.J., Scott R.P and others. 1984. The cassava economy of Java. *Stanford University Press*. Stanford, California, USA, pp. 28-32.

Gomez, K. A. & Gomez, A.A. 1984. *Statistical Procedures for Agricultural Research*, 2nd ed., Singapore : Wiley.

Gliessman, S.R. and Amador, M.A. 1979. Ecological aspects of production in traditional agroecosystems in the humid lowland tropics of Mexico, Proceedings, Fifth International Symposium for Tropical Ecology, Kuala Lumpur, Malaysia.

Hamada J.I., Yamanaka M. D., Matsumoto J., Winarso P.A., and Sribimawati. 2002. Spatial and temporal variations of the rainy season over Indonesia and their link to ENSO. *Journal of the Meteorological Society of Japan*, Vol. 80, No. 2, pp. 285-310.

Hamada J.I., Yamanaka M. D., Mori S., Tauhid Y. I., and Sribimawati. 2008. Differences of rainfall characteristics between coastal and inferior areas of central western Sumatera, Indonesia. *Journal of the Meteorological Society of Japan*, Vol. 86, No. 5, pp. 593-611.

Hammond R.B., D.L Jeffers. 1990. Potato leafhopper (Homoptera: *Cicadellidae*) populations on soybean relay intercropped into winter wheat. *Environ. Entomol.* 19, pp. 1810-1819.

Hasanuzzaman M. et al. 2009. Plant characters, yield components and yield of late transplanted *Aman* rice as affected by plant spacing and number of seedling per hill. *Advances in Biological Research* **3**, pp. 201-207.

Harger, J.R.E. 1995. Air-temperature variations and ENSO effects in Indonesia, the Philippines and El Salvador: ENSO Patterns and Changes from 1866-1993. *Atmos. Environ* 29, pp. 1919-1942.

Haylock, M. & McBride J. 2001. Spatial coherence and predictability of Indonesian wet season rainfall. *J. Climate* 14, pp. 3882-3887.

Herbert, S.J. et al. 1984. Forage yield of intercropped corn and soybean in various planting patterns. *Agron. J.* **76,** pp. 507- 510.

Hodges, T. 1991. Temperature and water stress effects on phenology. In T. Hodges (ed.). Predicting crop phenology. CRC Press, Boca Raton, Fla. p.7-13.

Hoogenboom G. 2000. Contribution of agrometeorology to the simulation of crop production and its applications. *Agricultural and Forest Meteorology* **103**, pp. 137-157.

Howard D.D., G. Lessman. 1991. Nitrogen fertilization of wheat double-cropped following grain sorghum in a non-tillage system. *Agron. J.* 83, pp. 208-211.

Huang, S.N. 2003. Multiple cropping as a strategy in sustainable soil management. The 3rd APEC Workshop on Sustainable Agricultural Development, 16th to 22nd November 2003, Chinese Taipei, pp. 57-74.

Irawan, B. 2002. Stabilization of upland agriculture under El Nino-induced climatic risk: Impact Assessment and Mitigation Measure in Indonesia, Economics and Social Commission for Asia and the Pacific, CGPRT Center WORKING PAPER No. 62.

Irawan, P.B. and Sutanto, A. 1999. Impact of the economic crisis on the number of poor people. International Seminar on Agricultural Sector During the Turbulence of Economic Crisis: Lessons and Future Directions. Center for Agro-Socioeconomic Research: Bogor.

IRRI (International Rice Research Institute). 2004. Water requirements. Accessed at http://www.knowledgebank.irri.org/tropice/Water_Requirements.htm on December 20, 2010.

Ishikawa, I., H. Tsujino, M. Hirabara, H. Nakano, T. Yasuda and H. Ishizaki. 2005. Meteorological Research Institute Community Ocean Model (MRI.COM) Manual. *Technical Reports of the Meteorological Research Institute* 47, pp. 189.

Japan Meteorological Agency, 2012. Retrieved 27 November 2012. http://ds.data.jma.go.jp/tcc/tcc/products/elnino/elmonout.html

Kirono D.G.C and Khakhim N. 1998. Rainfall and El Nino Southern Oscillation: Link and its impact on crop production, a case study of Yogyakarta Special Province of Indonesia. The *Indonesian Journal of Geography*, 30, 76, pp. 21-34.

Kirono D.G.C and Tapper N.J. 1999. ENSO rainfall variability and impacts on crop production in Indonesia. *Physical Geography*, 20(6), pp. 508-519.

Maclean, J.L., Dawe, D.C., Hardy, B. & Hettel, G.P. (eds). 2002. Rice almanac (Third Edition). Philippines, IRRI, WARDA, CIAT and FAO

Martinez, C.J., Baigorria, G.A and Jones J.W. 2009. Use climate indices to predict corn yields in Southeast USA. *International Journal of Climatology* 29, pp. 1680-1691.

McPhaden, M.J. 1999. Genesis and evolution of the 1997-1998 El Nino. *Science* 283, pp. 948-949.

Murtiningrum, Willy A.P., Sewan D.L., and Wisnu Wardana. 2011. Mathematical models of rice tillers and crop height growth of rice cultivated with SRI method. *Journal of Agrotechnology* 5, pp. 92-107.

Nakano H. & Mizushima T. 1994. Effect of competition in a hill to seedling number per hill on yield components and yield in paddy rice. *Japanese J. Crop Sci.* **63**, pp. 452-459.

Naylor, R.L., Falcon W.P., Rochberg D. and Wada N. 2001. Using El Nino/Southern Oscillation Climate Data to Predict Rice Production in Indonesia. *Climatic Change* 50, pp. 255-265.

Naylor, R.L., Falcon W.P., Wada N. and Rochberg D. 2002. Using El Nino-Southern Oscillation climate data to improve food policy planning in Indonesia. *Bulletin of Indonesian Economic Studies*. Vol. 38. No. 1.

Naylor, R.L., Battisti, D.S., Vimont, D.J, Falcon, W.P and Burke, M.B. 2007. Assessing risks of climate variability and climate change for Indonesian rice agriculture. *Proceedings of the National Academy of the United States of America (PNAS)* Vol. 104, No. 19, pp. 7752-7757.

Nicholls N. 1981. Air-sea interaction and the possibility of long-range weather prediction in the Indonesian archipelago. *Mon. Wea. Rev.* 109, pp. 2435-2443.

Nicholls N. 1984. The Southern Oscillation and Indonesia sea surface temperature. *Mon. Wea. Rev.*, 112, pp 424-432.

Nitta T., Mizuno T., and Takahashi K. 1992. Multiscale convective systems during the initial phase of the 1986/87 El Nino. *J. Meteor. Soc.* Japan, 70, pp. 627-641.

Pauly D., I. Tukayama (Eds.). 1987. The Peruvian Anchoveta and its upwelling system:Three decades of change. International Center of Living Resources Management (ICLARM), Review 15, Manila. The Philippines, pp. 351

Petr, J. 1991. Weather and Yield. *Elsevier*, Amsterdam, Netherlands.

Press W.H, Flannery B.P, Teukolsky S.A, Vetterling W.T. 1989. Numerical Recipes: The art of Scientific Computing . *Cambridge University Press*. New York, NY, USA, pp. 702.

Putnam, D.H., Herbert S.J and Vargas A. 1985. Intercropped corn-soybean density studies. I. yield complementarily. *Expl. Agric.* **21**, pp. 41-51.

Putnam, D.H., Herbert S.J. and Vargas A. 1986. Intercropped corn-soybean density studies. II. yield composition and protein. *Expl. Agric.* **22**, pp. 373-381.

Roe, G.H. 2005. Orographic Precipitation. *Annu. Rev. Earth Planet. Sci* **33**, 645-71

Saji, N.H., Goswami, B.N., Vinayachandran, P.N. & Yamagata, T. 1999. A dipole mode in the tropical Indian Ocean. *Nature* 401, pp. 360-363.

Salisbury, J.I and Wimbush M. 2002. Using modern time series analysis techniques to predict ENSO events from the SOI time series. *Nonlinear Processes in Geophysics* 9, pp. 341-345.

Sardjiman and Mulyadi. 2005. Analisis neraca air lahan kering pada klim kering untuk mendukung pola tanam (In Indonesian), *Balai Pengkajian Teknologi Pertanian,* DI Yogyakarta.

Saseendran, S.A., Singh, K.K., Rathore, L.S., Singh S.V and Sinha S.K. 2000. Effects of climate change on rice production in the tropical humid climate of Kerala, India. *Climate Change* **44**, pp. 495-514

Sharma J. and Thakur R. 1993. Performance of rainfed Argentine rape (*Brassica napus*) under dates of sowing and row spacing in the mid-hills of north-western Himalayas. *Indian J. Agron.* **38**, pp. 254-256.

Singh, P and Kumar N. 1997. Effect of orography on precipitation in the western Himalayan region. *J. Hydrol.* **199**. Pp. 183-206

Stansel J.W. 1975. The rice plant-its development and yield. Six decades of rice research in Texas. Research Monograph 4. *Texas Agricultural Experiment Station*, pp. 9-21.

Tambunan, M. 1999. Economic crisis induced employment: can agricultural and rural economy play as the save heaven? International Seminar on Agricultural Sector During the Turbulence of Economic Crisis: Lessons and Future Directions. Center for Agro-Socioeconomic Research: Bogor.

Trenberth K.E and Hoar T.J. 1996. The 1990-1995 El Nino Southern Oscillation Event: Longest on Record. *Geophys. Res. Lett.* 23, pp. 57-60.

Trenberth K.E and Shea D. 1987. On the evolution of the Southern Oscillation. *Mon. Wea. Rev.* 115, pp. 3078-3096.

Uhlig, H. 1990. Man and tropical karst in Southeast Asia. *GeoJurnal* 4(1), pp. 31-44.

Urushibara-Yoshino, K. 1993. Human impact on karst soil: Japanese and other examples, in Williams, P.W., (ed.). Karst terrains: Environmental changes and human impact: Cremlingen, Catena Verlag, *Catena Supplement* 25, pp. 219-233.

Urushibara-Yoshino, K., Yoshino M. 1997. Palaeoenvironmental change in Java Island and its surrounding areas. *Journal of Quarternary Science* 12(5), pp. 435-442.

Waltham A.C., Smart P.L., Friederich H., Eavis A.J., Atkinson T.C. 1983. The caves of Gunung Sewu, Java. *Cave Science* 10(2), pp. 55-96.

Appendix 1. Multiple cropping systems in South Central Java

Appendix 2. Field experiment in Gunungkidul district (Saptosari)

Rain-gauge

Observation

Observation

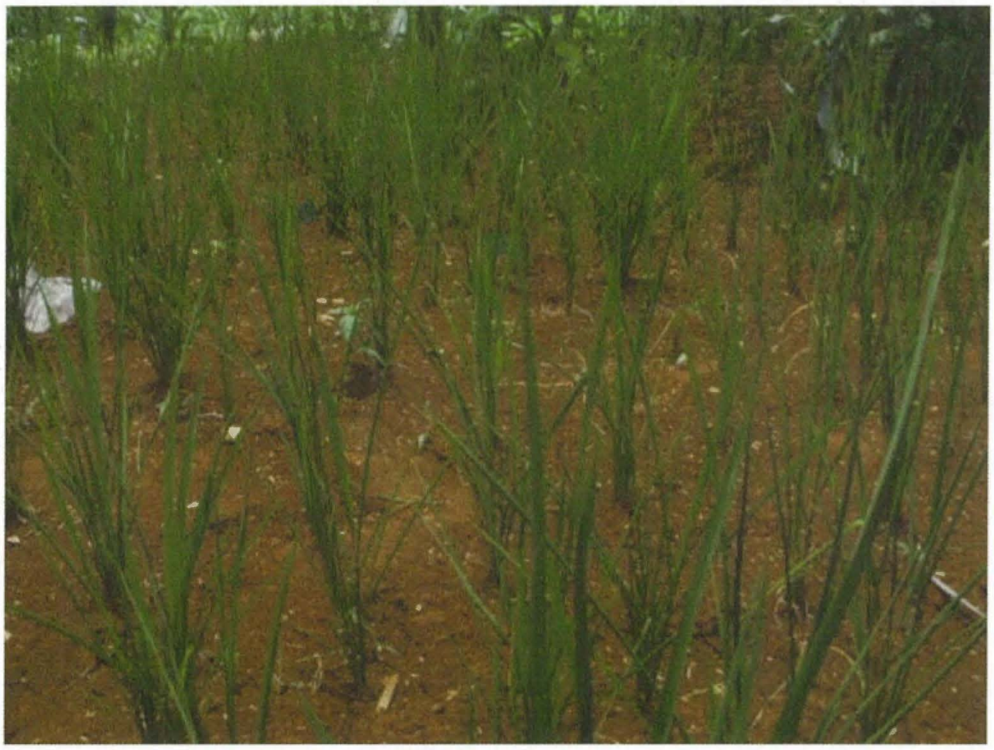
Observation data in the height of rice at Saptosari

Observations	Plant	Date of observations													
		30-Sep	10-Oct	20-Oct	30-Oct	9 Nov	19-Nov	29-Nov	9-Dec	19-Dec	29-Dec	8-Jan	18-Jan	28-Jan	7-Feb
C	**Rice**	**6.6**	**12.1**	**16.0**	**27.6**	**35.7**	**45.8**	**48.7**	**60.4**	**67.6**	**74.0**	**80.2**	**81.4**	**80.6**	**81.7**
MCS1	**Rice**	**8.2**	**11.3**	**15.7**	**25.1**	**35.5**	**49.8**	**51.0**	**58.6**	**66.0**	**68.7**	**73.1**	**73.5**	**73.6**	**74.8**
	Maize	9.1	14.6	32.5	59.9	106.1	161.1	188.3	195.5	195.3	189.3				
MCS2	**Rice**	**7.3**	**12.7**	**15.8**	**27.0**	**35.2**	**46.9**	**45.5**	**53.3**	**65.6**	**72.5**	**83.4**	**82.9**	**83.9**	**84.5**
	Cassava	21.7	27.5	33.3	39.3	51.8	57.3	72.2	82.1	97.4	107.0	113.0	120.3	124.9	129.7
MCS3	**Rice**	**6.1**	**12.0**	**14.5**	**21.8**	**30.9**	**40.5**	**41.7**	**53.5**	**62.7**	**68.8**	**76.1**	**76.9**	**77.8**	**80.3**
	Maize	10.3	16.1	25.4	41.3	75.1	106.5	144.3	145.5	161.8	178.3				
	Cassava	21.0	26.9	30.1	35.3	45.0	56.4	61.8	68.7	84.1	93.5	100.1	106.7	110.2	115.5

Appendix 4. Field experiment in Gunungkidul district (Tanjungsari)

Soil condition at field

Observation



Observation

Observation data in the height of rice at Tanjungsari

Observations	Plant	Date of observations											
		10-Oct	20-Oct	30-Oct	9 Nov	19-Nov	29-Nov	9-Dec	19-Dec	29-Dec	8-Jan	18-Jan	28-Jan
C	Rice	**13.1**	**15.6**	**25.7**	**37.5**	**51.0**	**52.9**	**69.4**	**75.6**	**77.9**	**90.2**	**88.3**	**89.2**
MCS1	Rice	**12.9**	**16.1**	**27.1**	**38.9**	**50.2**	**53.3**	**67.0**	**75.6**	**75.2**	**82.9**	**86.5**	**86.7**
	Maize	13.5	24.1	42.9	76.4	117.9	157.2	180.3	180.2	181.8			
MCS2	Rice	**12.8**	**15.6**	**26.6**	**38.5**	**50.9**	**54.2**	**63.7**	**74.3**	**71.7**	**80.7**	**81.3**	**82.7**
	Cassava	35.8	45.3	54.5	66.8	88.1	105.4	120.1	137.5	160.4	166.9	171.9	174.9
MCS3	Rice	**12.7**	**15.3**	**25.5**	**36.9**	**47.9**	**53.7**	**65.7**	**73.5**	**73.3**	**80.8**	**81.7**	**82.2**
	Maize	12.5	19.0	33.4	57.3	98.5	152.0	170.1	171.9	173.3			
	Cassava	34.7	46.7	57.7	70.3	85.6	110.0	130.0	145.5	167.8	173.6	179.5	180.3

Appendix 4. Field experiment in Gunungkidul district (Rongkop)

Rain-gauge

Soil condition at field


Observation