J. Basic. Appl. Sci. Res., 3(7)920-927, 2013
© 2013, TextRoad Publication

ISSN 2090-4304
Journal of Basic and Applied Scientific Research
www.textroad.com

Soil Moisture Balance in The Root Zone Under Different Cropping Systems at Pecatu Village, Bali-Indonesia

[1,2,*]I Made Sukerta, [1,3]Sugeng Prijono, [1,4]Roedy Soelistyono, [1,3]Soemarno

[1]Doctoral Program of Agriculture Sciences, Faculty of Agriculture, University of Brawijaya, Indonesia
[2]Department of Agro-technology, Faculty of Agriculture, University of Mahasaraswati Denpasar, Indonesia
[3]Department of Soil Science, Faculty of Agriculture Agriculture, University of Brawijaya, Indonesia
[4]Department of Agronomy, Faculty of Agriculture, University of Brawijaya, Indonesia

ABSTRACT

The actual crop evapotranspiration can be estimated by using the equation of soil moisture balance on the experimental plot under different cropping system. Field research was conducted during October 2010 to June 2011 on dry lands of Pecatu village, Badung. Cassava is planted in intercropping system on rainy season; groundnut is planted on the first dry season after harvest time of maize. The measurement of soil moisture content used the gravimetry method and by using tools of The Neutron Probe Type IH2 DIDCOT Wallingford, England. Total of soil moisture storage was calculated until the soil depth of 45 cm. Deep percolation was assumed as zero and surface run-off was estimated by using the method of SCS-USDA. Evapotranspiration of intercropping system was higher than monoculture system. Total of rainfall (P) on the cassava cropping (UK) was 2,416.50 mm and run-off (R) was 507.96 mm, and the gradient of soil moisture storage (ΔS) was 821.20 mm, so cropping water requirement (ET) of cassava was 1,087.34 mm. Rainfall (P) and run-off (R) in the casava cropping on the UKJ and UKJKT were the same, but ΔS on UKJ treatment was 819.65 mm and on UKJKT treatment was 798.55. Rainfall in groundnut cropping on UKJKT treatment was 1,169.40 mm, run-off (R) was 250.52 mm, and ΔS was 439.14 mm, so crop water requirement of groundnut with UKJKT treatment was 479.74 mm. Tuber yield of cassava on UK treatment was 24.19 ton/ ha, on UKJ treatment was 23.94 ton/ ha, and on UKJKT treatment was 22.54 ton/ ha. Grain yield of maize on UKJ and UKJKT treatments were 5.44 ton/ ha. However grain yield of groundnut on UKJKT treatment was 0.17 ton/ ha. Results of this research suggest that intensity of dryland use can be improved by optimizing the soil moisture storages.

KEYWORDS: soil moisture balance, soil moisture storage, evapotranspiration

INTRODUCTION

Drought has given the impact to design, planning, and management of infra structure on water supply. Drought is defiened as the period that water demand and supply are not sufficient to fullfill normal water demand [1]. Cropping management in dry land is generally restricted by water supply because the water supply is very depended on the rainfall and water holding capacity. Results of some studies in many institutions presented the prediction and estimation of water resource dynamic in long term period and its using, and giving more variations of anticipation to the water resource in the coming period [2]. The prediction and estimation are intended to analyze the soil moisture content, water resource demand, and the using ability of soil moisture.

Development of plantation on dry land in Indonesia is faced to some constraints as biotic as well as economic social and main limitation factor of growing such as the lower soil fertilization and inavailibility of water along the year. Therefore, water availability becomes as the important thing on the management of dry land. Water availibility in dry land is generally influenced by rainfall and soil ability for holding water. The possibility to increase crop yield in dry land agriculture is emphazied on how to maximaze the yield per-unit water [3]. There was the relation between crop water requirement and yield [4][5][6][7] which expressed that the relation between crop yield and water supply could be in variety on some intensitied and frequencies, and there were very complex. In addition, the high temperature and rainfall distrbution was not in average and soil susceptibility to the erosion has increased the complexity of problem. Economic social constraint which very determines the development of dry land includes poverty, stupidity, weak infra structure, etc. Based on the data of statistical report in 2009, the quantity of dry land in Indonesia was about 73.4 ha. This quantity was involving about 65.7 millions ha (90.5%) of dry land and about 7.7 millions ha (9.5%) of rice irrigated area. The dry land included not irrigated field, garden, arable land, or dry field of about 14.9 millions ha, big plantation (public and state) of 19.6 millions ha, yard of about 5.6 millions ha, dyke or pool of about 760 thousands ha, etc (it was cropped by wood and or while it was not producted and as the steppe) of 2.9 millions ha. The very wide dry land area is as the big enough of resources, but until now all of them have not been to be optimally empowered.

Soil water balance illustrates correlation between water input, output, and changes of soil moisture storage in a certain period. Water balance only illustrated the water volume and it does not consider any water qualities.

***Corresponding Author:** I Made Sukerta, Department of Agro-technology, Faculty of Agriculture, University of Mahasaraswati, Denpasar, Bali, Indonesia. Email: guntur_unmas@yahoo.co.id

Water input is as content change of soil moisture which comes from rainfall, irrigation water, and capilary water from saturated zone. However, water output is as the water loss through transpiration, evaporation, leaching, and percolation. Odofin *et al.* [8] said that water balance was needed to determine the efficient method of soil moisture management. This research intended to analyze soil moisture balance in the root zone under different cropping systems. Field research was conducted in drylands of South Bali. It is ecpected that results of this research can be implemented in optimizing uses of soil moisture in dryland cropping systems.

MATERIALS AND METHODS

Field research was conducted in South Bali, Badung Regency, South Kuta District, Pecatu Village, Indonesia. This location was located in the south longitude of $8^{O}\ 49'\ 51''$, east longitude of $115^{O}\ 07'\ 47''$, and altitute of 202 m dpl., field research was conducted during October 2010 until June 2011.

The field experiment involved the cassava cv. Adira-1 in monoculture and intercropping systems with the maize cv. Pertiwi 3 and the groundnut cv. Kancil. Cassava and maize intercropping system were planted on rainy season (October 22, 2010), while the groundnut were planted after harvesting time of maize, at beginning of dry season (February 3, 2011). Cassava planting-space was 100 cm x 80 cm. Maize was planted in between cassava rows, groundnut was planted at 20 cm on both sides of cassava row. The treatment of cropping pattern were cassava (UK), cassava+ maize (UKJ), and cassava + maize – groundnut (UKJKT); each of treatment were replicated three times. Field experiment was designed in the Randomized Block which involved three treatments and three replications. Fertilizers application were 200 kg ZA/ha, 100 kg SP36/ ha, 100 kg KCl/ha, and organic fertilizer "Temesi" 5 ton/ha.

Soil moisture content was measured by using the gravimetry method with the Probe Type IH2 DIDCOT Wallingford, England [9]. Soil moisture balance in the root zone was estimated by the Hartmann method [10]. Total of soil moisture storage was calculated until the soil depth of 45 cm by using the formula as follow:

$$ST_{45} = \left[150\ \theta_{10} + 100\ (\theta_{20} + \theta_{30} + \theta_{40})\right]\ \text{mm}$$

The change of moisture saving (ΔST) = ST2 – ST1, which the ST1 was the moisture saving on t1 and ST2 was the moisture saving on t2. [11]. The depth percolation (DP) was assumed very low because the solid content was very high, so DP was assumed as zero. Run-off was analized from the different between total and effective rainfall by using the method of SCS USDA-Cropwat 8 [12][13]. Rainfall was taken from climate data of Ngurah Rai station which was collected from the last period of 10 years (2000 to 2009).

RESULTS AND DISCUSSION

1. Soil Moisture Profile in the Root Zone

Soil moisture observation and analysis were conducted during early growing season up to harvesting time at the soil depth of 0-45 cm (Figures 1, 2 and 3)

Table 1 Total Rainfall in Each Growth Stages of Cassava

Growth Stages of Cassava	Total Rainfall (mm)	Average Rainfall (mm)
The Initial Stage	179.1	8.14
The Development Stage	496.1	11.02
The Middle Stage	1277.7	11.62
The Later Stage	136.6	2.10

Rainfall as in Table 1 indicated that the condition of water input into soil profile during the growth stages of cassava.

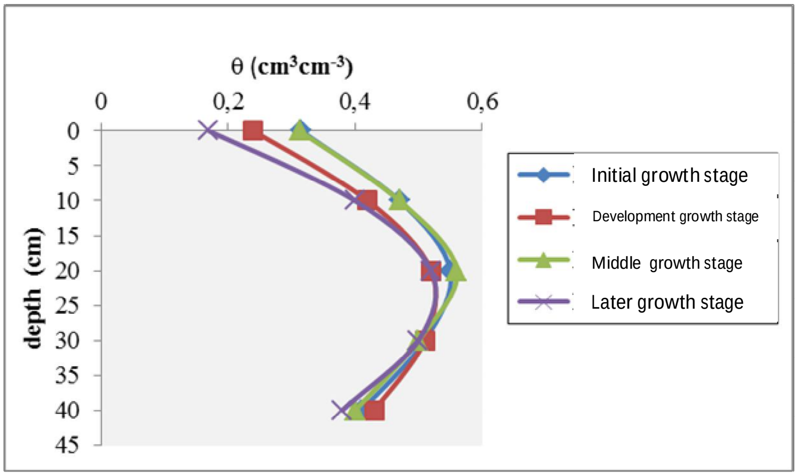

Figure 1. Soil moisture profile in the root zone of Cassava monoculture

Figure 1 presented the relationship between moisture content and soil depth in each growth stages of cassava monoculture. It was seem that a relatively low content of soil moisture was in surface soil (depth of 0 cm), at the initial, growth stage, and soil moisture content at the development growth stage, middle, and later growth stages were 0.32 cm^3/cm^3; 0.24 cm^3/cm^3; 0.31 cm^3/cm^3; and 0.17 cm^3/cm^3. At the soil depth of 10 cm there was a smaller differences of soil moisture content among the growth stages. At the soil depth of 20 cm, soil moisture content were higher than the layers of soil on the top and beneath, that are 0.55 cm^3/cm^3 at initial stage; 0.52 cm^3/cm^3 at the development stage; 0.56 cm^3/cm^3 at the middle stage; and 0.52 cm^3/cm^3 at the later growth stage. At the soil depth of 40 cm, soil moisture content were lower than the above for all of the crop growth stages. On the soil surface, soil moisture content were relatively low, then it increased upto the soil depth of 20 cm, and then decreased with the depth of soil upto the soil depth of 40 cm.

Total of soil moisture storage in the monoculture cassava root zone was 7.30 cm at 60 days after planting (dap); 8.76 cm at 83 dap; and 11.88 cm at the end of cropping (late season) in Nigeria [14]. Study of Odubanjo [15] indicated that the highest of soil moisture storage in cassava root zone was happened at the middle season that is 144 dap. According Nassar and Ortiz [16], if soil moisture decreased, cassava suggested response "dropping its leaves", however if an avaibale soil moisture was sufficient, cassava would reproduced its leaves. Vegetative growth of cassava was generally continuing for 5 months, however the root growth and tuber development were continuing for 8 months and it would stop in the age of 7 to 9 months.

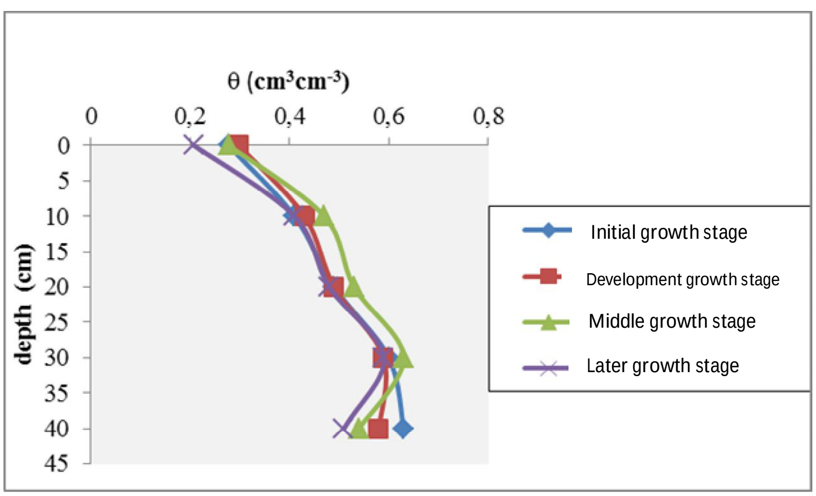

Figure 2. Soil moisture profile in the root zone of Cassava + Maize intercropping system (UKJ)

Figure 2 presented the relationship between soil moisture content and soil depth at each of crop growth stages. It was ssuggested that at the soil depth of 0 cm, soil moisture content at the growth at ages of initial, development, middle, and later were 0.28 cm^3cm^{-3}; 0.29 cm^3cm^{-3}; 0.27 cm^3cm^{-3}; and 0.20 cm^3cm^{-3}. Then, soil moisture content increased up to the soil depth of 30 cm for the all of growth stages, there respectively were 0.60 cm^3cm^{-3}; 0.59 cm^3cm^{-3}; 0.63 cm^3cm^{-3}; and 0.59 cm^3cm^{-3}. At the soil depth of 40 cm, soil moisture content were lower than the above soil layer, there respectively were 0.63 cm^3cm^{-3}; 0.58 cm^3cm^{-3}; 0.54 cm^3cm^{-3}; and 0.51 cm^3cm^{-3}. The average of soil moisture storage in the cassava root zone under the intercropping system of UKJ was between 188.95 mm to 260.66 mm, or 90.84% to 125.32% of field moisture capacity. However, the average of soil moisture storage in the maize root zone under intercropping system was between 220.73 mm to 252.36mm or 106.12% to 121.33% of field moisture capacity.

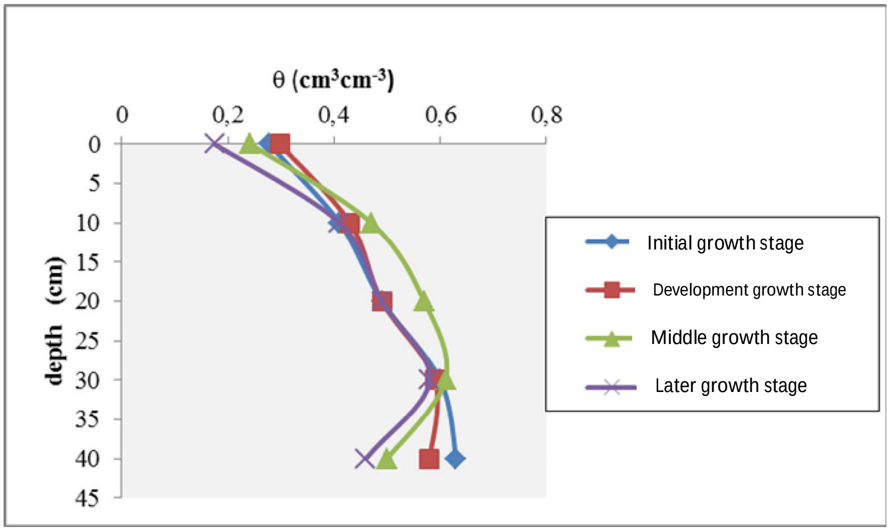

Figure 3 Soil moisture profile in the root zone of Cassava + Maize + Groundnut intercropping system (UKJKT)

Figure 3 presented the relationship between soil moisture content and soil depth at each growth stages of cassava intercropping system. It suggested that at the surface of soil (depth of 0 cm), the soil moisture content for the growth stages of initial, development, middle, and later, were 0.27 cm^3cm^{-3}; 0.29 cm^3cm^{-3}; 0.24 cm^3cm^{-3}; and 0.17 cm^3cm^{-3}. These soil moisture content increased with soil depth up to the soil depth of 30 cm. At the soil depth of 30 cm, soil moisture content were higher that the soil beneath and above, for all growth stages respectively were 0.60 cm^3cm^{-3}; 0.59 cm^3cm^{-3}; 0.61 cm3/cm3; and 0.58 cm^3cm^{-3}. At the soil depth of 40 cm, soil moisture content for each growth stages respectively were 0.63 cm^3cm^{-3}; 0.58 cm^3cm^{-3}; 0.50 cm^3cm^{-3}; and 0.46 cm^3cm^{-3}. The average of soil moisture storage in the cassava root zone under intercropping system of UKJKT was between 194.08 mm to 254.55 mm or 88.50% to 122.38% of field moisture capacity. However, the average of soil moisture content on the maize root zone under the intercropping systems of UKJKT and UKJ were relatively similar. The average of soil moisture storage in groundnut root zone under the cropping pattern of UKJKT was between 213.54 mm to 254.55 mm or 102.66% to 122.38% of field moisture capacity.

2. Soil moisture balance in monoculture and intercropping systems

Soil moisture balance in the cassava root zone under various cropping patterns were presented in Table 2, 3, and 4. There were different changes of soil moisture content (ΔS) in the cassava root zone between the monoculture and intercropping systems, it due to the difference of evapotranspiration (ET). The highest ET was on the intercropping system of Cassava + Maize - Groundnut, and the lowest ET was on the cassava monoculture.

Table 2. Soil moisture balance during the growing season (Cassava monoculture)

Year	Months	P	R	D*	ΔS	ET
		(mm)	(mm)	(mm)	(mm)	(mm)
2010	November	137.2	10.15	0	31.13	95.92
	December	564.1	166.44	0	193.79	203.87
2011	January	372	63.21	0	154.73	154.06
	February	433.4	114	0	150.04	169.36
	March	417	66.25	0	180.34	170.41
	April	288.9	68.8	0	99.39	120.71
	May	114.8	9.79	0	-17.09	122.1
	June	89.1	9.3	0	28.89	50.91
Total		**2416.5**	**507.96**	**0**	**821.2**	**1087.34**

Tabel 3. Soil moisture balance during the growing season (Cassava + Maize intercropping system)

Year	Months	P	R	D*	ΔS	ET
		(mm)	(mm)	(mm)	(mm)	(mm)
2010	Nopember	137.2	10.15	0	27.01	100.04
	December	564.1	166.44	0	207.84	189.82
2011	January	372	63.21	0	150.75	158.04
	February	433.4	114	0	165.94	153.46
	March	417	66.25	0	178.32	172.43
	April	288.9	68.8	0	85.74	134.36
	May	114.8	9.79	0	-18.3	123.31
	June	89.1	9.3	0	22.37	57.43
Total		**2416.5**	**507.96**	**0**	**819.65**	**1088.89**

Table 4. Soil moisture balance during the growing season (Cassava + Maize + Groundnut intercropping system)

Year	Month	P	R	D*	ΔS	ET
		(mm)	(mm)	(mm)	(mm)	(mm)
2010	November	137.2	10.15	0	27.01	100.04
	December	564.1	166.44	0	207.84	189.82
2011	January	372	63.21	0	150.75	158.04
	February	433.4	114	0	163.2	156.2
	March	417	66.25	0	183.7	167.05
	Aprl	288.9	68.8	0	74.22	145.88
	May	114.8	9.79	0	-26.69	131.7
	June	89.1	9.3	0	18.54	61.26
Total		**2416.5**	**507.96**	**0**	**798.55**	**1109.99**

P: total rainfall; R: total runoff; ΔS: changes of soil moisture storage; ET: total evapotranspiration.

Table 5. Soil moisture balance during the growing season (Field experiment)

Crop	Total Rainfall (P) (mm)	Total *Run Off* (R) (mm)	Total Change of moisture storage (ΔS) (mm)	Total Evapotranspiration (ET) (mm)	Crop yield (t ha^{-1})
Cassava (UK)	2,416.50	507.96	821.20	1087.34 (4.49 mm/day)	24.19
Cassava + Maize (UKJ)					
Maize (J)	1,073.30	239.81	385.59	447.90	5.44
Cassava (UK)	2,416.50	507.96	819.65	1088.89 (4.50 mm/day)	23.94
Cassava + Maize - Groundnut (UKJKT)					
Maize (J)	1,073.30	239.81	385.59	447.90	5.44
Groundnut (KT)	1,169.40	250.52	439.14	479.74	0.17
Cassava (UK)	2,416.50	507.96	798.55	1109.99 (4.59 mm/day)	22.54

Soil moisture balance in the cassava root zone under monoculture cropping pattern (UK) indicated that during the growth of cassava, there was rainfall of 2,416.50 mm, run-off of 507,96 mm, and change of soil moisture storage (ΔS) was 821.20 mm (Table 5). Total evapotranspiration was 1087.34 mm. It was as the different between total of rainfall, run-off, and the change of soil moisture storage during the cassava growth under the monoculture cropping pattern (UK). Total evapotranspiration suggested water requirement of cassava monoculture in research location. Tuber yield of cassava monoculture was 24.19 t ha^{-1}, it is lower than potential tuber yield of cassava cv. Muara, that is 38.2 ton/ha (Department of Foodcrop Agriculture and Horticulture in Badung Regency, 2009).

Water requirement of cassava was relatively low [17][15], an excess of soil moisture during the growing season of cassava results in the rot of tuber [18]. Alves [17] said that cassava was generally cropped in the area with the annual rainfall less than 800 mm and the dry months of 4 to 6 months. Although cassava was classified as the tolerant crop to the soil moisture stress, however tuber yiled of cassava decrease significantly under condition of water stress in a long time. The decrease of cassava tuber yield was depended on the duration of water-stress and its growth stages. Water stress critical period of cassava was at 1 to 5 months after planting. [17]. Water stress during 2 months within the growing period of cassava decreased tuber yield about 32 to 60% [19][17]. The other studies presented that water stress significantly reduced vegetative and generative growth of cassava [20]. It was mentioned that soil moisture stresses are more seriously reduced tuber yield than shoot growth. The water stress conditions was responsed by cassava by covering stomata on their leaves so the transpiration decreased [21][15][22].

Soil moisture balance on the maize root zone under cropping pattern of UKJ (Table 5) indicated that total of rainfall was 1,073.81 mm; total of run-off was 239.81 mm; and total change of soil moisture storage was

385.59 mm. Based on these data, water requirement of maize (ET) under the cropping pattern of UKJ was 447.90 mm. Fimprong *et. al* [23] said that water requirement of maize during its growing season was 350 - 450 mm. Critical period of maize growth were the tasseling and filling stages [24]. Soil moisture storage in cassava root zone under cropping pattern of UKJ (Table 5) indicated that total of rainfall and run-off were the same as the cropping pattern of UK, however total change of soil moisture storage (ΔS) was lower, that is 819.65 mm. Therefore, water requirement (ET) under cropping pattern of UKJ was lower than cassava monoculture that is 1,088.89 mm. Soil moisture storage was influenced by the precipitation, irrigation, water interception of capillary pore to the roots, run-off, percolation, eveporation and transpiration [10]. The intercropping systems caused the serious competition utilizing available soil moisture [25]. So soil moisture storages became lower compared with the monoculture system.

Tuber yield of cassava under cropping pattern of UKJ was as 23.94 ton/ ha (Table 5). This yield was lower than the UK cropping pattern, that is 24.19 ton/ha. Daellenbach *et al*.[25] showed that there was decreasing the tuber yield of cassava and the biomass yield under intercropping systems compared with the yield of cassava monoculture in Rio Cabuyal. However, Hartoyo and Widodo [26] reported that maize hybrids which are intercroped with cassava did not influence the cassava tuber yield Indonesia, but the dry weight yield of maize was 5.44 ton/ha (Table 5). This yield was lower than the average yield of maize cv. Arjuna in Badung , that is 5.64 ton/ha (Department of Foodcrop Agriculture and Horticulture, Badung Regency, 2009). Intercropping system caused the significant competition in utilizing soil nutrients, soil moisture, and solar radiation, which were needed during the plant growth and its production [25]. Soil moisture stress decreased maize yield about 50-60% [26]. Soil moisture stress at the flowering and tasseling stages decreased maize yield about 40%, however soil moisture stress at the filling period of grains decreased the maize yield about 66-93% [28][27].

Soil moisture balance on the maize root zone (Table 2) under the cropping pattern of UKJKT was as same as the UKJ. Soil moisture balance on the groundnut root zone under the cropping pattern of UKJKT (Table 5) indicated that total rainfall was 1,169.40 mm, total run-off was 250.62 mm, and change of soil moisture storage (ΔS) was 439.14 mm. Therefore, water requirement of groundnut in research location was 479.74 mm. According to Idinoba *et al.* [29], water requirement of groundnut was 302.5 mm during its growing period. Soil moisture balance on the cassava root zone under the cropping pattern of UKJKT (Table 5) indicated that total rainfall and run-off were as same as the cropping pattern of UK and UKJ, however change of soil moisture storage (ΔS) on the Cassava root zone under the cropping pattern of UKJKT was lower than the cropping pattern of UK and UKJ that is 798.55 mm. Therefore, water requirement of cassava under the cropping pattern of UKJKT was 1109.99 mm. Table 5 indicated that water requirement of cassava was higher under the intercropping system of UKJ as well as UKJKT if it is compared with the cassava monoculture. Cropping pattern of intercropping system had the strengthen and weakness, one of the impacts from the cropping pattern of intercropping system was there was the competition on using of nutrition, sunshine, and groundwater [25].

Tuber yield of cassava under cropping pattern of UKJKT was 22.54 ton/ ha (Table 5). The tuber yield of cassava under intercropping system of UKJKT was lower than tuber yield of cassava monoculture (UK) and cassava+maize intercropping system (UKJ). The intercropping systems suggested decrease tuber yield of cassava, it is supported by the research of Moriri *et. al* [30]. Moriri *et.al* [30] concluded that intercropping pattern increase growth of cowpea as the secondary crop, it decrease growth of maize as the main crop in Limpopo. However, research of Njoku and Muoneke [31] indicated that tuber yield of cassava intercropped with cowpea in Nigeria was higher than the cassava monoculture. It was predicted that cowpea supplied amount of available nitrogen into the soil.

Amanullah *et.al* [32] suggested that intercropping system of cassava and legume increased nutrients availability in soil. Dry weight yield of maize in the treatment of UKJKT was the same as the treatment of UKJ (Table 5). The same yield was also presented in the research of Adeniyan and Ayoola [33] in which the yield of cassava and maize was not significantly different among the intercropping systems of maize + cassava + soybean. It was explained that the different maturity time and growth patern of each crop determined productivity of intercropping system. The yield of pod dry weight in the cropping pattern of UKJKT was 0.17 ton/ ha (Table 5). This pod yield was lower than average pod yield of Kancil variety 2 ton/ ha [34]. It due to the competition in utilizing soil nutrients, radiant energy, and soil moisture [25] between crop in the intercropping system. Pod yield of groundnut was very influenced by the availability of soil moisture. According to Rahmianna *et.al* [35], groundnut yield decreased about 15% if the groundnut accepted enough water during the vegetative growth stages but there was water-stress during the pod-filling stage up to the harvest time. It was supported by Aboamera [36] which explained that critical period of legume was the flowering and pod-filling stages, in which water stress in these periode have decreased pod yield about 35% - 69%.

Based on the balance of water requirement and rainfall during the growth stages, there could be estimated the accurate time of seeds planting, but it was generally occured less water mainly when the time of planting, before and on the end of rainy season. The important thing was the evenly distribution of rainfall along the crop growth stages. It was due to that each type of crop had the different growth stages which needed in different amount of water supply. Every period of crop growth stages suggest the spesific tolerance to the water stress and the certain growth stage was very sensitive to the water stress, it generally happens when the crop growth reached the critical period. To determine the accurate time of planting, it is needed to consider the critical period of crop growth, and water must be supplied in this critical period.

It was seem that soil moisture profile on each of soil depth during the different crop growth stages were varied, the low moisture content in topsoil and it decreased with the soil depth up to 40 cm. It due to the characters of clay soil which had a limited permeability.

CONCLUSION

Under different cropping patterns studied, the soil moisture profile on the root zone showed any variability in accordance with the crop growth stage, soil depth, and total rainfall. Evaporation of monoculture cropping system was lower than intercropping systems. Total rainfall (P) on the cassava cropping system (UK) was 2,416.50 mm, total runoff (R) was 507.96 mm, change of soil moisture storage (ΔS) was 821.20 mm; and the water requirement (ET) of cassava cropping system was 1,087.34 mm. P and R on the cassava cropping under the treatments of UKJ and UKJKT were the same, however ΔS on UKJ was 819.65 mm and ΔS on UKJKT was 798.55 mm, ET of cassava cropping under the treatment of UKJ was 1,109.99 mm and UKJKT was 1,088.89 mm. Cassava yield under the treatment of UK was 24.19 ton/ ha, UKJ was 23.94 ton/ ha, and UKJKT was 22.54 ton/ ha.

REFERENCES

1. Loaiciga, Hugo A. 2005. On the Probability of Droughts: The Compound Renewal Model. *Journal of Water Resources Research*, Vol. 41, W01009m doi: 10, 1029/2004/WR003075
2. Shiklomadov, I.A.; V.I.Babkiu, and Zh.A. Balouishu;kov. 2011. Water Resources, Their Use, and Water Availability in Rusia: Current Estimates and Forecasts. *Journal of Water Resources* (38) no. 2, p 139-148
3. Smith M. 1992.. CROPWAT, a computer program for irrigation planning and management, Irrigation and Drainage Paper 46, FAO, Rome, Italy.
4. Al-Jamal M.S., T.W. Sammis, S. Ball and D. Smmeal. 1999. Yield-Based, Irrigated onion crop coefficients, Applied Engineering in Agriculture, 15(6):656-668
5. Rockstron, J. 2001. On food and nature in water scarce Tropical countries, *Journal of Land and Water International Series* 99, pp 4-6
6. Upton, M. 1996. The economics of farming system, Cambridge Univerity Press, UK.
7. Prijono, S. 2009. *Agrohidrologi Praktis*. (Practical Agrohydrology). Cakrawala Indonesia. pp 168.
8. Odofin A.J., N A. Egharevba, A.N. Babakutigi and P.C. Eze. 2012. Drainage Beyond Maize Root Zone In An Alfisol Subjected To Three Land Management Systems At Minna, Nigeria. Journal of Soil Science and Environmental Management, 3(9):216-223.
9. Lal R. 1991. Current Research On Crop Water Balance And Implications For The Future. IAHS Publ., 199:31-44.
10. Hartman, D. 1983. Water Balance in the Field. Master Program of Soil Science. Gajah Mada Universty. Yogyakarta.
11. Obalum S.E., U.C. Amalu, M.E.Obi and T. Wakatsuki. 2011. Soil Water Balance And Grain Yield Of Sorghum Under No-Till Versus Conventional Tillage With Surface Mulch In The Derived Savanna Zone Of Southeastern Nigeria. *Expl Agric*., 47(1):89–109.
12. Doorenbos J. and A.M. Kassam. 1986. Yield response to water, Irrigation and Drainage Paper 33, FAO, Rome, Italy
13. Clarke D, Smith M, Askari KE. 1998. CROPWAT for Windows: User Guide, Food and Agriculture Organization of The United Nations.
14. Kehinde O, O. Yahaya, Oloruntade A.J., and Afuye G.G. 2011. Effect of Supplemental Irrigation on Growth, Development and Yield of Cassava Under Drip Irrigation System in Akure, Ondo State Nigeria. *Journal of Sciences and Multidisciplinary Research*, 3:62-73.
15. Odubanjo O.O., A.A. Olufayo and P.G. Oguntunde. 2011. Water Use, Growth, and Yield of Drip Irrigated Cassava in a Humid Tropical Environment. *Soil & Water Res*., 6 (1):10–20.
16. Nassar N.M.A. and R. Ortiz. 2007. Review Cassava Improvement: Challenges And Impacts. *Journal of Agricultural Science*, 145:163–171.
17. Omonona, B.T and Akinpelu, A.O. 2010. Water, Environment And Health: Implications On Cassava Production. Continental *J. Agricultural Science*, 4:29-37.

18. Fasinmirin J.T., J.M.Reichert. 2011. Conservation Tillage For Cassava (*Manihot esculenta crantz*) Production In *The Tropics. Soil & Tillage Research*, 113:1–10.
19. Connor, D.J., J.H. Cock and G.E. Parra. 1981. Response of Cassava to Water ShortageI. Growth and Yield. Field Crops Research 4: 181-200.
20. Laban T.F.,E.B. Kizito, Y. Baguma and David Osiru. 2013. Evaluation Of Ugandan Cassava Germplasm For Drought Tolerance. International Journal of Agriculture and Crop Sciences, 5(3):212-226.
21. Oguntundea, and M.O. Alatisea. 2007. Environmental Regulation And Modelling Of Cassava Canopy Conductance Under Drying Root-Zone Soil Water. Meteorological Applications, 14: 245–252.
22. El-Sharkawy. 2012. Stress-Tolerant Cassava: The Role of Integrative Ecophysiology-Breeding Research in Crop Improvement. Open Journal of Soil Science, 2:162-186.
23. Frimpong, H.M. Amoatey, E.O. Ayeh, and D.K. Asare. 2011. Productivity And Soil Water Use By Rainfed Maize Genotypes In A Coastal Savannah Environment. International Agrophysics, 25:123-129.
24. Thimme G.P., Manjunaththa S. B., Yogesh T. C. and S.A. Satyareddi. 2013. Study on Water Requirement of Maize (*Zea mays L.*) using CROPWAT Model in Northern Transitional Zone of Karnataka. Journal of Environmental Science, Computer Science and Engineering & Technology, 2(1):105-113.
25. Daellenbach, P.C. Kerridgea, M.S. Wolfec, E. Frossardb, M.R. Finckhd. 2005. Plant Productivity In Cassava-Based Mixed Cropping Systems In Colombian Hillside Farms. Agriculture, Ecosystems and Environment, 105:595–614.
26. Hartoyo, K and Widodo, Y. 1991. In: Malang Research Institute for Food Crops. Indonesia. pp. 11-13.
27. Sahindomi B., S.Prijono, Ariffin, Soemarno. 2013. The Effect of Soil Management on the Availability of Soil Moisture and Maize Production in Dryland. International Journal of Agriculture and Forestry, 3(3):77-85.
28. Bruce W.B., Edmeades G.O., Barker T.C. 2002. Molecular and Physiological approaches to Maize Improvement for Drought Tolerance. Journal of Experimental Botany 53: 13-25.
29. Idinoba, P.A. Idinoba, A.Gbadegesin and S.S. Jagtap. 2008. Growth and Evapotranspiration of Groundnut (*Arachis hypogaea*) In A Transitional Humid Zone of Nigeria. African Journal of Agricultural Research, 3(5):384-388.
30. Moriri, L.G. Owoeye and I. K. Mariga. 2010. Influence of component crop densities and planting patterns on Maize production in dry land Maize/Cowpea intercropping systems. African Journal of Agricultural Research,5(11):1200-1207.
31. Njoku D.N., Muoneke C.O. 2008. Effect Of Cowpea Planting Density On Growth, Yield and Productivity of Component Crops in Cowpea/Cassava Intercropping System. Journal of Tropical Agriculture, Food, Environment and Extension, 7 (2):106 -113.
32. Amanullah M.M., E. Somasundaram, K. Vaiyapuri and K. Sathyamoorthi. 2007. Intercropping In Cassava – A Review. Agricultural Review., 28(3):179-187.
33. Adeniyan, O. N. and Ayoola, O. T. 2006. Growth And Yield Performance Of Some Improved Soybean Varieties As Influenced By Intercropping With Maize and Cassava in Two Contrasting Locations in Southwest Nigeria. African Journal of Biotechnology,5(20):1886-1889.
34. Balitkabi. 2010. Teknologi Produksi Kedelai, Kacang tanah, Kacang hijau, Ubi kayu & Ubi jalar. Balai Penelitian Tanaman Kacang-kacangan & Umbi-umbian. Pusat Penelitian & Pengembangan Tanaman Pangan. Badan Penelitian & Pengembangan Pertanian. Retrived from : www.balitkabi.litbang.deptan.go.id/publikasi/teknologi-inovasi.html, Accessed 30-5-2013
35. Rahmianna, A. Taufiq, dan E. Yusnawan. 2009. Pod Yield and Kernel Quality of Peanut Grown Under Two Different Irrigations and Two Harvest Times. Indonesian Journal of Agriculture, 2(2):103-109.
36. Aboamera, M.A. 2010. Response Of Cowpea To Water Deficit Under Semi-Portable Sprinkler Irrigation System. Misr J. Ag. Eng., 27 (1): 170- 190.