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AN INTERACTION MODEL BETWEEN ENVIRONMENTAL FACTORS AND BLACK RICE GROWTH IN IRRIGATED ORGANIC PADDY FIELD

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ABSTRACT

Black rice production in organic farming system does not meet the demand of local customers because of its low productivity. This research aimed to set an interaction model using multivariate analysis via smartPLS to identify environmental factors which simultaneously affects the growth of black rice. The growth of black rice in two irrigated organic paddy field in Malang, Indonesia was observed during planting period from November 2011 to March 2012. In each rice field, the growth was periodically recorded during planting periods: 19-29 days after planting (dap), 41-45 dap, 62-66 dap, 77-81 dap, 90-94 dap and 104-106 dap. Environmental factors such as water quantities, soil conditions, weed communities and cultivation system around the black rice population were also measured. Black rice growth was influenced simultaneously by water quantities, soil, weed communities and cultivating systems with predictive-relevance value reaching 92.83%. Based on the model, water quantities in paddy field is a key factor which directly and indirectly determined the growth and productivity of black rice.

Keywords: black rice growth, environmental factors, interaction model, organic paddy field

INTRODUCTION

Black rice is one of the rice families which has large advantages for human health because it contains anthocyanin compounds. Anthocyanin extracts from black rice significantly inhibit the growth of liver cancer cells (Chen *et al.*, 2006) and effectively reduce cholesterol level on blood plasma, LDL (low-density lipoprotein) and triglycerides, increase HDL (high-density lipoprotein), and as an alternative therapy for cardiovascular diseases (Kim *et al*., 2006; Xia *et al.*, 2006; Wang *et al*., 2007; Zawistowski *et al*., 2009; Salqado *et al*., 2010).

Unfortunately organic black rice production doesn't even meet the demand of the local customers due to its low productivity. The production of woja laka black rice cultivars which is cultivated in irrigated organic paddy field only reached 6 t ha^{-1} especially in dry seasons. The production might be fewer in rainy seasons. This condition is related to sensitivity of black rice populations to natural enemies such as birds and rats and their responses to environment conditions (Budiman *et al*., 2012).

Previous researches reported by Senewiratne and Mikkelsen (1961), Skerman and Riveros (1990), De Datta and Vergera (1996), Leesawatwong (2005), Rao *et al.* (2006), Sanusan *et al.* (2010) and Zhu *et al.* (2010) implied that altitude, microclimates (temperatures, precipitations and radiation), soil conditions (textures, organic matters, pH, bulk density and nutrition), water availability and weeds density significantly influenced the growth of rice. However, the researches were conducted and analyzed partially (univariate) without considering the system of complexity, and most of them were not conducted in organic agricultural system.

In nature, environmental factors interacted simultaneously with each other and affected the growth of black rice either directly or indirectly. Therefore, this research used multivariate analysis to create an interaction model of black rice growth. This model is required to obtain precise information about environmental factors that influence black rice growth in organic agricultural system. The information of this

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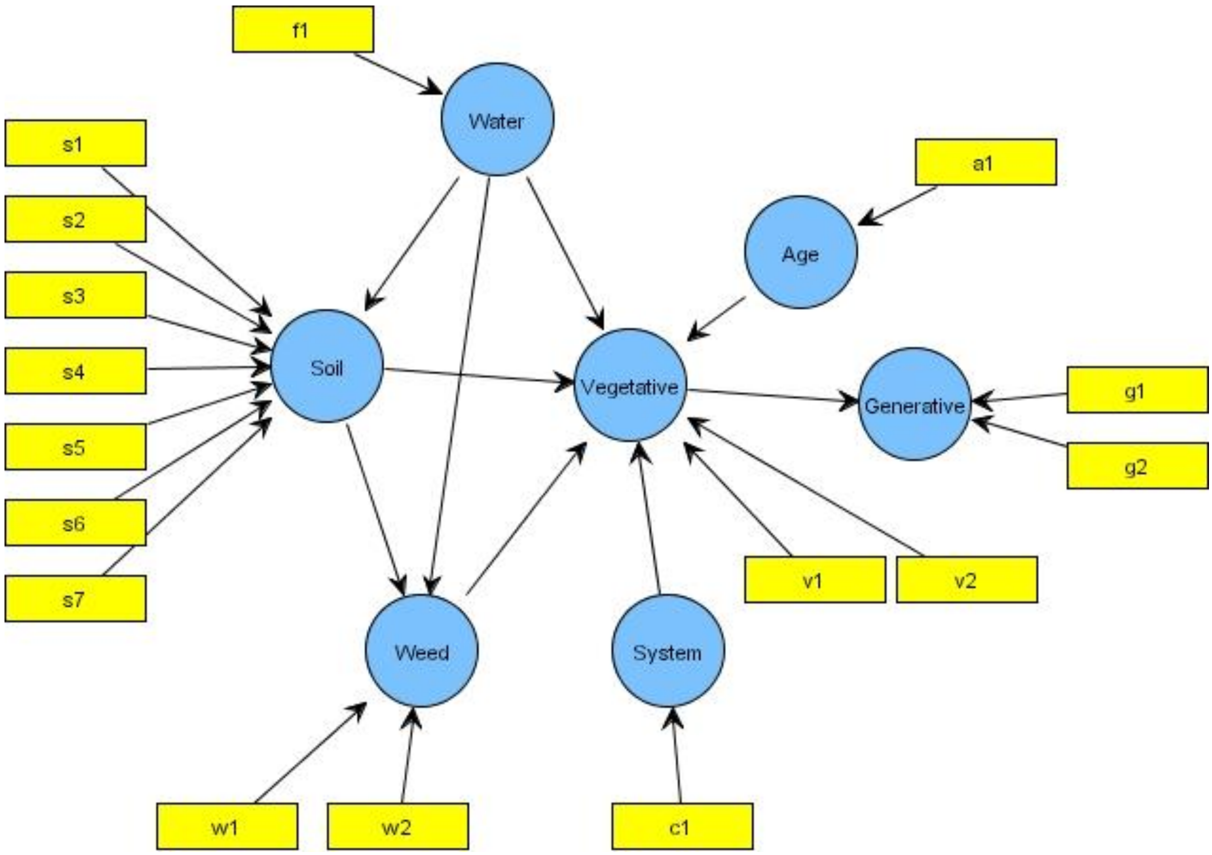
research can contribute to the development of sustainable agriculture of black rice.

MATERIALS AND METHODS

This descriptive exploratory research was conducted by using purposive sampling method in two organic paddy fields in Kepanjen District, Malang Regency – Indonesia. The observation of black rice growth and its environmental conditions was performed during rainy season from November 2011 to March 2012.

In each field, black rice growth was measured periodically 15-30 days after planting (dap), 40-45 dap, 60-66 dap, 70-80 dap, 90-94 dap and 104-106 dap in triplicates, including clump height, number of tillers, panicles and spikes. Meanwhile, habitat conditions as independent variables i.e. soil (pH used pH meter, conductivity used conductivity meter, organic matters used Kurmies method, bulk densities used cylindrical method, porosity, cation exchange capacity (CEC) used percolation method and N content used Kjeldahl method), water quantities and weed communities (densities and biomass) were simultaneously observed with black rice growth measurement.



Remarks: Seventh variables including **age** (a1 = age class of black rice), **cultivation systems** (c1 = cultivated Laka black rice cultivar with planting distance 22 cm x 22 cm is scored 1 and cultivated Woja Laka black rice cultivar with planting distance 25 cm x 32 cm is scored 2), **water quantities** (f1 = irrigated water availability is scored 1 as flooded and scored 0 as unflooded), **soil** (s1 = pH, s2 = conductivity, s3 = bulk density, s4 = porosity, s5 = organic matters, s6 = nitrogen content, s7 = CEC), **weed communities** (w1 = biomass, w2 = % coverage) influenced **vegetative organ growth** variables (v1 = clump height, v2 = number of tillers), which in turn affected the **generative organ growth** variable of black rice (g1 = number of panicles, g2 = number of spikes).

Figure 1. Interaction model of environmental factors and black rice growth in irrigated organic paddy field

As many as 153 paired data were tabulated in MS Excel to create structural equation model of environmental factors with black rice growth by multivariate analysis using open source SmartPLS software (Ghozali, 2008; Solimun and Fernandes, 2008). The sequentially steps involved: (i) designing structural model (inner model) and measuring model, (ii) constructing path diagrams, (iii) converting path diagram to equations, (iv) estimating path coefficients, loading, and weight, (v) evaluation of goodness of fit and (vi) hypothesis examination by bootstrapping resampling method (500 number of samples) using t-test with α 5%. If t-statistics is higher than 1.96 then the model is significantly valid. Significant outer model shows that indicator is valid to form latent variables, and significant inner model shows that the interaction between the latent variables is valid. Goodness of Fit of structural model was determined by predictive-relevance (Q^2) value = $1 – (1 – R_1^2) (1 – R_2^2) ... (1- R_p^2)$, where R_1^2, R_2^2,... R_p^2 are R-square of latent variable in inner model.

RESULTS AND DISCUSSION

A structural model of black rice growth was arranged based on theoretical studies (Figure 1). Latent variables (sylindrical shapes) was composed by one or more indicators, as presented by rectangular shapes. Each variable is connected by an arrow as a form of interactions. Soil, water quantities, weed communities and cultivation system at the sixth age class influenced vegetative growth which in turn affected the generative growth of black rice.

Results for Outer Weight (Outer Model) Examination

Results for outer weight examination of black rice growth model showed pH (s1) and conductivity (s2) indicators, irrigated water availability (f1), weed biomass (w1), age class (a1) and planting distance (c1), which formed their each latent variables. Besides, latent variable of vegetative growth was formed by clumps height (v1) and generative growth was formed by number of spikes (g2) indicator (Table 1, Table 2 and Table 3).

Table 1. Results for indicators examination which formed latent variables

Variables	Original sample estimate	Standard deviation	T-statistic
Soil			
s1	0.798	0.101	7.911*
s2	0.324	0.126	2.573*
s3	-4.536	2.319	1.956
s4	-4.566	2.367	1.929
s5	-0.189	0.151	1.250
s6	0.223	0.110	2.027*
s7	-0.030	0.097	0.308
Water Quantities			
f1	1.000	0.000	
Weed Communities			
w1	1.068	0.321	3.323*
w2	-0.083	0.370	0.225
Vegetative Growth			
v1	0.972	0.109	8.894*
v2	-0.284	0.431	0.660
Generative Growth			
g1	-0.714	0.564	1.265
g2	1.449	0.417	3.475*
Cultivating System			
c1	1.000	0.000	
Age Class			
a1	1.000	0.000	

Remarks: * means significant (t-statistics ≥ 1.96)

Goodness of Fit of Black Rice Growth Model

The result of predictive-relevance (Q^2) value calculation of black rice growth structural model is 92.83% (Table 4). The value explains that 92.83% of black rice growth was influenced by all variables that included model, namely water quantities, soil condition, weed communities and cultivation systems, whereas 7.17% is explained by others which did not include the model (Figure 2). Due to the Q^2 value more than 80%, the model explains interaction between environmental factors and black rice growth properly.

Table 2. Results for repeating examination of outer model

Variable	Original sample estimate	Standard deviation	T-Statistic
Soil			
s1	0.826	0.072	11.416*
s2	0.252	0.104	2.430*
s6	0.119	0.080	1.495
Water Quantities			
f1	1.000	0.000	
Weed Communities			
w1	1.000	0.000	
Vegetative Growth			
v1	1.000	0.000	
Generative Growth			
g2	1.000	0.000	
Cultivating System			
c1	1.000	0.000	
Age Class			
a1	1.000	0.000	

Remarks: * means significant (t-statistics ≥ 1.96)

Results for Inner Model Examination

Results for inner *model* (*structural model*) examination showed that growth of vegetative organs (clump height) of black rice was directly influenced by the ages, water quantities, weed communities (biomass) and cultivating system. Then, growing vegetative organs influenced generative organs (number of spikes) growth. Meanwhile, soil properties (pH and conductivity) had indirect effect on black rice growth through growth of weed communities (Table 5 and Figure 2).

Table 3. Results for final examination of outer model

Variable	Original sample estimate	Standard deviation	T-Statistic
Soil			
s1	0.826	0.073	11.254*
s2	0.261	0.101	2.586*
Water Quantities			
f1	1.000	0.000	
Weed Communities			
w1	1.000	0.000	
Vegetative Growth			
v1	1.000	0.000	
Generative Growth			
g2	1.000	0.000	
Cultivating System			
c1	1.000	0.000	
Age Class			
a1	1.000	0.000	

Remarks: * means significant (t-statistics ≥ 1.96)

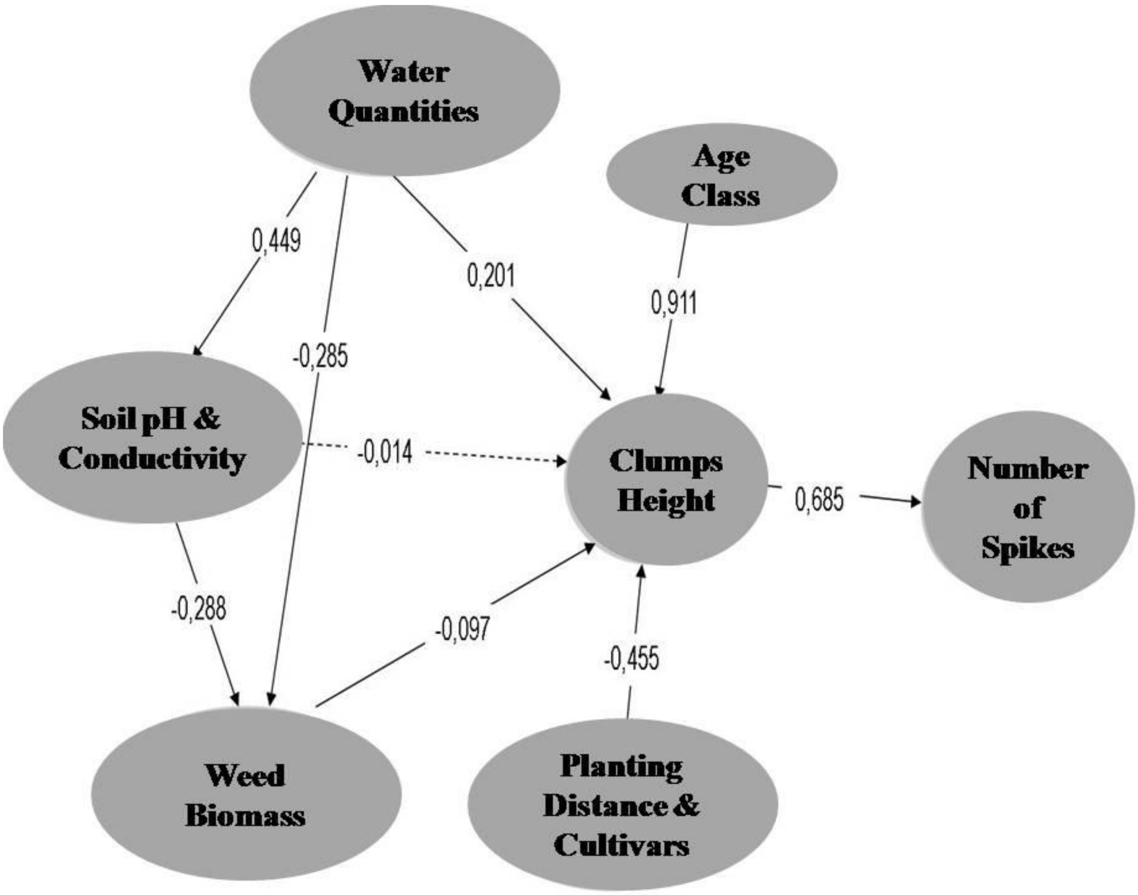
Table 4. Q^2 and R^2 value for goodness of fit examination

Variable	R-square	$1- R^2$
Water Quantities		
Soil	0.201	0.799
Weed Communities	0.238	0.762
Vegetative Growth	0.778	0.222
Generative Growth	0.470	0.530
Cultivating System		
Age Class		

$Q^2 = 1 – (1 – R_1^2) (1 – R_2^2) ... (1- R_p^2)$
$Q^2 = 1 – ((0.799) x (0.762) x (0.222) x (0.530))$
$Q^2 = 0,9283$ or 92.83%

Table 5. Results for direct effect between latent variables

Variable		Original sample estimate	Standard deviation	T-Statistic
Water Quantities	-> Soil	0.449	0.079	5.695*
Soil	-> Weed Communities	-0.288	0.058	4.967*
Water Quantities	-> Weed Communities	-0.285	0.079	3.598*
Soil	-> Vegetative Growth	-0.014	0.068	0.211
Water Quantities	-> Vegetative Growth	0.201	0.049	4.087*
Weed Communities	-> Vegetative Growth	-0.097	0.049	1.964*
Cultivating System	-> Vegetative Growth	0.455	0.043	10.640*
Age Class	-> Vegetative Growth	0.911	0.062	14.626*
Vegetative Growth	-> Generative Growth	0.685	0.038	17.974*



Remarks: Dash lines show that indirect effect of independent variables on dependent variable.

Figure 2. Model interactions of environmental factors with growth of black rice vegetative and generative organs.

Based on the model, water condition in paddy field was a key factor which directly and indirectly determined the growth and productivity of black rice. Flooded paddy field increased soil pH and conductivity, and it contributed to inhibition of weed biomass which in turn increased clump height of black rice and the number of spikes (Figure 2). Retnaningdyah and Arisoesilaningsih (2012) reported that the level of sodiums, clorides and bicarbonates on irrigation water around the organic paddy field was at range FAO irrigated water standart and Udayasoorian *et al*. (2009) added that high level of the cation increased soil pH and conductivity significantly.

Flooded condition on paddy field also directly decreased weed biomass grown around the black rice plants through their role on selecting weed species composition. *Pistia* sp., *Lemna* sp. *Salvinia* sp. *Monochoria* sp. and *Limnocharis flava* which have shallow root and low biomass were dominance in flooded paddy field, whereas grass species with deep rooted and high biomass were presented when the paddy field was unflooded. Therefore, flooded conditions at paddy field also increased the clump height and the number of spikes of black rice through their role on changing weed composition and decreasing its biomass around the crops (Figure 2).

Naharia *et al.* (2005) reported that paddy field which was flooded produced highest number of tillers and spikes than that with boggy and drought conditions. Sari-Gorla *et al.* (1999) also reported that drought conditions at paddy field have decreased rice production until 60%. It was caused by the rate of grain filling which was decreasing in drought conditions (Pringgohandoko, 2004).

The model also described that cultivation systems with wide spacing increased black rice growth. The paddy field of Laka cultivar with 25 x 32 cm spacing showed high growth of clumps and in turn increased the number of spikes. Meanwhile, Woja Laka cultivar planted with spacing of 25 x 25 cm had lower growth. Wider spacing provided broader space for black rice to grow maximally and reduced competition for nutrition uptake.

CONCLUSIONS AND SUGGESTIONS

Interaction model of environmental factors and black rice growth which was created is valid and has high relevancy value for prediction because the *predictive-relevance* (Q^2) value reached 92.83%. Flooded conditions at paddy field increased soil pH and conductivity and also decreased weed biomass which in turn increased clump height and the number of spikes of black rice. Cultivation system with wider spacing should be applied because it was able to increase black rice growth and productivity.

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