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SOIL WATER BALANCE, BIOMASS AND YIELD OF POTATO CROP (*Solanum tuberosum* L.) GROWN IN HIGH ALTITUDE HUMID TROPICS OF INDONESIA

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ABSTRACT

This research was aimed at obtaining information about the dynamics of soil water content in potato cultivation at high altitude of Indonesia; its relation to rainfall, soil water loss through surface runoff and actual evapotranspiration using water balance calculations, and at finding the relationship between the availability of soil water content, crop growth and yield. The treatments consisted of two row spacings and three seed sizes for sowing. Soil water contents of six combination of treatments were measured weekly to the soil depth of 100 cm to calculate water loss by actual evapotranspiration and runoff. Water loss by ETa+Ro was much higher (average of 18.2 mm/day) compared to average potential evapotranspiration (7.5 mm/ day). Despite high rainfall during the growing season (1314 mm), actual evapotranspiration could reduce soil water content to 60 cm soil depth due to the high runoff caused by limited capacity of water infiltration into the soil. Total ETa+Ro average for all treatments was 1365 mm which was comparable among treatments. Higher soil water content resulted in larger crop biomass and higher tuber yield. On the other hand, larger seed size produced greater crop biomass and tuber yield irrespective of the variation of soil water contents in the treatments.

Key words: potato, crop, evapotranspiration, runoff, soil, water.

INTRODUCTION

Potato crops in Indonesia are generally cultivated at altitudes higher than 800 m (Sutapradja 2008). The total area of potato in Indonesia is about 60,000 ha with the largest areas in six provinces namely West Java, Central Java, East Java, North Sumatera, West Sumatera and South Sumatera (Nurtika *et al.* 2008). Since the planting

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is conducted in mountainous areas with high slope, water often becomes a serious problem in the rainy season due to large surface runoff. On the other hand, in the dry season, low soil water content becomes a limitation to support crop growth. Therefore, determining the proper planting time to get adequate water is needed to fullfil supply crop water requirement, while minimizing water loss through surface runoff is an important alternative for potato crops. Information is needed to understand the dynamics of soil water content in relation to rainfall and water loss through runoff and evapotranspiration. Such information can be obtained through the analysis of water balance in potato fields that requires input of rainfall data and soil profile of water contents during potato growth.

Potato roots can reach soil depths more than 80 cm making the crop more resistant to water stress because it can absorb water reserves in deeper soil layers in addition to the more efficient delivery of irrigation water (Stalham and Allen 2001). Research conducted in Turkey with a daily temperature range of 7-25 °C found that the influence of irrigation on potato is very significant, however, water loss through evapotranspiration at full irrigation treatment can achieve the range of 382-473 mm, whereas in the control (without irrigation) only 166-226 mm (Onder *et al.* 2005). Fabeiro *et al.* (2001), Ferreira and Goncalves (2007) and Unlu *et al.* (2006) also found that tuber yield increased in response to more water use (*i.e.* water loss) by the crop.

This study aimed at obtaining information on the dynamics of soil water content in potato cultivation areas; its relation to rainfall, soil water loss through surface runoff and actual evapotranspiration using water balance calculations. Further analysis was also conducted to find the relationship between the availability of soil water content and crop growth and yield.

MATERIALS AND METHODS

Time and Place

The study was conducted from December 2009 to March 2010 at Biogenetics Field Research Station, Pacet-Cipanas, Cianjur Regency, West Java, Indonesia. The potato field used has a slope of about 20%. Potatoes were planted on December 14, 2009 and harvested on March 25, 2010.

Materials and Equipment

The materials used were: (1) Granola cultivar, G0 seed potatoes; (2) organic fertilizers (Urea, KCl, SP-36) and inorganic substances like manure or straw; and (3) insecticides to control pests and plant diseases. The tools used were: (1) potato farming equipment such as: hoes, machetes, shovels, rakes, buckets, drums, hoses supplier of water, plastic bags, rope, knives, stakes; (2) soil moisture content measuring device comprising from the ring sampler, soil drilling, soil moisture content sensors at various depths (0, 10, 20, 40, 60, 80 and 100 cm); (3) automated weather station placed at the experimental site.

Experimental Design

The treatment consists of three seed sizes (U1, U2 and U3) and two row spacings (J1 and J2). The experiment employed a split-block design with three replications, and spacing as the main plot. The treatments of seed size (U) and row spacing (J) were as follows:

U : seed weight of 1.5 - 3.5 grams
U2 : seed weight of 0.5 - 1.5 grams
U3 : seedling weight less than 0.5 grams

J1 : spacing of 20 cm x 20 cm or 3 rows each plot with width of 80 cm
J2 : spacing of 40 cm x 20 cm or 2 rows each plot with width of 80 cm

Data of measured soil water content (θ_v) and electrical resistance (R) were plotted and the calibration curve was derived using the relevant equation.

Measurement of Infiltration Rate

Infiltration rates were measured once during the crop growing period for each soil depth (0, 10, 20, 40, 60, 80 and 100 cm) to represent the entire experimental plots. Measurements were taken on February 17, 2010. Soil was dug up using a hoe to different depths of measurements, then infiltration rate was measured using a stopwatch and a single-ring infiltrometer at each soil depth.

Plant Measurements

Measurements of crop biomass (roots, stems and leaves) were carried out simultaneously with measurements of soil moisture contents. Biomass was measured by collecting plants samples from each treatment and replication, and then the samples were dried using an oven at 80 ^{o}C for 24 hours and subsequently weighed using an analytical balance. Measurements of crop biomass were conducted weekly from January 9, 2010 to February 3, 2010 after which no plant samples were collected until tuber yields of all treatments were measured at harvest on March 25, 2010. Measurements of tuber yields were conducted for all plants in each treatment and replication which were then calculated in kg/m^2.

Water Balance

Water balance calculation was based on input and output of water on the potato crop land of each treatment, as follows :

$$\theta_t = \theta_{t-1} + P_t - (ETa_t + Ro_t) \quad (1)$$

Therefore,

$$ETa_t + Ro_t = \theta_{t-1} - \theta_t + P_t \quad (2)$$

Eta_t : actual evapotranspiration at day t (mm)
Ro_t : surface runoff at day t (mm)

θ_t : soil water content at day t (mm)
θ_{t-1} : soil water content at day t- 1 (mm)
P_t : daily rainfall at day t (mm).

RESULTS

Soil Water Content and Water Balance

Soil water content profiles of various treatments show considerable variation between treatments (Fig. 1). In general, the large changes in soil water content occurred from soil surface to the depth of 60 cm. Under soil depth of 60 cm the changes in soil water content were small, and at 100 cm depth there was almost no change in soil water content. This phenomenon was associated with the infiltration rate that decreased with soil depth (Fig. 2). At soil depth to 10 cm, the infiltration rate was as high as 75 cm $hour^{-1}$, while at the depth of 60 cm the rate was reduced to less than 20 cm $hour^{-1}$. At the depth of 100 cm, the rate was even less than 10 cm $hour^{-1}$.

As soil water movement to soil layer below 100 cm was small, therefore, we could calculate cumulative water loss through actual evapotranspiration (ETa) and surface runoff (Ro) by employing water balance approach presented in Table 1. However, by this approach we were unable to calculate ETa and Ro separately. The cumulative water loss (ETa+Ro) of all combination of treatments ranged from 1273 mm to 1415 mm (*i.e.* for the period of 75 days). Row spacing treatment did not cause significant difference in water loss between J1 and J2 with the value of (1392 $\pm$ 110) mm and (1338 $\pm$ 17) mm, respectively. Moreover, all combination of treatments did not cause significant difference in the water loss with an average of (1365 $\pm$ 76) mm. Thus, we consider water loss of each treatment could be represented by the averaged ET+Ro of all treatments. This amount of water loss was higher than cumulative rainfall during the same period (1314 mm) as shown in Fig. 3.

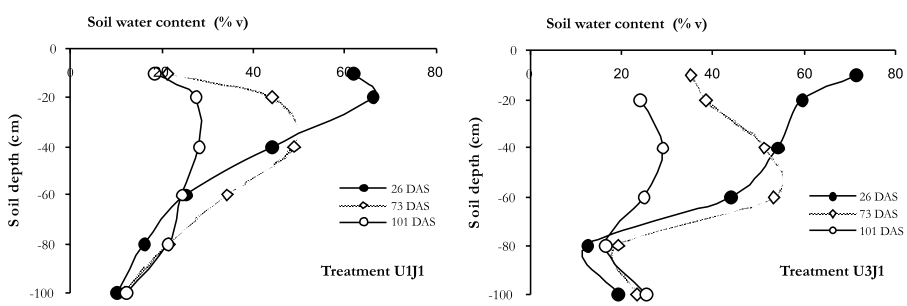

Figure 1. Profiles of soil water content from two treatments up to 1 m depth at three times of measurements (days after sowing, DAS).

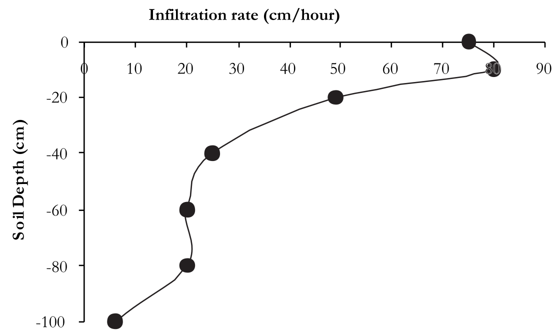

Figure 3. Infiltration rate of saturated soil at different depths.

Table 1. Comparison of water balance components among combinations of treatments during the experiment.

No	Water Balance Components	Treatments					
		J1			J2		
		U1	U2	U3	U1	U2	U3
1	Cumulative Rainfall (mm)*	1314	1314	1314	1314	1314	1314
2	Initial soil water content (mm/m)*	218	197	215	116	256	197
3	Final soil water content (mm/m)*	319	232	390	148	291	202
4	Δ SWC (mm/m)**	-101	-35	-175	-32	-35	-5
5	ETa+Ro (mm)***	1415	1273	1489	1347	1350	1319
	ETa+Ro (mm)*** by J1 and J2		[1392 ± 110]			[1338 + 17]	
6	Treatments						
7	Averaged ETa+Ro (mm)***			[1365 ± 76]			

Note
* First measurement was at 26 days after sowing (DAS) and last measurement at 101 DAS
** Change in Soil Water Content
*** ETa (actual evapotranspiration) and Ro (runoff)

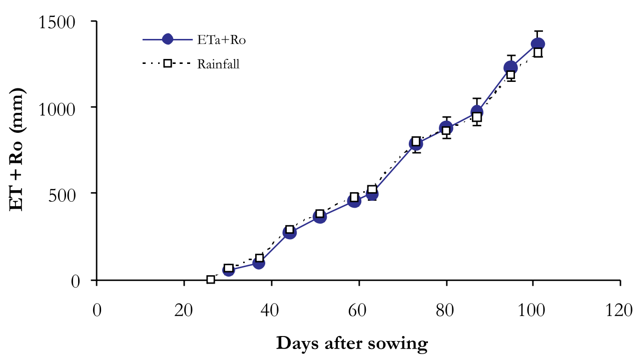

Figure 3. Cumulative water loss (ETa+Ro) and rainfall during the potato growth measured during DAS 26-101. [vertical bars indicate standard deviations]

Soil Water Balance, Crop Biomass and Yield

Total soil water contents to a depth of 100 cm for all combinations of treatments which changed with the course of time are presented in Figure 4. Soil water content at row-spacing treatment of J1 ranged from 215 to 431 mm, while at J2 ranged from 116 to 315 mm. Hence, the soil water content of J1 was generally higher than that of J2; and this corresponds to larger crop biomass at J1 compared with J2 (Fig. 5) and tuber yield (Fig. 6). On the other hand, larger seed size produced bigger crop biomass (Fig. 5) and greater tuber yield (Fig. 6) irrespective of soil water contents between treatments as shown in Figure 4.

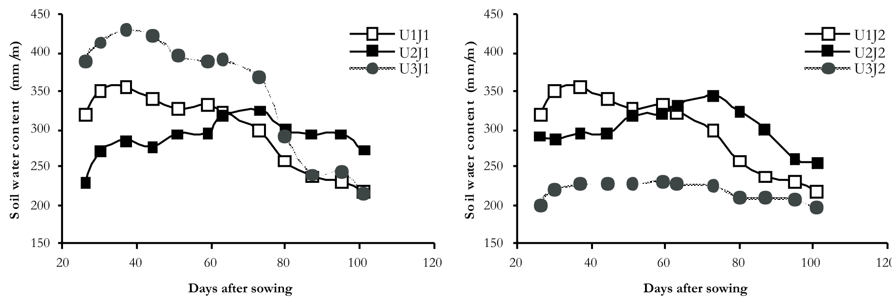

Figure 4. Total soil water content of various treatments up to 1 m depth over time.

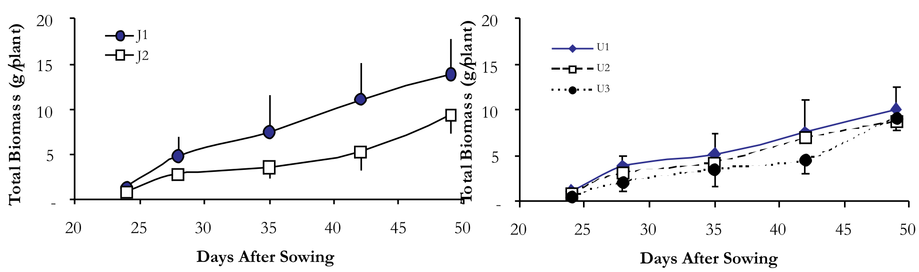

Figure 5. Crop biomass at J1 and J2 treatments (left) and at U1, U2 and U3 treatments (right) with the course of time. [vertical bars represent standard deviations]

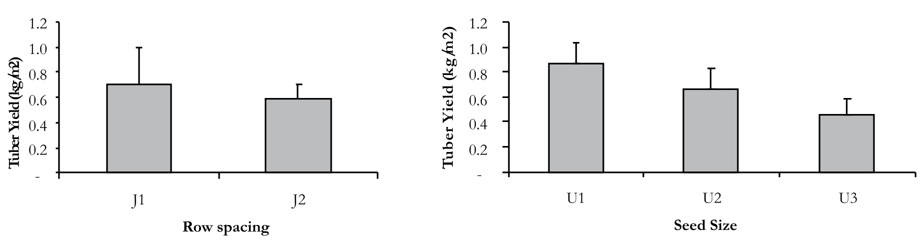

Figure 6. Tuber yield at harvest at J1 and J2 treatments (left) and at U1, U2 and U3 treatments (right). [vertical bars represent standard deviations]

DISCUSSIONS

Profiles of soil water content (Fig. 1) suggest that large changes of soil water content that occurred near the soil surface corresponded to crop water uptake at the rooting zone. Change of soil water content in deeper layers (more than 60 cm deep) were less than 5 %v associated with much lower infiltration rate (< 20 cm/hour) compared to that of near the soil surface (> 70 cm/hour). We may derive ETa+Ro from Figure 3 resulting daily ETa+Ro equaled to 1365 mm/75 days = 18.2 mm/day which was much higher than averaged potential evapotranspiration (ETp) calculated by Thornthwaite method at the experimental site of 7.5 mm/day. The big difference between ETa+Ro and ETp (10.7 mm/day) was due to large surface runoff (Ro) that occurred during the crop growth associated with the slope of the experimental site (20%). These suggest that rainfall water that reached soil surface did not infiltrate into deeper soil layers as much as which was lost through surface runoff. Ferreira and Carr (2002) found that total evapotranspiration (ETa) of potato crop in hot dry climate of northeast Portugal was in the range of 150-550 mm depending on irrigation treatment and duration of growing season. This range is comparable to that found by Onder *et al*. (2005) in the range of 166-473 mm; but is much less than total water loss found in this experiment (ETa+Ro =1365 mm) indicating large amount of surface runoff (Ro). In this relation, more cumulative water loss of ETa+Ro (1365 mm) than rainfall (1314 mm) caused decreasing soil water content in all combinations of treatments (Fig. 4), particularly to the soil depth of 60 cm (Fig. 1). The decreasing soil water content occurred in all treatment combinations of treatments after DAS 70 (Fig. 4) when cumulative water loss exceeded the rainfall (Fig. 3).

The soil water content of J1 (215-431 mm/m) which was generally higher than that of J2 (116-345 mm/m) provided more available water to crop growth of J1 that may explain bigger crop biomass and slightly higher crop yield of J1 than J2 (Fig. 5). This is consistent with Ierna and Mauromicale (2006) who found that decreasing water supply resulted in lower tuber yield in a Mediterranean environment irrespective of planting date. On the other hand, Ahmadi *et al*. (2010) argued that the difference in crop biomass and tuber yield was probably caused by the sensitivity of potato to drought stress due to its sparse and shallow root system. This statement was, however, contradictory with Stalham and Allen (2001) who suggested that potato roots could reach to 80 cm depth allowing to survive water shortage.

The higher soil water content of J1 than J2 was not, however, due to different row spacing between J1 (20cm x 20cm) and J2 (40cm x 20cm) because J1 and J2 had comparable water losses (ETa+Ro). The different range of soil water contents was due to soil water contents that had already been different between combination of treatments since the beginning around sowing time (Fig. 4). However, higher soil water content did not necessarily correspond to bigger crop biomass when the sown seed was less in size. Larger seed size (U1>U2>U3) resulted in larger crop biomass (Fig. 5) as also shown by Sutapradja (2008) for potato with the same cultivar grown at 1250 m altitude in Lembang, West Java, Indonesia. A larger crop biomass generally represents a higher growth rate of the crop which finally results in a higher crop yield. This explains higher total tuber weight at harvest for bigger seed size as shown in Figure 6. This finding is consistent with that has been reported by Engels *et al.* (1993) that bigger seed size resulted in greater tuber number per area and mean weight per tuber; and resulting to higher tuber yield (*i.e.* total tuber weight). Engels *et al.* (1993) also found that tuber yields were positively correlated with number of stems per area. Bigger seed would probably produce more stems which explains the correlation between seed size and tuber yield.

CONCLUSIONS

Changes in soil water content was associated with rainfall, surface runoff, and crop water uptake (evapotranspiration) which occurred to 60 cm soil depth. Below the depth of 60 cm, changes in soil water content was relatively small which was also associated with less infiltration rate at deeper soil layers.

The water balance calculations in this study produced water loss value in the form of the sum of actual evapotranspiration (ETa) and runoff (Ro). The large value of ETa+Ro (18.2 mm/day) suggests that runoff was relatively high, greater than potential evapotranspiration (7.5 mm). The large runoff was caused not only by high rainfall but also by the limited soil infiltration rate at the soil surface as well as its diminishing rate with the soil depth.

Soil water contents were highly varied between treatments that corresponded to biomass differences of potato between row-spacing treatments (J1 and J2). J1 treatment (20 cm x 20 cm) had higher soil water content than J2 (40 cm x 20 cm) resulting to a larger biomass and higher tuber yield (J1>J2) although the differences in soil water content was not caused by the treatment, but rather caused by initial soil water content at sowing. However, larger seed size caused bigger biomass resulting to higher tuber yield (U1> U2> U3), irrespective of the variation in soil water contents of the various treatments.

Overall findings suggest that growth and yield of the potato crop are the result of the interaction between the available soil water content and initial crop condition represented by its seed size for sowing. Larger crop biomass and higher tuber yield will be produced when soil water content is more available and the seed size is bigger.

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