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Influence of furrow with organic material and *Chromolaena odorata* compost on upland rice productivity in an agroforestry system with *Melaleuca cajuputi*

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Abstract. *Suryanto P, Kurniasih B, Faridah E, Nurjanto HH, Rogomulyo R, Handayani S, Kastono D, Muttaqien AS, Alam T. 2020. Influence of furrow with organic material and* Chromolaena odorata *compost on upland rice productivity in an agroforestry system with* Melaleuca cajuputi. *Biodiversitas 21: 780-791.* The main problems of rainfed areas for upland rice cultivation in agroforestry system with *Melaleuca cajuputi* (*kayu putih*) were limited to soil moisture availability and low fertility of the soil. The experiment was conducted from March to August 2018 in Menggoran Forest Resort, Playen Forest Section, Yogyakarta Forest Management District, Indonesia. The experiment was arranged in strip plot design with three blocks as replications. The vertical plots were rainwater harvesting technique (RHT) consist of without furrow (WF) and furrow with organic material (FWOM). The horizontal plot was *Chromolaena odorata* (siam weed) compost (SWC) applications consist of 0, 5, 10, and 15 tons ha^{-1}. The data analyzed by ANCOVA, ANOVA, SEM, and stepwise regression. The results of the study informed that the FWOM with SWC of 10 tons ha^{-1} showed the highest yield of upland rice per hectare was 2.97 tons ha^{-1} and yields increased by 91.75% compared to the WF without SWC. The environmental variables that significantly affected the yield of upland rice were WUE and Tsoil. The growth variables that significantly affected the yield of upland rice were SDW, RSA, and RDW. The yield component that had a very significant affected on the yield of upland rice was NP.

Keyword: *Chromolaena odorata, Melaleuca cajuputi*, rainwater harvesting, soil moisture, upland rice

Abbreviations: RHT: rainwater harvesting technique, WF: without furrow, FWOM: furrowed with organic material, SWC: siam weed compost, SM: soil moisture, Tsoil: soil temperature, Kc: crop coefficient, ETa: actual evapotranspiration, Dp: deep percolation, WUE: water use efficiency, LAI: leaf area index, LDW: leaf dry weight, RDW: root dry weight, RL: root length, RSA: root surface area, SDW: shoots dry weight, NP: number of panicle, PL: panicle length, NSP: number of seed per panicle, PFGC: percentage of filled grain per clump, GW1000: 1000 grain weight, Yield: yield per hectare

INTRODUCTION

Rice production in Indonesia in 2014 was 70.83 million tons or decreased by 0.45 million tons (0.63%) compared to 2013. The decline in rice production in Indonesia is estimated to occur due to a decrease in the harvested area of 41.61 thousand hectares (0.30%) and a decrease in productivity of 17 kg ha^{-1} (0.33%) (BPS 2015). Based on the results of the study stated that the rate of conservation of rice fields in Indonesia amounted to 96,512 ha^{-1} per year so that the existing rice fields covering an area of 8.1 million hectares would be reduced to only around 5.1 million ha by 2045 (Mulyani et al. 2017).

One alternative to the development of rice is by utilizing space between *Melaleuca cajuputi* Powell (*kayu putih*) stands. The vacant space between *M. cajuputi* in a forest has the potential for growing annual crops. Therefore, the shade factor does not interfere with the cropping system. Intercropping in *M. cajuputi* forest can be done continuously for up to 30 years (Suwignyo et al. 2015).

The first problem with upland rice cultivation between *M. cajuputi* forest is the limitation of soil water content because the *M. cajuputi* forest is a rainfed area. Water scarcity limits the sustainable development of rainfed areas in semi-arid areas (Qin et al. 2014). Therefore, the key to increase agricultural productivity lies in the maximum utilization of rainwater. One way is to collect rainwater with rainwater harvesting techniques (Li 1997; Qin and Li 2005; Qin et al. 2013).

The practice of water management is aimed to increase limited water efficiency (Shan and Xu 1991). In recent years, several new technologies have been developed and adopted to improve crop yields, including rainwater harvesting, timely fertilization, application of organic fertilizers, and use of terraces in agroecosystems (Li et al.

1999; Qin et al. 2013; Wang et al. 2008). The results of the rainwater harvesting study conducted by Alam (2012) showed that the use of furrow with organic material was able to increase maize yield by 40.34% or 5.68 tons ha^{-1} compared to without furrow and organic material of 4.05 tons ha^{-1}.

The second problem related to upland rice cultivation in the *M. cajuputi* forest is low fertility of the soil. The results of the study by Suryanto et al. (2017) provide information that soil fertility in the research location classified as a low category which reflected in soil organic matters, available nitrogen, phosphorus, and potassium content of 2.26%, 117.70 ppm, 6.87 ppm, and 0.78 cmol $^{(+)}$ kg^{-1}, respectively.

Siam weed (*Chromolaena odorata* (L.) R.M.King & H.Rob.) is weeds with a perennial life cycle. Siam weed is a potential source to develop alternative organic material. Siam weed is a type of weed that is very difficult to control (Zachariades et al. 2009) and causes many problems on various agricultural and plantation lands (Muniappan and Bamba 1999; Zachariades et al. 2009). Siam weed is ranked as the fastest-spreading species after aquatic invaders (Wise et al. 2007). Siam weed grows wildly between *M. cajuputi* forest and has the potential to be used as a source of organic matters because of high biomass production.

Siam weed biomass has high nutrient content (2.65% N, 0.53% P, and 1.90% K) and the biomass is a potential source of organic matter to be used (Suntoro et al. 2001). Based on these considerations, it is necessary to conduct a study that integrates the management of rainwater harvesting technique and the application of siam weed compost. The results of the study expected to improve soil moisture content and soil fertility so that it can increase the productivity of upland rice between *M. cajuputi* stands.

MATERIALS AND METHODS

Study area with GPS point

The experiment conducted from March to August 2018 in Menggoran Forest Resort, Playen Forest Section, Yogyakarta Forest Management District, Indonesia. Menggoran Forest Resort is located ±43 km to the south-east from downtown Yogyakarta City (Figure 1) (Alam et al. 2019). Upland rice varieties used Situ Patenggang from the Indonesian Center for Rice Research (ICRR), West Java, Indonesia.

Agro-ecological condition of the research area

The altitude of the study site varies around ±100 meters above sea level. Total rainfall observed during the experiment was ± 407.00 mm with two wet months and three dry months. Air temperature average and the relative humidities were 25.54°C and 83.90%, respectively. The study site had an ustic soil moisture regime. Ustic is a soil regime containing limited moisture, but it suitable for plant growth when the environmental conditions favorable (Boettinger et al. 2015).

The interpretation of soil horizons in each soil profile at the site identified the soil type of Lithic Haplusterts. Lithic Haplusterts is a Vertisol soil type that has shallow solum and a lithic contact within 50 cm of the soil surface (Soil Survey Staff 2014). The seasonal cracking pattern pertains to non-irrigated soils. Cracks are >5 mm wide and extend through >25 cm of the upper 50 cm (Boettinger et al. 2015). Soil texture in the location was clay with drainage in the very poorly drained category. Water was available at 9.15%. CEC was included in the very high category, while pH H_2O included in the alkaline category. Soil organic matters, available N, P, and K included in the low category (Table 1) (Soil Survey Staff 2014).

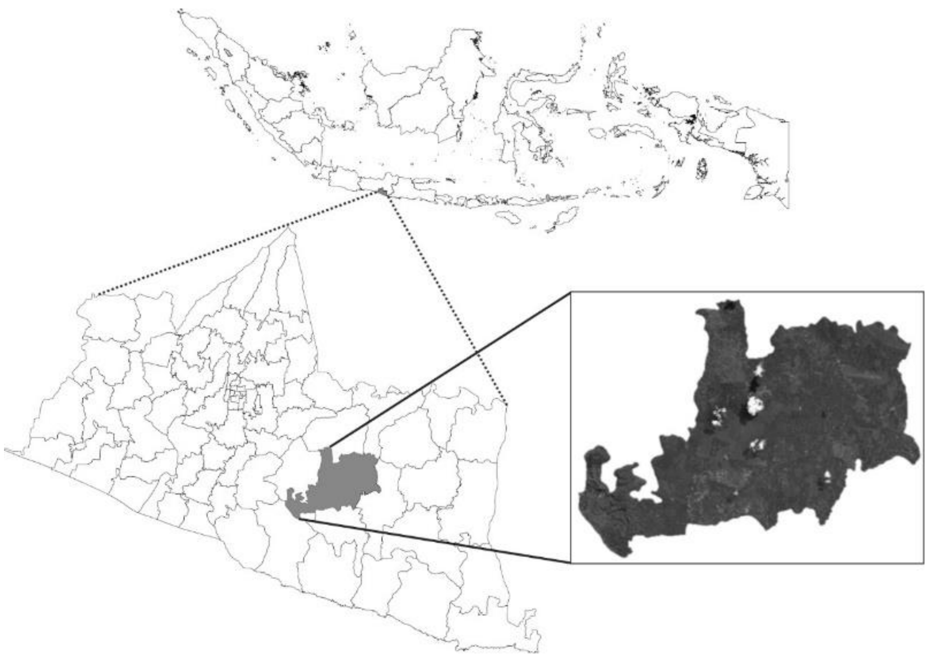

Figure 1. Geographical locations of the study area in Menggoran Forest, Yogyakarta Province, Indonesia (latitude 7º 52` 59.5992`` S to 7º 59` 41.1288`` S and longitude 110º 26` 21.462``E to 110º 35` 7.4868`` E)

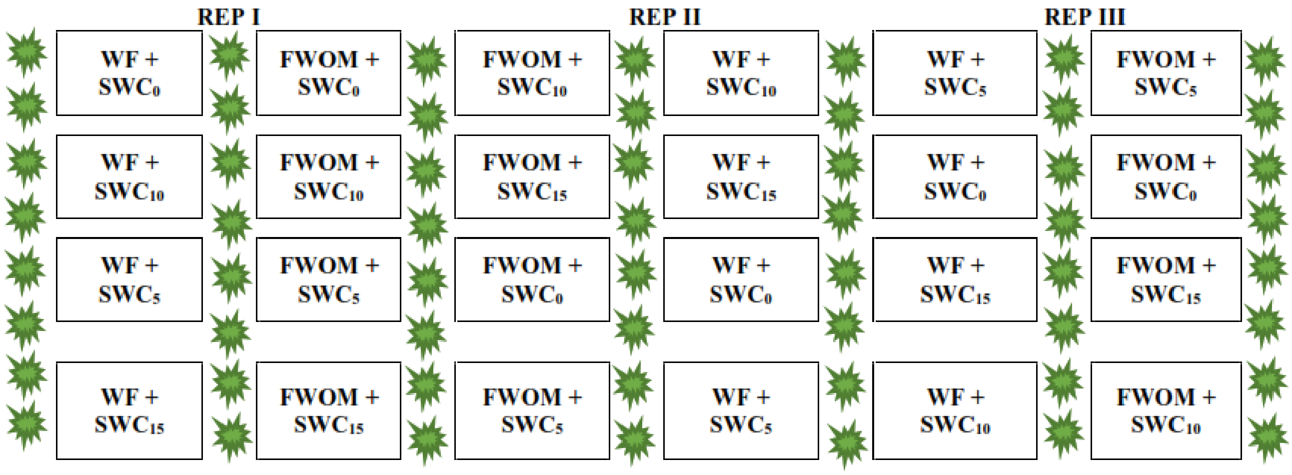

Figure 2. The arrangement of treatment plots based on strip plot design. WF: Without furrow, FWOM: Furrow with organic material, SWC_0: 0 tons ha^{-1} of siam weed compost, SWC_5: 5 tons ha^{-1} of siam weed compost, SWC_{10}: 10 tons ha^{-1} of siam weed compost, SWC_{15}: 15 tons ha^{-1} of siam weed compost. *ajuputi* stands

Table 1. Physical and chemical characteristic of soil in study area, Menggoran Forest, Yogyakarta, Indonesia (Alam et al. 2019)

Soil properties	Unit	Value	Notes
Physical characteristic			
Soil Texture:			
Sand	%	7.08	Clay texture
Silt	%	32.58	class
Clay	%	60.34	
Soil Moisture (pF):			
pF 0	%	55.83	
pF 2.54	%	48.54	
pF 4.2	%	39.39	
Bulk Density (BD)	g cm^{-3}	1.15	
Permeability	cm hour^{-1}	0.001	Very poorly drainage
Chemical characteristic			
pH H_2O	-	8.2	Alkaline
Soil Organic Matters (SOM)	%		Low
Cation Exchange Capacity (CEC)	cmol $^{(+)}$ kg^{-1}	58.83	Very high
Soil nutrient available:		2.6	
Nitrogen (N)	ppm	125.6	Low
Phosphorus (P)	ppm	18.8	Low
Potassium (K)	ppm	0.9	Low

Treatment and design

The experiment was arranged in Strip Plot Design with three blocks as replications. The vertical plots were rainwater harvesting technique (RHT) consisting of without furrow (WF) and furrow with organic material (FWOM). The horizontal plot was siam weed compost (SWC) applications consisting of 0 tons ha^{-1}, 5 tons ha^{-1}, 10 tons ha^{-1}, and 15 tons ha^{-1} (Figure 2).

The composting of siam weeds used the Traditional Method (Misra et al. 2003). SWC was applied on land when soil tillage following the treatment dose. Modification of furrow using the permanent materials, namely gutters equipped with capillary axes. The purpose of the capillary axis installation was to drain the water slowly from the furrow.

The furrow length was 50 cm, 12 cm wide, and 10 cm high. Furrow filled with organic materials until those from *in situ* plant residues from the previous crop. Each 10 m^2 area filled with four furrows. Upland rice planting was carried out by direct seed planting method. The number of seeds per planting hole was three seeds with a spacing of 40 x 10 cm. The recommended doses of Urea, SP-36, and KCl for upland rice were 200, 100, and 50 kg ha^{-1}, respectively (Yuliani et al. 2014).

Data collection and their procedure

Soil sampling and analysis

The measurement of soil involves physical and chemical characteristics. The soil variables observed were soil texture (Aubert et al. 1954), bulk density (Blake and Hartge 1986), soil moisture (pF 0, 2.54, 4.2) (Blake and Hartge 1986), permeability (Blake and Hartge 1986), pH H_2O (Van Reeuwijk 1993), CEC (Van Reeuwijk 1993; Hajek et al. 1972; Burt 2004), available of nitrogen (Stenholm et al. 2009), available of phosphorus (Olsen et al. 1954), and available of potassium (Burt 2004; Jones 1984). Observations were made on the site and in the General Soil Laboratory, Faculty of Agriculture, Universitas Gadjah Mada, Yogyakarta, Indonesia.

Soil moisture

Soil moisture (SM) determined by the gravimetric method (using the oven method at 110 °C to constant weight). Soil moisture recorded at 06.00–07.00 local times (LT), 13.00–14.00 LT, and 20.00–21.00 LT at two weeks intervals between planting and harvesting. The daily average of soil moisture calculated as the mean of the three times daily readings. Soil moisture was calculated using (Edy 2012; Alam 2014):

$$SM_{(i)h} = \frac{FW_{(i)h} - ODW_{(i)h}}{ODW_{(i)h}} \times 100$$

Where, $SM_{(i)h}$ is soil moisture content of the soil at the end of day i for the h^{th} layer (%weight); FW_h is soil sample weight for the h^{th} layer (g); ODW_h is oven-dry the soil at 110 °C to constant weight for the h^{th} layer (g).

The soil moisture content of the soil at the end of the day i (SM_i) computed as:

$$SM_i = \sum_{h=1}^{n} SM_{(i)h} \times BD_h \times D_h \times 10$$

Where, SM_i is soil moisture content of the soil at the end of day i (mm); $SM_{(i)h}$ is soil moisture content of the soil at the end of day i for the h^{th} layer (decimal, unitless); BD_h is the bulk density of the soil for the h^{th} layer (g cm^{-3}); D_h is the thickness of the soil for the hth layer in cm; 10 is conversion factor from cm to mm; BD_h is conversion factor from SM gravimetric methods to SM volumetric methods; n is the number of the soil layer.

Soil temperature

Soil temperature (Tsoil) observations using soil thermometers were carried out randomly in each experimental plot at a depth of 30 cm. Soil temperature recorded at 06.00-07.00 LT, 13.00-14.00 LT, and 20.00-21.00 LT at two weeks intervals between planting and harvesting. The daily average of soil temperature calculated as the mean of the three times daily readings (Edy 2012; Alam 2014).

Crop coefficient

Crop coefficient (Kc) was calculated using (Dwidjopuspito 1986):

$$Kc = (SM_{fc} - SM_{pw})/(SM_{sat} - SM_{pw})$$

Where, Kc is crop coefficient for the various stage; SM_{fc} is soil moisture content at field capacity (mm); SM_{pw} is soil moisture content at permanent wilting point (mm); SM_{sat} is soil moisture content at saturation (mm).

Actual evapotranspiration

Actual evapotranspiration (ETa) was calculated using (Dwidjopuspito 1986):

$$ETa_i = \frac{ASM_{i-1}}{ASMC} \times PET_i \times Kc_i$$

Where, ETa_i is actual evapotranspiration on day i (mm day^{-1}); ASM_{i-1} is available soil moisture at the end of day (i-1) (mm); ASMC is available soil moisture at field capacity (mm); PET_i is potential evapotranspiration on day i (mm day^{-1}); Kc_i is crop coefficient on day i.

Potential evapotranspiration (ETo) was calculated using (Raes 2012):

$$ETo = \frac{0.480\Delta(Rn-G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1+0.34U_2)}$$

Where, ETo is evapotranspiration (mm day^{-1}); Rn is crop surface net radiation (MJ m^{-2} day^{-1}); G is soil heat flux density (MJ m^{-2} day^{-1}); T is daily average air temperature at 2 m height (°C); U_2 is wind speed at 2 m height (m s^{-1}); e_s is saturation vapor pressure (kPa); ea is actual vapor pressure (kPa); e_s-e_a is saturation vapor pressure deficit (kPa); D is slope vapor pressure curve (kPa °C^{-1}); g is psychrometric constant (kPa °C^{-1}). PET was calculated by ETo Calculator software (Raes 2012).

Deep percolation

The deep percolation (Dp) was calculated using water balance equations. The water balance equation was calculated using the formula (Dwidjopuspito 1986):

$$SM_i - SM_{i-1} = RR_{i-1} - ETa_i - RO_i - Dp_i$$

Where, SM_i is soil moisture at the end of day i (mm); SM_{i-1} is soil moisture at the end of day (i-1) (mm); RR_{i-1} is total rainfall on day i (mm); ETa_i is actual evapotranspiration on day i (mm.day^{-1}); RO_i is runoff on day (mm); Dp_i is deep percolation on day i (mm).

Runoff was calculated using the rational equation as stated in (LMNO 2013):

$$Q = C \times I \times A$$

Where, Q is runoff (mm day ha^{-1}); C is the rational method runoff coefficient; I is rainfall intensity (mm $hour^{-1}$); A is the drainage area (ha).

Water use efficiency

The water use efficiency (WUE) was calculated using (Hussain and Al-Jaloud 1995):

$$WUE = \frac{Y}{ETa}$$

Where, WUE is water use efficiency (kg ha^{-1} mm^{-1}); Y is per hectare yield of rice (kg ha^{-1}), and ETa is the actual total evapotranspiration (mm) over the growing season.

Growth, yield component, and yield of upland rice variable

Growth observation, yield component, and yield of upland rice observed variables were root surface area (RSA) (Shabani and Sepaskhah 2017), root length (RL) (Shabani and Spaskhah 2017), root dry weight (RDW) (Wood and Roper 2000), stem dry weight (SDW) (Wood and Roper 2000), leaf dry weight (LDW) (Wood and Roper 2000), leaf area index (LAI) (Alam 2012), number of panicle (NP) (Yoshida 1981), panicle length (PL) (Yoshida 1981), number of seed per panicle (NSP) (Yoshida 1981), percentage of filled grain (PFG) (Yoshida 1981), 1000 grain weight (GW1000) (Yoshida 1981), and yield per hectare (Yield) (Yoshida 1981).

Statistical methods those were used in the research

The models must be evaluated so that assumptions can be fulfilled. The normality test was carried out using the Kolmogorov test and Q-Q plot (Mocanda et al. 2014). Analysis of covariance used for the relationship between RHT (qualitative factors) with SWC (quantitative factors) on environmental variables (Snedecor and Cochran 1967).

Two-way analysis of variance (ANOVA) utilized to test the environment, growth, yield component, and yield of upland rice toward RHT and SWC treatment and the separation of means was subjected to Tukey's HSD test α = 5% (Hinkelman and Kempthorne 2008). Structural equation modeling (SEM) was used to see the path coefficient and the cumulative effect of environmental variables, growth, and yield components on the yield of upland rice (Ghozali 2008; Fernandes 2008). Stepwise regression was used to see in detail the parameters of each variable that affects the yield of upland rice (Krall et al. 1975). All analysis was performed by using the PROC GLM and PROC REG in SAS 9.4 (SAS Institute 2013).

RESULTS AND DISCUSSION

Environmental conditions

The ANCOVA provides information that there was an interaction between RHT and SWC in the WUE while no interaction found in the SM, Tsoil, ETa, Dp, and Kc. SM, Tsoil, ETa, Dp, and Kc showed linear patterns in RHT with SWC. Increasing the dose of SWC in WF and FWOM could increase the values of SM, ETa, and Kc, whereas the opposite pattern observed in Tsoil and Dp (Figure 3).

SM, ETa, and Kc showed positive linear patterns on WF and FWOM with SWC. FWOM showed the highest values in SM, ETa, and Kc at SWC fertilization doses of 15 tons ha^{-1} with values of 45.49%, 1.50 mm day^{-1}, and 0.37, respectively. FWOM with SWC significantly increased the values of SM, ETa, and Kc by 6.77%, 119.54%, and 126.93% compared to WF without SWC. WF showed the highest values in SM, ETa, and Kc at SWC fertilization doses of 15 tons ha^{-1} with values of 44.15%, 1.19 mm day^{-1}, and 0.29, respectively. WF with SWC significantly increased the values of SM, ETa, and Kc by 4.73%, 84.24%, and 88.77% compared to WF without SWC (Figures 3.A, 3.C, and 3.D).

FWOM showed the lowest value in Tsoil and Dp at SWC fertilization doses of 15 tons ha^{-1} with values of 25.45 °C and 2.98 mm^{-1} day^{-1} plots^{-1}, respectively. FWOM with SWC markedly reduced Tsoil and Dp by 7.22% and 17.39% compared to WF without SWC. WF showed the lowest value in Tsoil and Dp at SWC fertilization doses of 15 tons ha^{-1} with values of 26.45 °C and 3.30 mm^{-1} day^{-1} plots^{-1}, respectively. WF with SWC markedly reduced Tsoil and Dp by 4.88% and 12.25% compared to WF without SWC (Figures 3.B and 3.E).

WUE showed a positive linear pattern on WF with SWC and showed a quadratic pattern on FWOM with SWC. FWOM showed the highest value on WUE at SWC fertilizer dosage of 10 tons ha^{-1} with a WUE value of 18.09 kg ha^{-1} mm^{-1}. FWOM with SWC significantly increased the WUE value by 361.55% compared to WF without SWC. WF showed the highest value at WUE at an SWC dose of 15 tons ha^{-1}. WF with SWC significantly increased the WUE value by 151.19% compared to WF without SWC (Figure 3.F).

Growth and yield performance of upland rice

The ANOVA provides information that there was an interaction between RHT with SWC on all growth variables of upland rice (Figure 4). FWOM with 10 tons ha^{-1} of SWC showed the highest value in RL of 1,691.33 cm. WF without SWC showed the lowest value of 816.48 cm. FWOM with 10 tons ha^{-1} of SWC increased RL by 107.15% compared to WF without SWC. In the RSA parameter, the FWOM treatment with 10 tons ha^{-1} of SWC showed the highest value compared while WF without SWC showed the lowest value with each value of 174.27 cm^2 and 66.02 cm^2 or an increased of 163.97% (Figures 4.A and 4.B).

RDW showed the highest value in FWOM with 15 tons ha^{-1} of SWC with a value of 25.45 grams clump^{-1}, while RDW in WF without SWC treatment showed the lowest value of 18.85 grams clump^{-1}. FWOM with 15 tons ha^{-1} of SWC increased RDW by 41.68% compared to WF without SWC. SDW and LDW showed the highest value on FWOM with 10 tons ha^{-1} of SWC with values of 44.15 and 24.21 grams clump^{-1} while WF without SWC showed the lowest value of 31.10 and 18.03 grams clump^{-1}, respectively. SDW and LDW increased by 41.96 and 34.28%. FWOM with 10 tons ha^{-1} of SWC showed the highest LAI value of 4.02, while WF without SWC showed the lowest value of 1.12. The percentage increased in LAI with FWOM treatment with 10 tons ha^{-1} of SWC against WF without SWC was 258.93% (Figures 4.C, 4.D, 4.E, and 4.F).

The ANOVA provides information that there was an interaction between RHT and SWC on all variable yield components and yield of upland rice (Figure 5). FWOM with 10 tons ha^{-1} of SWC showed the highest value in NP of 13.40 grains clump^{-1} while WF without SWC showed the lowest value of 7.06 grains clump^{-1} or an increase of 89.63%. In PL, the FWOM treatment with 10 tons ha^{-1} of SWC showed the highest value, while WF without SWC showed the lowest value with each value of 15.52 cm and 8.45 cm or increased by 83.56% (Figures 5.A and 5.B).

The NSP and PFGC parameters showed the highest value on FWOM with 10 tons ha^{-1} of SWC with values of 100.66 grains and 56.77%, respectively, while WF without SWC showed the lowest value of 47.06 grains and 47.39%, respectively. NSP and PFG increased by 1.14 and 0.20%. FWOM with 10 tons ha^{-1} of SWC shows the highest value on 1,000-grain weight of 15.52 grams while WF without SWC showed the lowest value of 5.45 grams or an increase of 179.78% (Figures 5.C and 5.D).

The FWOM treatment with 10 tons ha^{-1} of SWC showed the highest yield of upland rice value of 2.97 tons ha^{-1}, while the WF without SWC treatment showed the lowest value of 0.22 tons ha^{-1}. The percentage increased in yield of upland rice with FWOM treatment with 10 tons ha^{-1} of SWC was 91.75% (Figures 5.E and 5.F).

Relationship between environment, growth, and yield component variable to the yield of upland rice

The results of the SEM-PLS analysis provide information that generally the growth and yield component variables had very significant path coefficients on the yield of upland rice, namely ($p<0.001$) and ($p<0.000$). Environment, growth, and yield component variables showed a very significant total effect on yield ($p<0.000$) (Figure 6). The environment variable that had a very significant effect on the yield of upland rice were water use efficiency (WUE) and soil temperature (Tsoil) (Table 2). Growth variables that had a very significant effect on the yield of upland rice were shoot weight dry (SDW), root surface area (RSA), and root dry weight (RDW) (Table 2). The yield component that had a very significant effect on the yield of upland rice was the number of panicles (NP) (Table 2).

Discussion

The first problem with upland rice cultivation among the *M. cajuputi* forest is the limitation of the soil water content, which is very dependent on rainfall. The limitation of the soil water content has the potential to cause drought stress in cultivated plants (Alam 2012). Water is essential for plant growth and plant functions will be disturbed if the water is not enough. Plants are most susceptible to damage from water deficiency during the vegetative and reproductive stages of growth (Scherer et al. 2017). The soil and moisture conservation in the semi-arid regions. Drainage facilities may be required, especially in black soils (Magray et al. 2014).

Another problem is the low fertility of the soil. The type of soil at the study site is included in the order of Vertisol (Suryanto et al. 2017). These soils are often less productive and are observed to be mainly in areas where the population is suffering from low nutrition and high poverty (Moussadek et al. 2017). The environment variable that has a very significant effect on the yield of upland rice is water use efficiency (WUE) and soil temperature (Tsoil). WUE is the ratio between effective water use and actual water withdrawal. It characterizes, in a specific process, how effective is the use of water (FAO 2017).

Table 2. Stepwise regression for the determination of upland rice parameters affected of the treatments

Variable	Regression equation	R2
Environment	Y = 6.111* + 0.158 WUE** - 0.226 Tsoil*	0.991**
Growth	Y = -10.619** + 0.211 SDW** - 0.021 RSA** + 0.291 RDW**	0.999**
Yield Component	Y = -3.123** + 0.450 NP**	0.984**

Note: * significant level at $\alpha = 5\%$. ** = significant level at $\alpha = 1\%$.

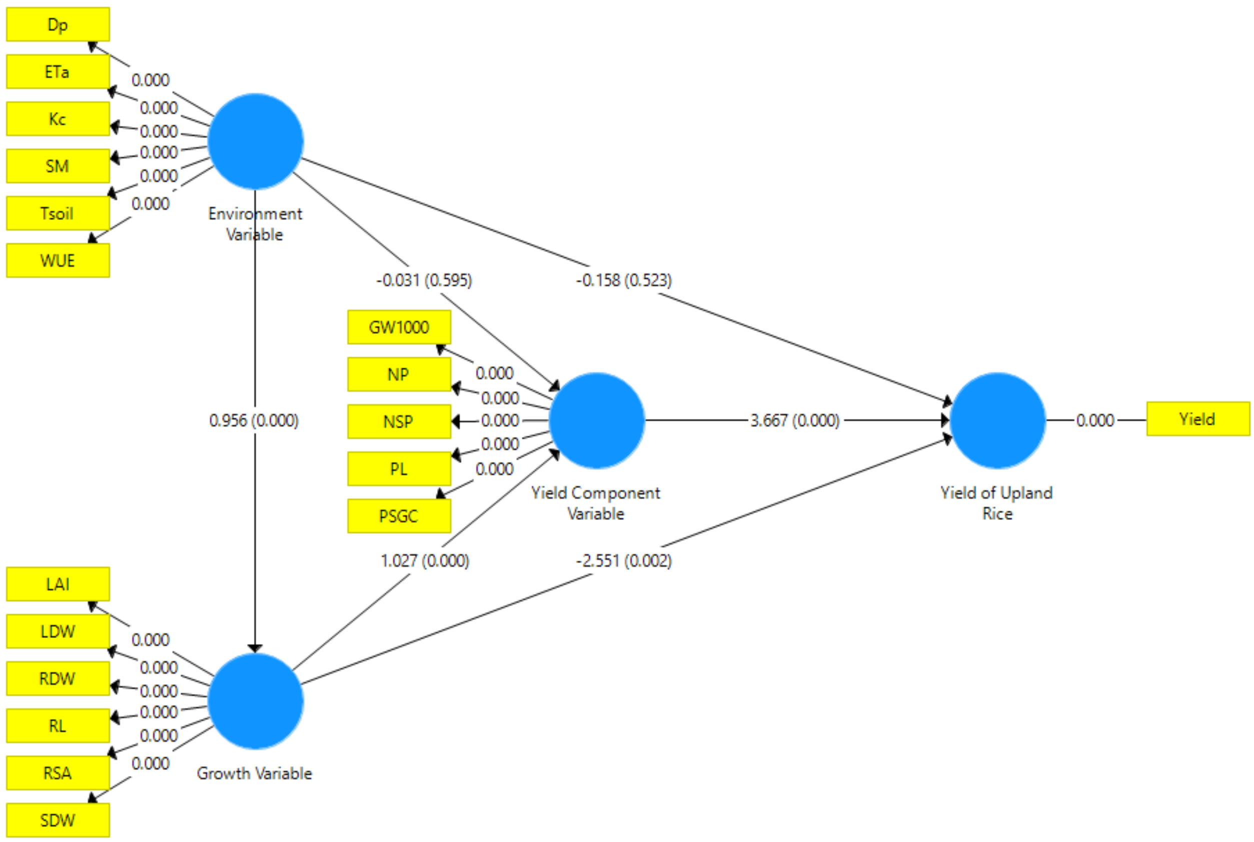

Figure 6. Structural equation modeling (SEM) of the relationship between environment, growth, and yield component variable on the yield of upland rice

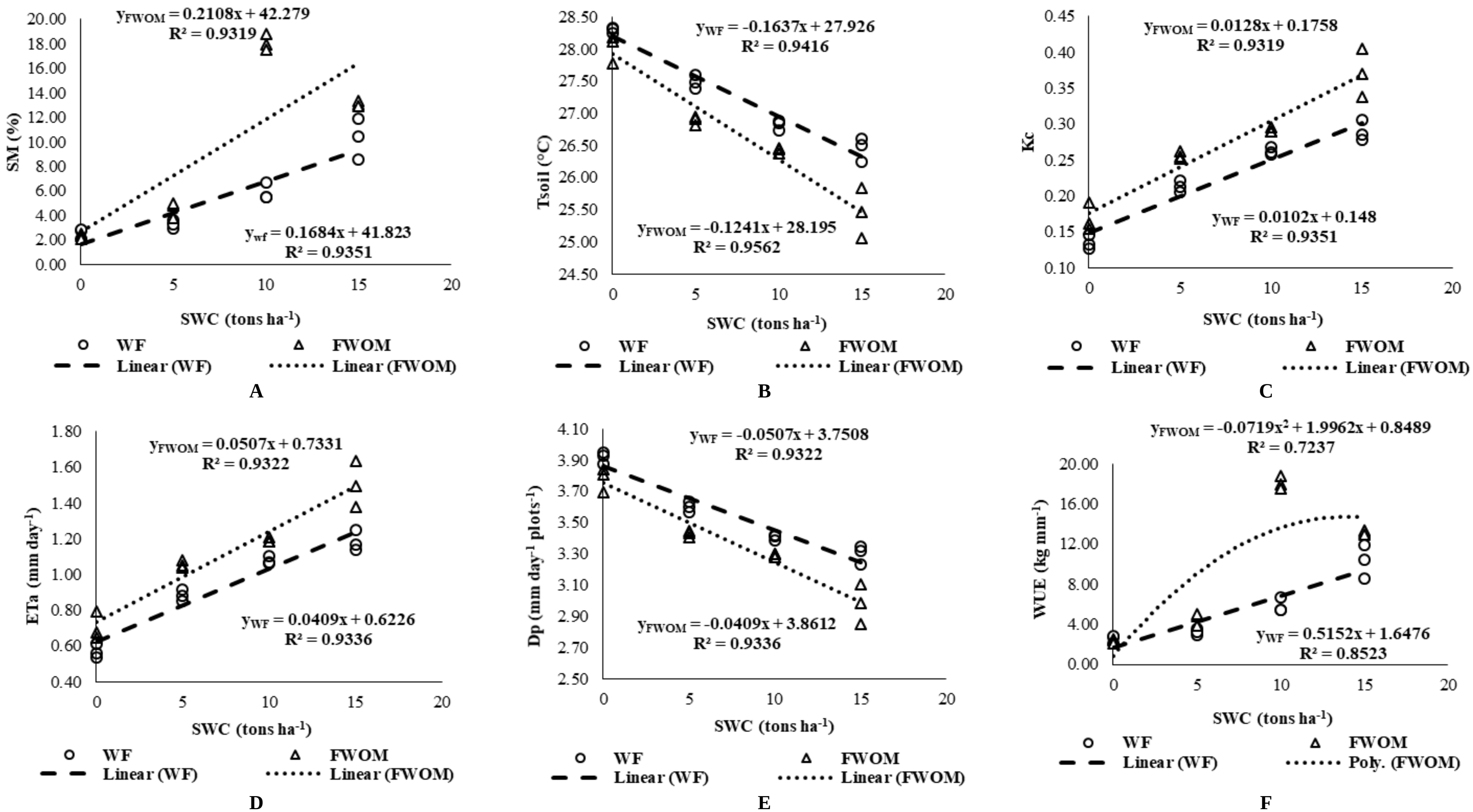

Figure 3. Analysis of covariance (ANCOVA) to the environment variable. A. Soil moisture (SM), B. Soil temperature (Tsoil), C. crop coefficient (Kc), D. Actual evapotranspiration (ETa), E. Deep percolation (Dp), and F. Water use efficiency (WUE)

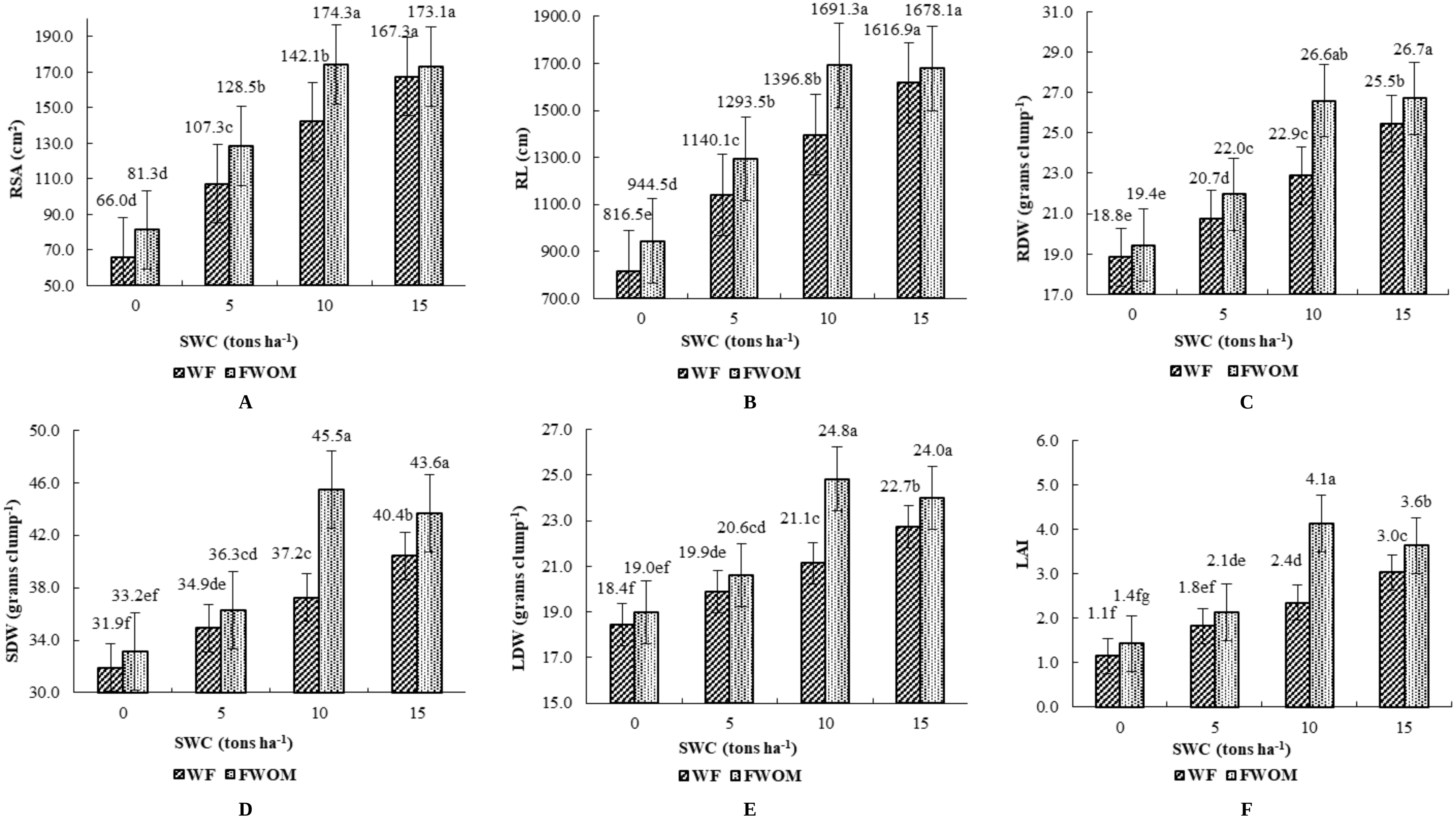

Figure 4. Values followed by the same lowercase letter are not significantly different according to HSD-Tukey (P < 0.05). The bars were indicated standard error of mean (SEM). A. Root surface area (RSA), B. Root length (RL), C. Root dry weight (RDW), D. Shoots dry weight (SDW), E. Leaf dry weight (LDW), and F. Leaf area index (LAI)

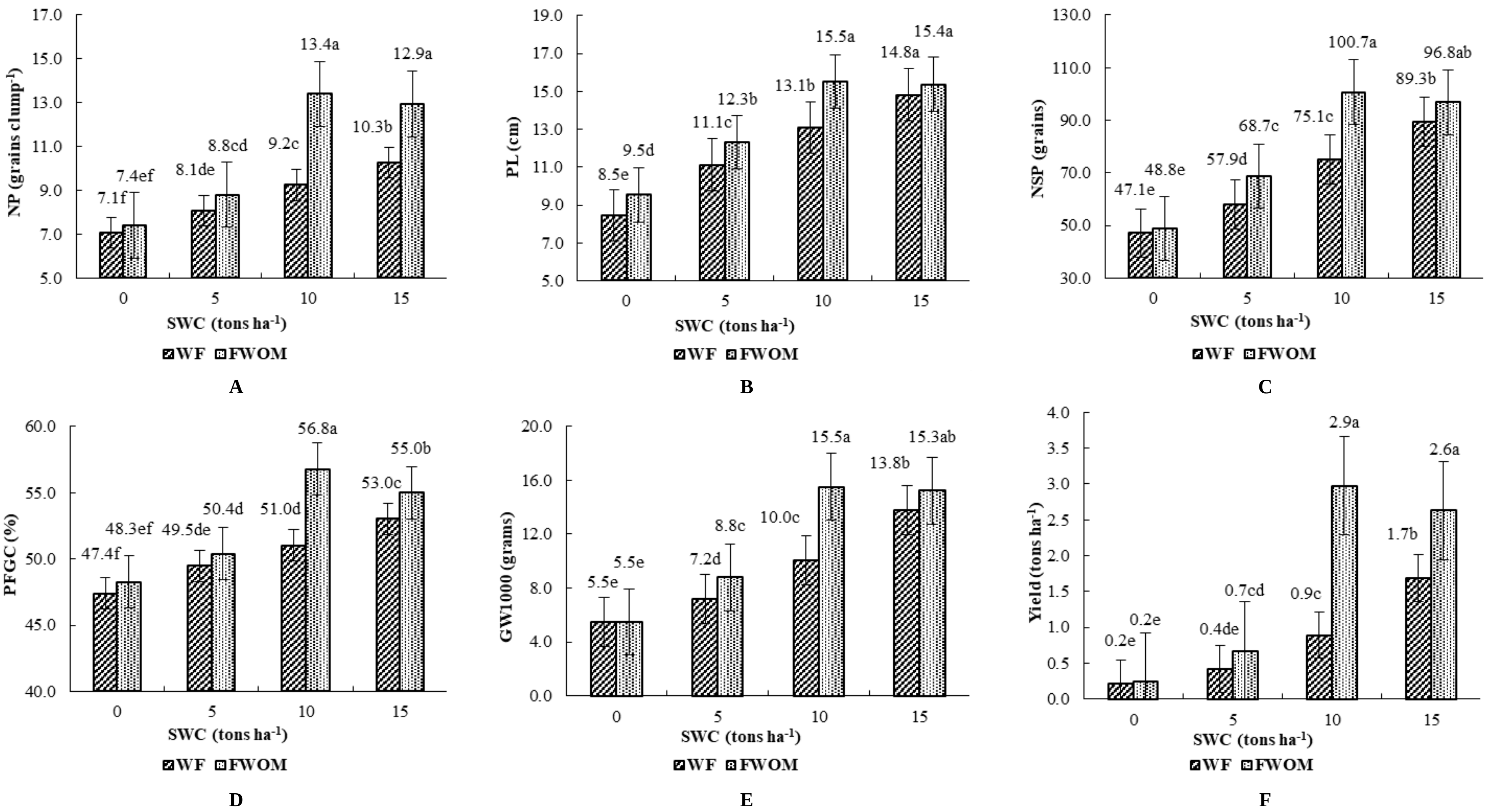

Figure 5. Values followed by the same lowercase letter are not significantly different according to HSD-Tukey ($P < 0.05$). The bars was indicated standard error of mean (SEM). A. Number of panicle (NP), B. Panicle length (PL), C. Number of seed per panicle (NSP), D. Percentage of filled grain per clump (PFGC), E. 1000 Grain Weight (GW1000), and F. Yield per hectare (Yield).

FWOM with 10 tons ha^{-1} showed the highest WUE value, then an increase in WUE was positively correlated with an increase in yield of upland rice. FWOM and SWC increased soil moisture content. Rennenberg et al. (2006) showed that maize yield was increased with ridge and furrow rainfall harvesting cultivation 82.8%, 43.4%, and 11.2%, respectively, while the water use efficiency increased by 77.4%, 43.1%, and 9.5% when compared with at cultivation without ridge and plastic. The findings in this research indicated that cultivation with ridge and furrow mulching further improved the soil moisture and temperature status. and it increased the maize yield and WUE by 1.6-15.0% and 1.8-15.7%, respectively. The use of furrow mulching was the same as using furrow with organic material because it has almost the same function for saving water.

Soil temperature is more influential than the air temperature on plant growth, photosynthesis, and respiration in the grass (*Agrostis palustris* Huds.) (Xu and Huang 2000). Increasing soil moisture content in the FWOM and SWC treatments lowers soil temperature. Very significant increase in Tsoil decreased the yield of upland rice. Tsoil in WF without SWC was 28.30ºC, and it will inhibit the growth of upland rice roots and will further reduce rice yield. Arai-Sanoh et al. (2010) provide information that the optimum temperature in the rice root zone was ± 25ºC.

FWOM with SWC decreased Tsoil by 26.04ºC compared to WF without SWC. FWOM with SWC increased moisture and nutrient availability in the soil. SWC used as a mulching material, it reduced bulk density and increased soil organic matter, nitrogen, phosphorus, potassium, calcium, and magnesium concentrations (Agbede et al. 2013). Application of SWC increased the activities of beneficial soil fauna in organic matter decomposition. Also, the mulch protects the soil, stabilize the soil structure against raindrop impact and thereby, preventing soil erosion and soil compaction (Olabode et al. 2007).

Growth variables that had a very significant effect on the yield of upland rice are root surface area (RSA), root dry weight (RDW), and shoot dry weight (SDW). FWOM with SWC significantly increased RL and RDW. FWOM with SWC increased the moisture content of the soil while increasing the nutrients in the soil. Soil moisture and nutrients used for root growth and development. Drought stress caused pronounced changes in root structure, such as increased branching and density (Eghball and Maranville 1993).

Low soil moisture in WF without SWC treatment causes drought stress in upland rice. Drought stress is a critical factor for plant growth and affects both elongation and expansion growth (Kusaka et al. 2005; Shao et al. 2008). Water deficit is one of the environmental stresses affecting agricultural production and productivity around the world and may result in considerable yield reduction. Among the crops, rice is probably more susceptible to drought as compared to other crops. Water stress reduces the leaf area, cell size, and intercellular volume (Kramer 1969).

High-temperature stress reduces root growth, number, and mass (Huang et al. 2012), which affects the growth of aboveground tissue by restricting the supply of water and mineral nutrients, affecting production of hormones synthesized in roots and transported to shoots, and altering sink-source relationships between shoots and roots (Huang et al. 2012; Rennenberg et al. 2006; Wahid et al. 2007; Hao et al. 2012).

The upland rice variable yield component that had a very significant effect on the yield of upland rice was the number of panicles (NP). The increase in NP was directly proportional to the increase in yield of upland rice. Upland rice with WF without SWC treatment had a low yield component because plants experience drought stress due to lack of moisture. Drought stress reduces the tiller number per plant in all rice genotypes (Singh et al. 2018). The number of tillers reduces due to reduced growth and photosynthesis processes of the plant (Quampah et al. 2011). Drought stress highly reduced yield and yield components of rice genotypes (Singh et al. 2018).

The yield of upland rice per hectare in the FWOM treatment with 10 tons ha^{-1} SWC showed the highest yield of 2.97 tons ha^{-1} while the lowest yield in WF without SWC treatment was 0.22 tons ha^{-1}. The treatment of FWOM with SWC increased the availability of moisture so that it prevents the rice from drought stress. The results of research related to rainwater harvesting systems to increased water infiltration were studies conducted by Vohland and Barry (2009) showing that in situ rainwater harvesting practices can improve crop yields.

These practices also explain how *Atriplex shrubs* under rainwater harvesting systems could survive for two or three successive dry seasons. Oweis and Hachum (2006) reported that *Atriplex shrubs* supported with rainwater harvesting bunds survived the three consecutive years of drought in the Badia and were still growing. In a similar rainwater harvesting system, Akhtar and Attila (2007) attributed the survival of *Atriplex* after the second dry year (44 mm rainfall), mainly to the drought tolerance of the shrub species rather than to the better soil water regime that had been created by the rainwater harvesting contour ridges.

Another function of SWC was increasing soil fertility. Sukartono et al. (2011) informed that siam weed when incorporated into the soil, can increase amounts of nitrogen, phosphorus, potassium, calcium, magnesium, and C/N ratio but not the soil pH. According to Tanhan et al. (2007), low C/N ratio means poor soil fertility, which leads to the reduction of microbial activities hence low nutrient mineralization due to the shortage of energy sources. The increase or decrease of some nutrients in the soil depends on soil pH, organic matter, and flooding (Flis 2008; Hesse 1971; Sillanpaa 1982; Welch et al. 1991; Shuman 1991).

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