Multiple Cropping Scenario Based on Local Climate and the Growth of Dryland Rice against Regional Climate Change in Stabilizing Agricultural Production (Case Study in South Central Java Rain-fed Agriculture)

Bayu Dwi Apri Nugroho

Department of Agricultural Engineering, Faculty of Agricultural Technology
Gadjah Mada University, Yogyakarta, Indonesia

Abstract

In this study, we observe four combinations of crops: rice (C), rice – maize (MCS1), rice – cassava (MCS2) and rice – maize – cassava (MCS3) with 3 m x 3 m each plots at two field areas, Saptosari and Tanjungsari. Both field areas are located in Gunungkidul district, South-Central of Java Island, with 93% at those areas are 185 to 500 above sea-level and high proportion of multiple cropping systems. The aim of this study is to observe the effect of multiple cropping systems on growth and yield response to water of rice based on local climate in rain-fed agriculture. Mathematical models developed to describe rice growth. The rice height was followed monomolecular function and the number of tillers followed exponential polynomial function. 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.

Keywords: growth, multiple cropping systems, rain-fed agriculture, rice, yield

1. Introduction

The island of Java is the biggest contribution of rice production in Indonesia. Around 50% of farmlands of the island are irrigated, but the southern highland remains as dryland agriculture. 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.

The main problem of agriculture in highland fields is water scarcity due to less amount of rainfall (Hoogenboom, 2000). Irawan (2001) 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). The objective of this study was to observe the effect of multiple cropping systems on growth and yield in response to water of rice based on local climate in rain-fed agriculture and to determine the suitability of crops and cropping systems in the South-Central of Java.

2. Materials and Methods

Gunungkidul district was selected as a study area (Fig. 1). 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.

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 practicerain-fed agriculture and cultivate multiple cropping systems. They use *pranatamangsa,* a

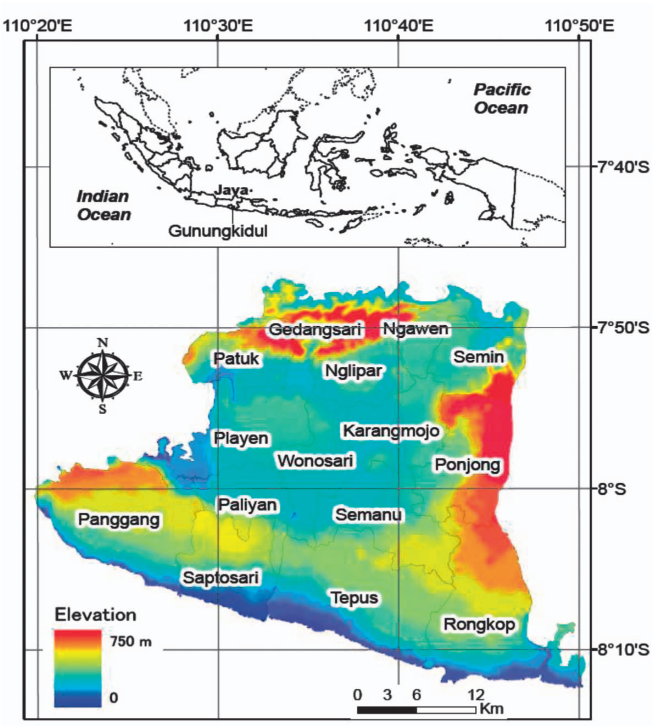

Fig. 1 The 18 sub-districts of Gunungkidul and its topography. The variations in elevations show distinct landscape characteristics of each district (Nugroho et al., 2013)

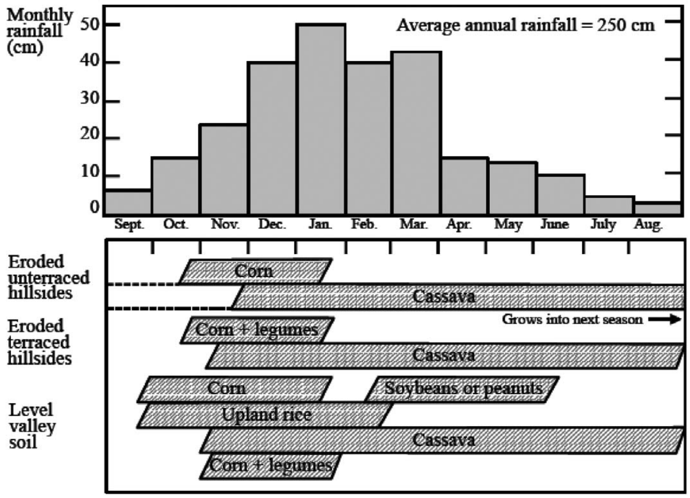

Fig. 2 Monthly rainfall distribution and cropping patterns based on three landform types (level valley soil, eroded terrace and unterraced hillsides) in Gunungkidul (Falcon et al., 1984)

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 2 shows rainfall distribution and cropping patterns in various land types in Gunungkidul (Falcon et al., 1984). Maize 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.

In this study, 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 (Agricultural Service for Food Crops and Horticulture, 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 (Agricultural Service for Food Crops and Horticulture, Gunungkidul District, 2006).

The observation design was based on cropping pattern at Saptosari and Tanjungsari, and arranged in a randomized completely block design. Observations were repeated three times, so there are 3 x 4 = 12 plots:

1. Rice monoculture: C
2. Rice + maize multiple cropping: MCS1
3. Rice + cassava: MCS2
4. Rice + maize + cassava: MCS3

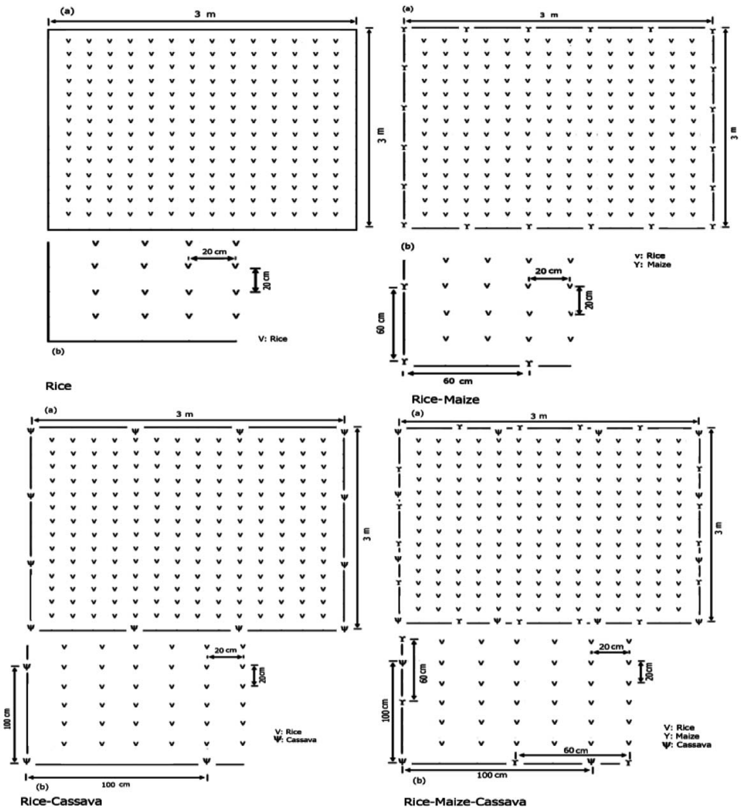

Fig. 3 Spacing in C, MCS1, MCS2 and MCS3

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 Fig. 3. The difference of planting date was 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 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:

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

While,

Tf = the height of rice in the harvesting,

To = 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:

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

While,

A = the number of tillers.

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 4 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.

3. Results

Observation data of the height and number of tillers were collected every 10-days during plantings season at Saptosari and Tanjungsari. Figure 5 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 6 that shows the highest number of tillers is in C, while the least number is in MCS3 at both field areas.

Tables 1 and 2 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 ($p<0.05$).

Figure 6a and Fig. 6b 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 6c and 6d show the most optimum tillers

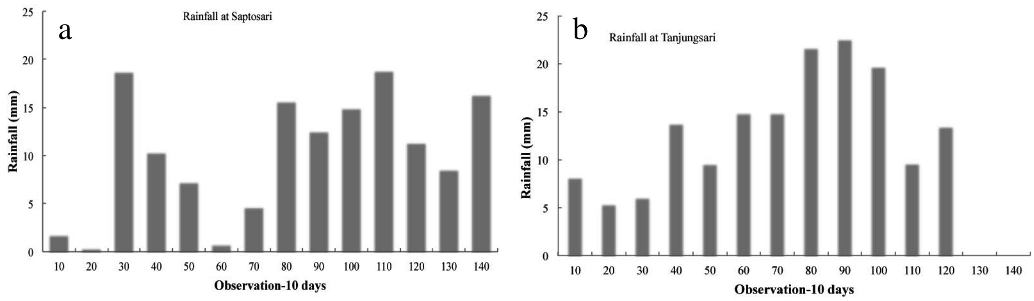

Fig. 4 Rainfall data during observation at Saptosari (a) and Tanjungsari (b)

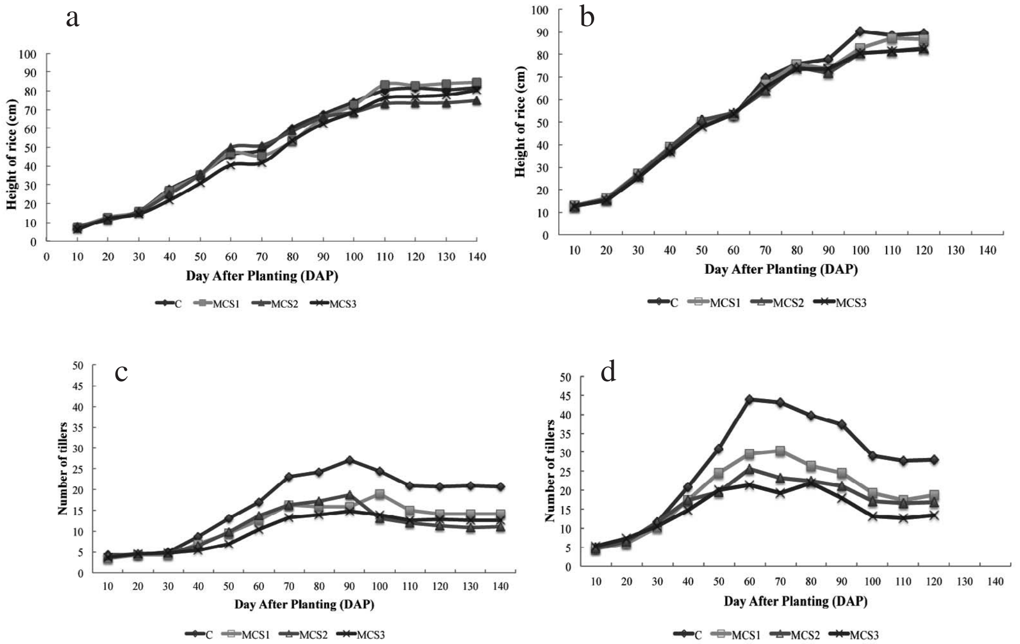

Fig. 5 Height of rice and number of tillers in rice monoculture (C), rice - maize (MCS1), paddy - cassava (MCS2), and paddy - maize - cassava (MCS3) at Saptosari (a, c) and Tanjungsari (b, d).

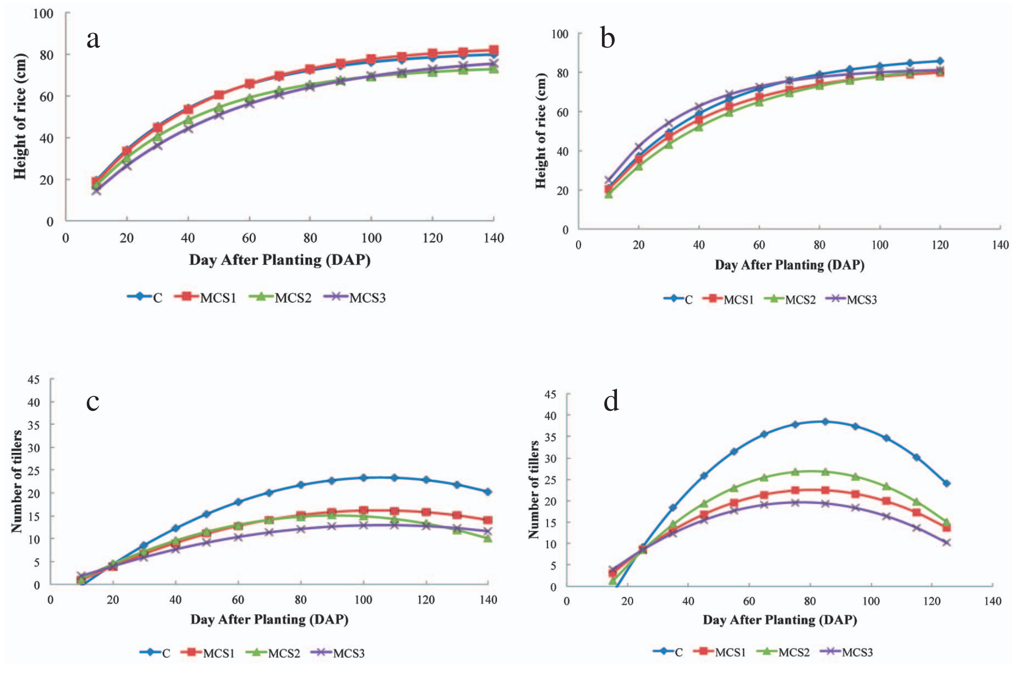

Fig. 6 Height of rice using monomolecular function at Saptosari (a) and Tanjungsari (b), and number of tillers using exponential polynomial function at Saptosari (c) and Tanjungsari (d)

Table 1 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 2 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

formation is in monoculture, because there is no competition in obtaining solar radiation or soil moisture. Themaximum 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.

The productivity of rice at Saptosari and Tanjungsari (Fig. 7a and Fig. 7b) 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. Multiple cropping decreased the rice growth and yield due to competition of each crops. There are competition among different plants to get solar radiation and affected on photosynthesis process. Further, multiple cropping also increased the competition between plants to absorb water and nutrients from the soil.

4. Discussion

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

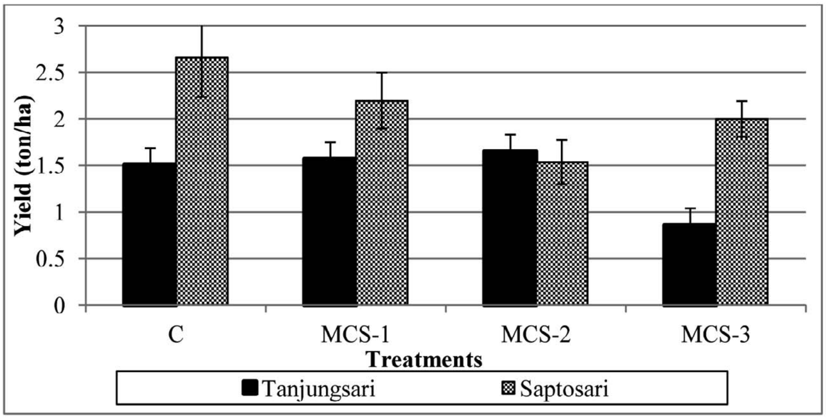

Fig. 7 Productivity of rice at Tanjungsari and Saptosari

nutrients, water and light for their growth and development. Basically, multiple cropping patterns will affect the rate 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 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.

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.

5. Conclusions

In this study, 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

Agricultural Service for Food Crops and Horticulture, Gunungkidul District, 2006. Profil TanamanPangan Kabupaten Gunungkidul, pp. 5–34 [In Indonesian].

Agricultural Service for Food Crops and Horticulture, Gunungkidul District, 2009. Rainfall Database in Gunungkidul District, pp. 10-130.

Beets, W.C., 1975. Multiple-cropping practices in Asia and the Far East, *Agric. Environ.,* 2: 219–228.

Falcon, W.P., Jones, W.O. and Pearson, S.R., 1984. The Cassava Economy of Java, Stanford University Press, Stanford, California, USA, 234 pp.

Hoogenboom, G., 2000. Contribution of agrometeorology to the simulation of crop production and its applications, *Agric. Forest Meteorol.,* 103: 137–157.

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, CGPRT Center Working Paper No. 62, 78 pp.

Murtiningrum, W.A.P., Sewan, D.L. and Wardana, W., 2011. Mathematical models of rice tillers and crop height growth of rice cultivated with SRI method, *J. Agrotech.,* 5: 92–107.

Nugroho, B.D.A., Prima, A.O.D., Kanno, H., Sameshima, R., Fujii, H. and Lopez, L.C.M., 2013. Relationships between global climate indices and rain-fed crop yields in highland of South-Central Java, Indonesia, *J. Geogr.,* 122: 438–447.