Multiple Cropping Scenarios 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)

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Summary: In this study, we observe four combinations of crops: rice (C), rice – maize (MCS1), rice – cassava (MCS2) and rice – maize –cassava (MCS3) with 3m x 3m 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 described rice growth. The rice height was followed monomolecular function and the number of tillers followed exponential polynomial function. Yield response to water was calculated from ETa and ETm. Our result shows the height of rice and number of tillers was not significantly different between each combination ($p>0.05$). Based on the calculation of evapotranspiration, water deficit is happen on initial and mid-season (ETa < ETm) and affected water stress. Statistical analysis showed that cropping method is not significantly affected on rice growth and yield ($p>0.05$).

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

1. INTRODUCTION

The main problem of agriculture at those highland fields is water scarcity due to less amount of rainfall, and it is appropriate with Hoogenboom (2000). He stated that local climate, which has a major impact on plants as well as plants growth is precipitation. Water scarcity is a major factor limiting agricultural production for millions of farmers in poor dryland resources. The occurrence of periods of water deficit for crop production, referred to as 'climatic drought', commonly observed and leads to low water availability for crops. Additionally, the soil cannot hold the rainwater adequately due to the soil profile. Finally, even water is very limited, particularly in the driest areas; a surprisingly small proportion of the available water is actually transpired by the crop (Van Duivenbooden et al. 2000).

Within this context, improving cropping system management has been identified to achieve sustainable production systems. Farmers in Indonesia particularly South-Central of Java commonly use monoculture system by adopting multiple cropping system (MCS) for efficiency purposes. MCS is multiple crops, which are planted on the same field, but not simultaneously, during a season (Beets 1975), intensification of cropping in time and space dimension (Francis 1986). But in modern countries, the monoculture is more popular than the MCS. However, in considering the sustainability, the MCS is better than the monoculture in dryland because it needs less input such as chemical fertilizer, pesticides and farm machinery (Huang 2003). Some investigators have concluded that the advantages of multiple cropping of cultivar mixtures depend on plant population density (Herbert et al, 1984; Putnam et al, 1985; Putnam et al. 1986), plant spacing (Sharma and Takur, 1983; Nakano and Mizushima, 1994; Hasanuzzaman et al, 2009) and economic analyses (Francis 1986; Tsai et al. 1987; Rosyadi and Nuryartono 2003). Nowadays, there is no clear result that investigated the height and tillers of rice and its influence by the combination of crops at the rain-fed highland.

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

2.1 Experimental site

Experiments were conducted in Saptosari and Tanjungsari sub-districts (Fig. 1). About 93% of areas are 185 to 500 above sea-level with high proportion employing multiple cropping systems (ASCFH 2009). Mean totals of rainfall from 1989-1998 are 1400 and 1700 mm for Saptosari and Tanjungsari respectively during rainy season.

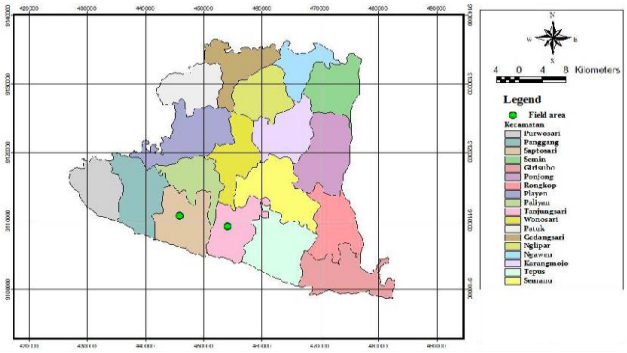

Fig. 1. Location of Saptosari and Tanjungsari in Gunungkidul district (green dot).

2.2 Experimental design and data analysis

The observation was arranged in a Randomized Completely Block Design (RCBD) Gomes (1984), where individual plots were same in size. Each of observations was repeated three times, so there are 3 x 4 = 12 plots with the following details:

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)

Seeds of rice, maize and cassava were planted together in each plot with different planting dates from September to February. The difference of planting date is caused by local tradition and decision of farmer in the areas. Crop samples (five samples in each plot) were taken periodically every 10 days. Fertilizer and organic nutrient were used in this study by referring to local schedule of the farmers in the areas.

To analyze height of rice, we use monomolecular equation as stated by Murtiningrum et al. (2011), if the growth of rice will be plotted in the graph, it will follow monomolecular equations. The equations as below:

$$\ln = ((Tf-To)/(Tf-T))=kt \quad \ldots\ldots (1)$$

While,
Tf is the height of rice in the harvesting, To is the height of rice seed in the beginning of planting, and T is the height of rice at day of observation.

And for the number of tillers, using exponential polynomial equation as below:

$$A = \exp (a\,0 + a1t + a2t2) \quad \ldots\ldots (2)$$

While,

A = the number of tillers.

To analyze yield response to water, we calculated the value of actual evapotranspiration (ETa) and maximum evapotranspiration (ETm). ETa could be estimated from data on evapotranspiration rate, available soil water and wetting intervals (Steduto et al, 2012).

3. RESULTS

3.1 Observation of the height and number of tillers in rice

Observation data of plant height and number of tillers were collected every 10 days. Fig. 2 (a, b) 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. Fig. 2 (c, d) shows the highest number of tillers is in C, while the least number is in MCS3 at both field areas.

3.2 Model of the height and tillers of rice

The model is fit for the growth of rice based on height and number of tillers (p<0.05).

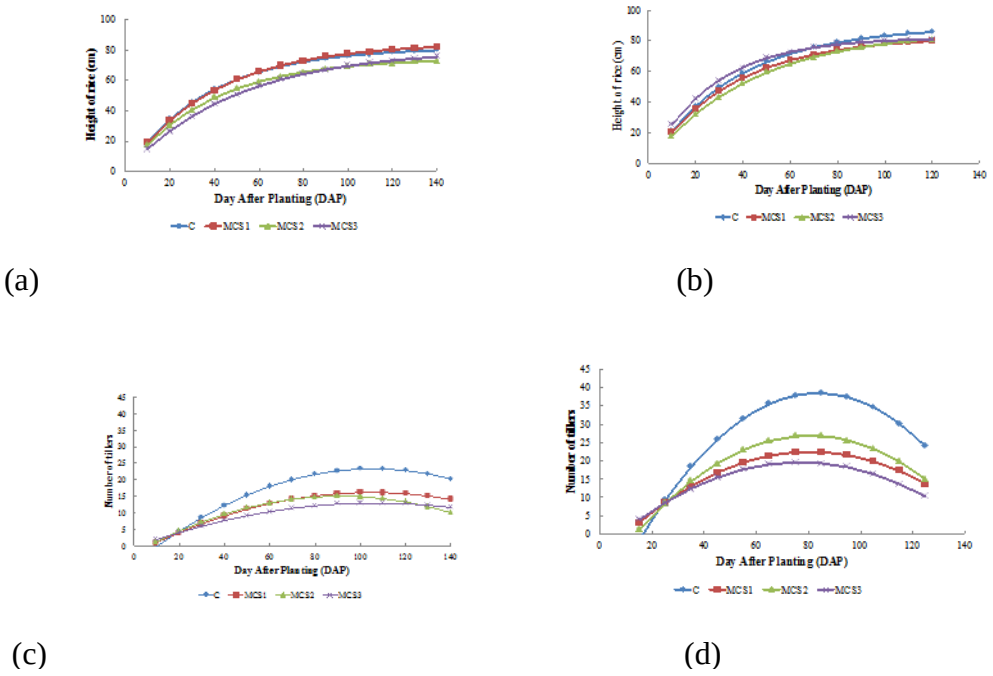

Fig 2. Height of rice using monomolecular function at Saptosari (a) and Tanjungsari (b), and number of tillers using exponential polynomial function at Saptosari (c) and Tanjungsari (d).

In Figure 2, a and b 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. It 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). In Figure 2, c and d 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 65 to 93 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.

3.3 The response of rice yield on water

Fig. 3 shows daily evapotranspiration (ETm and ETa). Evapotranspiration is the parameter related with rice production. Soil water is readily available for the crop if ETa equal with ETm (Steduto et al. 2012). Evapotranspiration was low in the early stage and then increased until vegetative stage and decreased at final stage of rice.

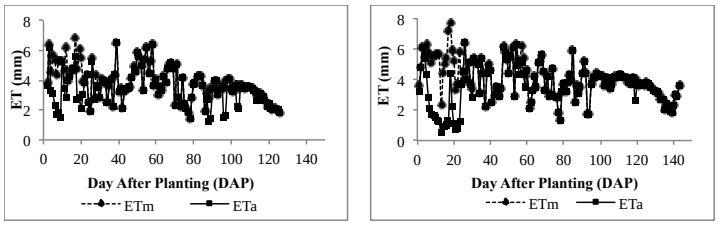

Fig. 3. Maximum evapotranspiration (ETm) and actual evapotranspiration (ETa) of rice in Saptosari (a) and Tanjungsari (b).

Fig. 3 shows that ETa of rice in the early season was smaller than ETm (ETa < ETm). The possible reason was due to low rain intensity. This condition affected water stress and most of the rice plant was died. Water stress in Saptosari occurred in the early and mid-seasons (Fig. 3a). On the other hand, in Tanjungsari occurred only in the early season (Fig. 3b). Commonly, intensity of water stress in Tanjungsari was higher than Saptosari. Water stress can have major impact on productivity and yield depending on timing, severity, and duration (Steduto et al. 2012). In the early stage, we replaced the dead plants with new seeds

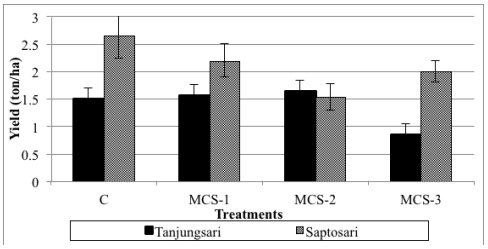

Fig. 4. Rice yield of monoculture (C), rice - maize (MCS1), rice - cassava (MCS2), and rice - maize - cassava (MCS3) in Saptosari and Tanjungsari.

Fig 4 shows that rice yield at Saptosari is higher than Tanjungsari. This result might be affected from total ET which Saptosari resulted higher ET than Tanjungsari. Akinbile (2010) reported that evapotranspiration has direct relationship with rice yield. Monoculture also shows higher yield than other treatments due to produce higher number of tillers. However, the effect of cropping system was not significant ($p>0.05$). Multiple cropping will decrease the rice growth and yield due to shading effect. There are competition among different plants to obtain solar radiation for photosynthetic process. Further, multiple cropping also increase the competition of plant to absorb water and nutrient from soil (Glodsworthy dan Fisher 1984; Herlina et al. 1996).

4. CONCLUSION

In this study, rice plant height and number of tillers was not significantly affected by cropping method ($p>0.05$). Further, water deficit was happen on initial and mid-season (ETa < ETm) and affected water stress. Statistical analysis showed that cropping method was not significantly affected on rice growth and yield ($p>0.05$). The achievement in this study provides valuable information to the policymaker in agriculture for this area, not only to estimate yield using multiple cropping system but also to decide suitable plants for the multiple cropping systems.

REFERENCES

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

Agricultural Service for Food Crops and Horticulture, Gunungkidul district. 2009: Rainfall database in Gunungkidul district, 10–130.

Akinbile, C.O. 2010. Crop Water Use Responses of Upland Rice to Differential Water Distribution under Sprinkler Irrigation System. *Journal of Advances in Applied Science Research* 1:133-144.

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

Doorenbos, J. and A.H. Kassam. 1979. Yield response to water. FAO Irrigation and Drainage Paper No. 33. FAO. Rome.

Goldsworthy, P.R. and N.M. Fisher. 1984. The physiology of tropical field crops. *John Wiley & Sons, Chicester*. New York, Brisbane, Toronto, Singapore.

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

Herlina, N., Didik, and F. Isnaini. 1996. Pengaruh waktu Tanam dan Kepadatan Tanaman Selada Terhadap Pertumbuhan dan Hasil Tanaman Bawang Merah dalam Sistem Tumpangsari (In Indonesian). *Agrivita*, 19:74-78.

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

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

Pusposutardjo, Suprodjo. 1984. Disertasi: Growth and Yield Modeling of Irrigated Soybean and Peanut in Tropical Rain Monsoon Climates. Utah State University.

Sitompul, S. M. and B. Guritno. 1995. Analisis Pertumbuhan Tanaman. Gadjah Mada University Press, Yogyakarta.

Steduto, P., T.C. Hsiao, E. Fereres, and D. Raes. 2012. Crop yield response to water. FAO Irrigation And Drainage Paper, 66.

Tao, F., S. Zhang, and Z. Zhang. 2012. Spatiotemporal changes of wheat phenology in China under the effects of temperature day length and cultivar thermal characteristics. *European J. of Agronomy*, 43:201–212.

Zhang, S. and F. Tao. 2013. Modeling the response of rice phenology to climate change and variability in different climatic zones: Comparisons of five models. *European J. of Agronomy*, 45:165–176.