RESEARCH ARTICLE OPEN ACCESS

Influence of tillage and mulching on soil water balance under pineapple crop (*Ananas comosus* (l) Merr)

Elvire LineSOSSA[*], Bidossessi Mathieu HOUNSOU[**], Codjo Emile AGBANGBA[***], Adémola Jules AyindéADEGNANDJOU[**],ComlanUlrich TCHEGNIMONHAN[**],LucOlivier SINTONDJI[**], Guillaume Lucien AMADJI[*], Kossi Euloge AGBOSSOU[**], Djidjoho Joseph HOUNHOUIGAN[****]

[*]*Research Unit of Eco-Pedology, Laboratory of Soil Sciences, Faculty of Agronomic Sciences, University of Abomey-Calavi,Abomey-Calavi, Benin.*
[**]*Laboratory of Hydraulics and Water Control, National Instituteof Water, Faculty of Agronomic Sciences,University of Abomey-Calavi, 03- BP. 1122. Jericho, Cotonou, Bénin.*
[***]*Laboratory of Research in Applied Biology, Department of Environmental Engineering, Polytechnic School of Abomey-Calavi, University of Abomey-Calavi, Abomey-Calavi, Benin.*
[***]*Laboratory of Biomathematics and Forest Estimations, Faculty of Agronomic Sciences, University of Abomey-Calavi,Abomey-Calavi, Benin.*
***** Laboratory of Nutrition and Food Sciences, Faculty of Agronomic Sciences, University of Abomey-Calavi, Abomey-Calavi, Benin.*
** Corresponding author : Elvire LineSOSSA*

ABSTRACT
Pineapple is Benin's third largest agricultural export product after cotton and cashew nuts. Its productivity is affected by water deficit. An experiment was conducted in southern Benin to assess the influence of tillage and mulching on soil water balance under pineapple cultivation. The plant material consists of the pineapple "SugarLoaf" variety. The experimental design used was a split plot with 4 replications where the main factor was the tillage method and the secondary factor, the usage of pineapple crop residues. Soil moisture was evaluated monthly by the gravimetric method, which allowed the calculation of water stocks and the estimation of the water balance at each phenological stage. The data were analyzed using the Excel software. The results revealed that soil water stocks are higher under ridging than under flat tillage during the vegetative and flowering stages in opposite to the fruiting-harvesting stage. Burying of fresh crop residues results in higher soil water stocks followed by surface mulching of residues during all phenological stages. Plants experienced water stress throughout the crop cycle (ETR/ETM <1), but more during the vegetative stage.
Keywords: water deficit, drainage, gravimetric method, evapotranspiration, soil water stock.

Date of Submission: 01-10-2020 Date of Acceptance: 14-10-2020

I. INTRODUCTION

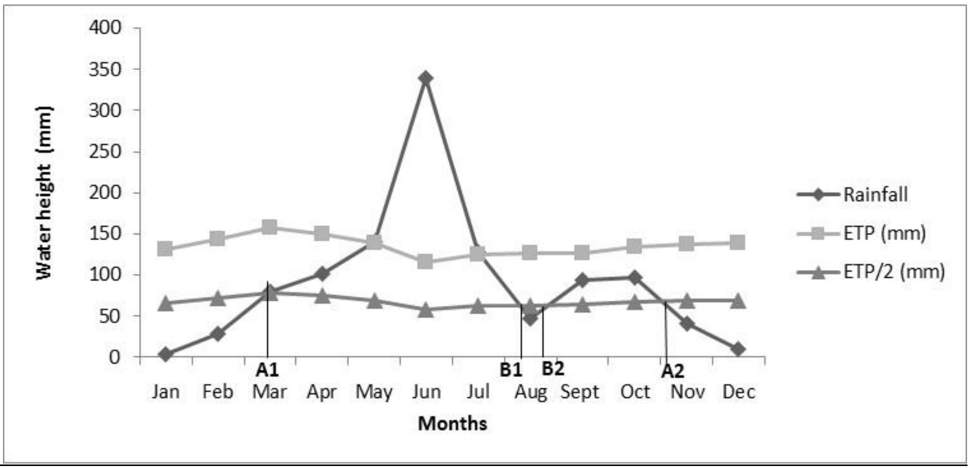
Achieving food self-sufficiency remains a priority for developing countries, particularly for sub-Saharan countries, where population growth and economic problems have reduced living standards and changed eating habits, leading to the malnutrition [1]. To achieve this goal, Benin, which economy is dominated by agricultural sector [2], has developed a strategic plan for revival of agricultural sector, which includes the pineapple sector. Pineapple is in fact the second most important tropical fruit in the world, accounting for 23% of the total tropical fruit produced, compared to 39% for mango [3]. It is used as an ingredient in the culinary field, for medicinal purposes and in the alcoholic beverages processing. In addition, pineapple stems and leaves are a source of fiber that can be processed into paper or fabric, while the waste products from processing are used as animal feeds [4]. In Benin, pineapple is the third most important agricultural export product after cotton and cashew nuts; it is cultivated in the south, mainly in the Atlantic department, which provides 95% of the total volume produced [5]. One of pineapple production constraints in Benin is the lack of water. Although pineapple is a CAM (Crassulacean Acid Metabolism) plant that adapts to low rainfall areas

[6, 4], its productivity is affected by water deficit. There is very little research on the assessment of pineapple water requirements and water stress influence on pineapple cultivation [4]. It is noted that water deficit causes pineapple plants to wilt the lower leaves, change leaf color from dark green to light green and then to yellow or red, reduce the number and weight of the fruit [7] and crack the fruit at maturity [8]. It seems appropriate to identify cultural practices that can increase soil water availability under pineapple cultivation in Benin, in view to develop this important sector for country's economy. Numerous authors such as [9], [10], [11] and [12] have shown that soil mulching contributes to soil moisture conservation and consequently to the dissolution and conservation of nutrients in the soil solution, thus making more nutrients available to the plants. [13] have shown that well-conducted tillage is essential to improve rooting and intensify plant production. Good tillage is necessary in fruit production to loosen the soil and facilitate root penetration [14]. This work aims to examine the influence of tillage and mulching on soil water availability in pineapple production.

II. MATERIALS AND METHODS

2.1. Study area

The experiment was conducted in the district of Allada, about 54 km from Cotonou. This district covers an area of 381 $km^2$and is located between 1°59' and 2°15' east longitude and between 6°34' and 6°47' north latitude. This area enjoys a sub-equatorial climate characterized by two rainy seasons and two dry seasons that alternate annually as follows: a long rainy season from mid-March to mid-July; a short dry season from mid-July to mid-September; a short rainy season from mid-September to mid-November and a long dry season from mid-November to mid-March [15]. Most of the rainfall is concentrated between March and June for the long rainy season and between September and November for the short season [16]. Considering the last 20 years, the average annual rainfall is 978.50 mm. The different breakdowns correspond to the following periods: A1-B1 and B2-A2 wet periods or periods of active vegetation (P ≥ ½ ETP), B1-B2 early rainy period (P < ½ ETP), A2-A1 dry period (P < ½ ETP) (fig.1).



ETP = Real Evapotranspiration, Jan = January, Feb = February, Mar = March, Apr = April, Jun = June, Jul = July, Aug = August, Sept = September, Oct = October, Nov = November, Dec = December.

Fig.1:Evolution of monthly average rainfall and ETP from 1994 to 2014.

The soil physico-chemical analyses of the experimental plot carried out in the Soil Science laboratory of the Faculty of Agronomic Sciences (FSA) of the University of Abomey-Calavi (UAC) in Benin, indicate that the soil has a silty-clay-sandy texture with low acidity (Table 1). The C/N ratio of 11.2 indicates that decomposition activity of organic matter by microorganisms is normally realized in the soil.

Table 1 : Physico-chemical soil's parameters of the experimental plot

Sand	Clay	Silt	MO	C/N	pH		Mwp (%)		da
%					water	KCl	2.5	4.2	
66.5	25.7	7	1.2	11.2	5.6	4.8	13.6	7.3	1.5

*Mwp= M*oisture *at the permanent wilting point, MO =* Organic Matter*, C/N = Carbon/Nitrogen, da = bulk density.*

2.2. Plant material and cultural practices

The plant material used in this study is the SugarLoaf pineapple variety, which is actually the most cultivated in the study area. The soil was ploughed with a hoe before planting and the experimental units were delimited. Pineapple residues from the same field were cut into 10-15 cm long pieces. These residues were used to mulch the soil at the rate of 10t/ha of fresh pineapple residues. Pineapple shoot of approximately 300 g were sorted and planted at a density of 41500 plants per hectare with 60 cm between rows and 40 cm between plants.

Phosphorus was applied two weeks after planting at a rate of 100 kg/ha. Identical combinations of different rates of nitrogen and potassium were split and applied to the plants at 45-day intervals. Plot weeding was done every month after planting.Flower induction treatment (FIT) was done in the 12^{th} month using calcium carbide. One kilogram of carbide was diluted in 200 liters of water. Each plant was given 50 cm^3 of this acetylene carbide solution in the cool hours of the day (between 6 and 8 am). Harvesting took place five months after this induction.

2.3. Experimental design

The experimental design used is a split plot with 4 replications. The main factor is the tillage (at two levels: flat tillage with a hoe [FT] and ridging with a hoe [R]) and the secondary factor is use of fresh pineapple residues at three levels (surface mulching at 10 t/ha [M]; 10 t/ha residues buried at 10 cm depth [B]; and no mulching [NM])Each subplot has measured 12 m² and has 48 plants among which, 24 are useful with the first lines being border lines.

2.4. Measured parameters

2.4.1. Cultural profile

A 1m deep soil profile was opened on the experimental site to identify the different soil layers and their depths. Soil samples were taken per layer in 100 cm^3 cylinders and in bags with a knife to determine the bulk density and soil moisture at wilting point WP2.5 and WP4.2. The plants root's depth was measured at each phenological phase by opening an 80 cm deep hole at the feet of 4 plants per experimental unit. After the hole was opened, the soil was gently chipped from bottom to top, allowing the longest root tip to be obtained and the rooting depth of each plant to be measured.

2.4.2. Evolution of humidity and water stock of the soil

Soil moisture was determined by gravimetric method. Three soil samples were taken per experimental unit at depths of 0 - 20 cm, 20 - 40 cm, and 40 - 60 cm. These samples, taken once a month using the auger, were dried in an oven at 105°C for 48 hours and the moisture content by weight was determined through the formula [17]**:** $\boldsymbol{\omega = \frac{P2-P1}{P1} \times 100}$(1) with P2 = soil's wet weight in grams; P1 = soil's dry weight in grams and ω = moisture content by weight in % of dry soil weight.The soil average bulk density was determined per layer using the formula: da = Ms/Vc [18] with Ms = mass of dry soil after drying and Vc = cylinder volume (100 cm^3). Soil bulk density values were obtained by the formula: θ = da x ω;the useful water reserve is determined by the formula: RU= (Mwp3 - Mwp4.2) × da × Z with Mwp3 = soil moisture at the field capacity; Mwp4.2 = moisture at the permanent wilting point, Z = rooting depth in mm, da = bulk density and RU = useful water reserve in mm [19].Soil water stock evolution on each layer of profile was evaluated by phenological stage using the formula: Si =Li × θi with Li = layer i thickness in mm, θi = volumetric humidity in cm^3/cm^3 and Si = water stock in mm [17]. The water stock over the total rooting depth of the crop was determined by the sum of the elemental stocks on each soil layer considered.

2.4.3. Soil water balanceestimation

The soil water balance was estimated by the formula: P + I = R+ΔS+D+ETR [20, 21] with I, the irrigation water in mm, which was considered to be zero during the experiment because there was no irrigation water supply; P = Precipitation in mm obtained from a direct-reading rain gauge installed on the site; D = Drainage in mm; ΔS = Soil water stock variation in mm; ETR= RealEvapotranspiration in mm and R = runoff which was considered null throughout the experiment since it was carried out on a flat soil (without slope).

2.4.4. Calculation of Real Evapotranspiration (ETR)

The ETR was calculated according to the formula of [22] adapted by [23]. It is assumed that ETR is equal to maximum evapotranspiration (ETM) until the fraction (p) of total water available in soil over the rooting depth is exhausted. Once dry, the fraction (p) of the total water available in the soil over the rooting depth (Sa.D), ETR falls below ETM until a heavy rainfall and is a function of the amount of water remaining in the soil (1 - p) St.D and ETM. Based on these hypothesis, the following relationships are derived:

$ETR = ETM = -\frac{dSt.D}{dt}$ if St.D≥ (1-p) x Sa.D (1)$ETR = \frac{St.D}{(1-p)Sa.D} \times ETM = -\frac{dSt.D}{dt}$ if St.D < (1-p) x Sa.D (2) With Sa.D, the total amount of water available in the soil over the rooting depth. It was calculated over 60 cm for pineapple based on the results of rooting depth measurements using the root profile: Sa.D (mm) = (HpF3 -HpF4.2) × da × 600 with 600 = pineapple rooting depth in mm, St.D = amount of water available in the soil at time t over the rooting depth; p is the fraction of the total amount of water available in the soil when ETM = ETR. The p values for soil under pineapple cultivation are given in Table 2.

Table 2: Fraction (p) of total soil's available water according toETM

ETM (mm/j)	2	3	4	5	6	7	8	9	10
Fraction p	0.80	0.70	0.60	0.50	0.45	0.425	0.375	0.35	0.30

Source : [23]

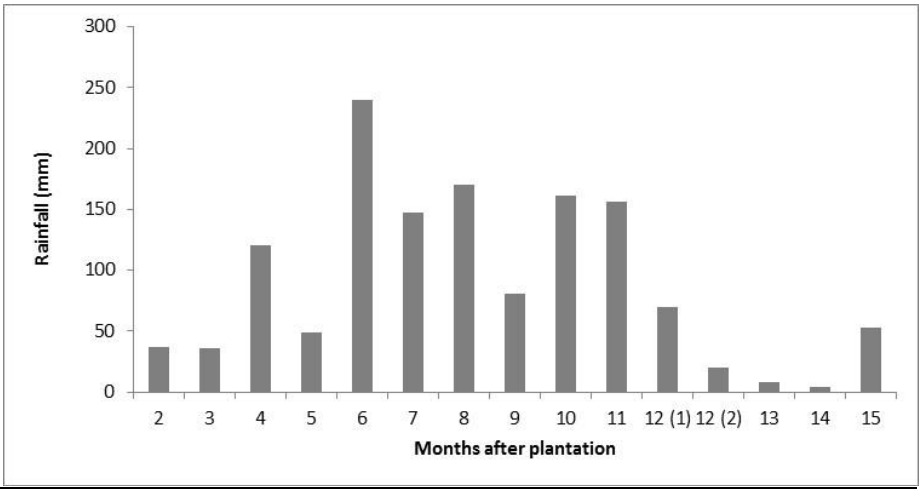
By integrating and replacing equations (1) and (2), the formula becomes:
$ETR = \frac{Sa.D}{t}(1-(1-p)\exp\left(\frac{-ETMt}{(1-p)Sa.D}+\frac{p}{1-p}\right)$ if t ≥ t' (3); t' is the time (in days) during which ETR = ETM, with $t' = \frac{p.Sa.D}{ETM/j}$; ETM/j is the maximum daily evapotranspiration for the period considered and ETR is the real evapotranspiration in mm for the same period. Notice that ETR is calculated by equation (3) when t ≥ t' and ETM = ETR when t<t'. Similarly, we calculated the amount of water available in the soil over the rooting depth by phenological stage to determine real evapotranspiration by the appropriate formula. Maximum evapotranspiration (ETM) was calculated by the formula:ETM = Kc x ETP with ETP, the potential evapotranspiration of the field, obtained from ASECNA (Agency of Aerial Navigation Safety); Kc = crop coefficient of pineapple which is about 0.4; 0.3 and 0.3 respectively for the vegetative, flowering and fruiting-harvesting stages [23, 4].

2.4.5. Drainage determination
Drainage D was determined from the water balance equation after calculating all other balance terms: D = P + I - ΔS- ETR.

2.4.6. Statistical analysis
The soil moisture data were processed in the excel spreadsheet to generate figures and tables.

III. RESULTS

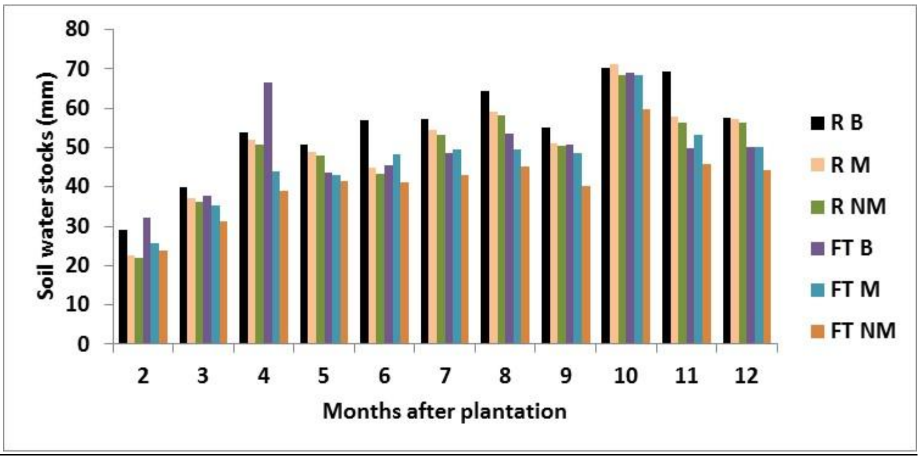
3.1. Evolution of rainfall during the test period
Fig.2 shows the evolution of rainfall during the experiment period. Overall, it can be seen that heavy rainfall was recorded during the vegetative phase of the crop, which includes the period from the 2nd to the 12th month after planting. The cumulative rainfall recorded during the vegetative, flowering and fruiting-harvesting stages were respectively 1266, 28 and 57 mm of water.



12(1) =12th month after plantation including in the vegetative stage 12(2) =12ème month after plantation including in the flowering stage.
Fig.2: Rainfall evolution during experimentation period

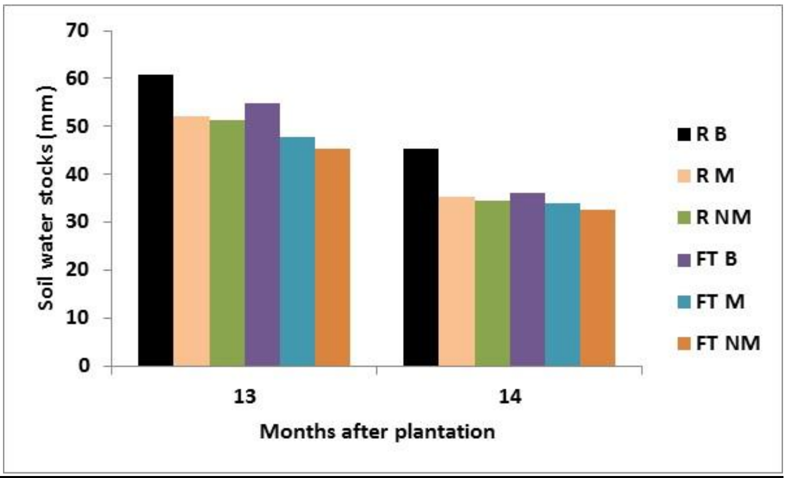
3.2. Influence of tillage and mulching on the variation in soil water stock

Fig. 3, 4 and 5 show the evolution of soil water stock over a depth of 60 cm, respectively during the vegetative (2nd to 12th month after planting), flowering (13th to 14th month after planting) and fruiting-harvesting (15th to 17th month after planting) stages of pineapple. Analysis of these figures shows that water stock values vary according to rainfall and phenological stages. Variations in water stock according to tillage or residue use are relatively small. However, during the vegetative and flowering stages, soil ridging results in higher water stocks than flat tillage, regardless of residue use pattern. To this end, the average water stocks (expressed in mm) recorded under treatments R B, R M, R NM, FT B, FT M and FT NM are respectively 54.9; 50.6; 49.4; 49.8; 46.9 and 41.3 during the vegetative stage and 53.1; 43.8; 43; 45.5; 40.8 and 39 during the flowering stage. In contrary, during the fruiting-harvest stage, the water stocks in plots under flat tillage are higher (104.7 mm; 109.4 mm and 98.9 mm for the FT B, FT M and FT NM treatments respectively) than those in plots under ridging (87.9 mm; 78.1 mm and 77.2 mm for the R M, R M and R NM treatments respectively), regardless the using residues mode is. During all phenological stages, it is noticed that burying of crop residues generally results in higher water stocks followed by surface mulching. As an example, the soil water stocks (expressed in mm) recorded during the 13th month after planting (flowering stage) are respectively 54.9; 47.6; 45.3; 60.8; 52.2; and 51.4 mm for the treatments FT B (flat tillage + burying), FT M (flat tillage + mulching), FT NM (flat tillage + no mulching), R B (Ridging + burying), R M (Ridging + mulching) and R NM (Ridging + no mulching).



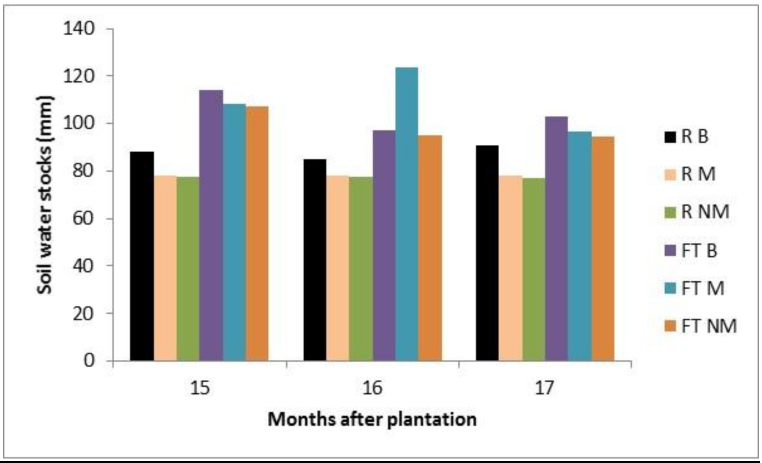
RB = Ridging + burying, RM = Ridging + mulching, RNM = Ridging + no mulching, FTB flat tillage + burying, FTM = flat tillage + mulching, FTNM = flat tillage + no mulching.

Fig.3: Evolution of water stock at 60 cm depth during the vegetative stage



R B = Ridging + burying, R M = Ridging + mulching, R NM = Ridging + no mulching, FT B flat tillage + burying, FT M = flat tillage + mulching, FT NM = flat tillage + no mulching.

Fig.4:Evolution of water stock at 60 cm depth during the flowering stage



RB = Ridging + burying, RM = Ridging + mulching, RNM = Ridging + no mulching, FTB flat tillage + burying, FTM = flat tillage + mulching, FTNM = flat tillage + no mulching.

Fig.5: Evolution of water stock at 60 cm depth during the flowering-harvesting stage

3.3. Influence of tillage and mulching on soil water balance

A 60 cm depth was chosen for water balance estimation, as monitoring of root development showed that roots do not grow deeper than this depth (Table 3).

Table 4 presents the results of soil water balance evolution according to tillage and mulching methods. The analysis of this Table shows through the ETR/ETM ratios that plant needs were satisfied between 81 and 91% during the vegetative stage, between 95 and 97% during the flowering stage and between 97 and 98% during the fruiting-harvesting stage. Within the same phenological stage, ETR/ETM ratio values varied only slightly between treatments. It is only during the vegetative stage that ETR/ETM ratios are higher under ridging than under flat tillage. Also during this stage, the RB treatment has the highest ETR/ETM ratio followed by the R M, R NM, FT B, FT M and FT NM treatments, respectively. Tillage and residue use patterns did not affect the ETR/ETM ratio during flowering and fruiting-harvest stages. Drainage showed positive values during the vegetative stage but negative values (reflecting capillary upwelling) during the flowering and fruiting-harvest stages.

Table 3: Average plant root’s length (in centimeter) during differents phenological stages.

Treatments	**Vegetative stage**	**Flowering stage**	**Fruition-harvesting stage**
RB	34.0 ± 3.78	40.0 ±3.58	57.3 ± 12.83
R M	33.7 ± 4.9	40.1 ± 3.69	53.9 ± 7.2
R NM	31.3 ± 2.71	34.2 ± 4.51	53.5 ± 8.58
FT B	28.5 ± 5.99	35.3 ± 6.29	60 ± 6.74
FT M	26.0 ± 3.31	33.3 ± 3.79	59.4 ± 4.32
FT NM	28.7 ± 2.71	33.8 ± 4.13	58.9 ± 10.15

R B = Ridging + burying, R M = Ridging + mulching, R NM = Ridging + no mulching, FT B flat tillage + burying, FT M = flat tillage + mulching, FT NM = flat tillage + no mulching.

Table 3: Soil’s water balance under pineapplecrop

Phenological stages.	**Treatments**	ETP (mm)	ETM (mm)	Rainfall (mm)	Stock variation (mm)	ETR (mm)	ETR/day (mm)	Drainage (mm)	ETR/ ETM
Vegetative stage	RB	1641	738.5	1266.2	28.6	674.4	1.85	563.1	0.91
	RM	1641	738.5	1266.2	34.9	655.3	1.80	576.0	0.89
	RNM	1641	738.5	1266.2	34.2	655.2	1.80	576.8	0.89
	FTB	1641	738.5	1266.2	18.0	635.5	1.75	612.6	0.86

	FT M	1641	738.5	1266.2	24.2	637.7	1.75	604.3	0.86
	FT NM	1641	738.5	1266.2	20.2	600.3	1.65	645.7	0.81
Flowering stage	RB	270.6	81.2	28	-15.4	78.1	1.26	-34.7	0.96
	RM	270.6	81.2	28	-16.8	77.8	1.25	-33.0	0.96
	RNM	270.6	81.2	28	-26.8	77.3	1.25	-22.6	0.95
	FTB	270.6	81.2	28	-18.8	78.3	1.26	-31.5	0.96
	FT M	270.6	81.2	28	-13.8	78.8	1.27	-37.0	0.97
	FT NM	270.6	81.2	28	-12.6	77.8	1.25	-37.2	0.96
Fruition-harvesting stage	RB	452.5	135.8	57	2.2	132.5	1.49	-77.8	0.98
	RM	452.5	135.8	57	0.1	132.2	1.48	-75.3	0.97
	RNM	452.5	135.8	57	-1.6	132.0	1.48	-73.3	0.97
	FTB	452.5	135.8	57	-11.2	132.0	1.48	-63.8	0.97
	FT M	452.5	135.8	57	-11.6	132.0	1.48	-63.4	0.97
	FT NM	452.5	135.8	57	-5.9	132.0	1.48	-69.1	0.97

R B = Ridging + burying, R M = Ridging + mulching, R NM = Ridging + no mulching, FT B flat tillage + burying, FT M = flat tillage + mulching, FT NM = flat tillage + no mulching.

IV. DISCUSSION

The study of influence of tillage and mulching on soil water availability has shown that tillage and mulching influence soil water stock and soil water balance according to phenological stages. In contrast to fruiting-harvesting stage, the vegetative and flowering stages show higher water stocks under ridging than flat tillage. These variations can be explained by the rate of root growth of the plants, since the roots are involved in the mobilization of water and nutrients necessary for plant development [24]. Indeed, during vegetative and flowering stages, the plants root lengths measured are higher under ridging than under flat tillage. However, during the harvesting fruiting stage, the roots are longer under flat tillage influence than under ridging. These observations corroborate those of [25] who mentioned that tillage allows better and faster root development, thanks to root system development which increases the water reservoir available to the plants. Similarly, [26], comparing different tillage methods, noted that ridging increases efficiency of water consumed by sorghum of 4%.

Soil moisture is also conserved through the crop residuesuse. Numerous authors such as [9], [10], [11] and [12] have shown that mulching with residues contributes to soil moisture conservation. Crop residues decomposition releases organic matter into the soil, which combines with soil clay fraction to ensure aggregatescohesion, thus improving soil structure and porosity [27, 28]. Residues protect the soil surface from erosion by limiting splashing, reducing evaporation, and improving water infiltration, thereby increasing the amount of moisture available for crop use [29, 30]. This certainly explains the increase of soil water stocks through residues burial and surface mulching. Residues Burial at tillage depth results in higher water stocks during all phenological stages than surface mulching. These results may be justified by faster degradation of buried residues which release earlier organic matter into the soil [31, 32]. As a result, overall ETR/ETM ratios are higher with residues burial, regardless of tillage practices.

During experimentation, 93.7%, 2.1% and 4.2% of total rainfall was respectively recorded during vegetative, flowering and fruiting-harvest stages. The ETR/ETM ratio ranged from 0.81 to 0.91 during the vegetative stage, 0.95 to 0.97 during the flowering stage and 0.97 to 0.98 during the fruiting-harvesting stage. Similarly, this ratio does not differ according to tillage and residue use practices, during flowering and fruiting-harvest stages. This indicates that pineapple plants were subject to water stress which was more pronounced during the vegetative stage, despite the high rainfall recorded during this period. These results corroborate those of [33] who studied pineapple water consumption and found that pineapple plants require more water during vegetative stage. This certainly also justifies the fact that it was only during the vegetative stage that ETR/ETM ratio varied between treatments.

The high drainage values recorded during the vegetative stage are explained by the abundant rainfall. The plants could not benefit from available water stock between rains over a long period of time due to their shallow rooting depth during this stage. During the flowering and fruiting-harvest stages, which received less water, the roots developed further and their strong biological activity caused drying in the area where they were concentrated. This drying caused water to move from deep layers (capillary upwelling) to the areas colonized by the roots. This explains drainage negative values recorded during flowering and fruiting-harvesting stages [34].

V. CONCLUSION

The study found that soil water stocks are higher as a result of ridging than flat tillage during the vegetative and flowering stages, which is contrary to the fruiting-harvesting stage. Burial of 1 kg/m² (or 10 t/ha) of fresh pineapple residues results in higher soil water stocks followed by surface mulching of residue during all phenological stages. Plants experienced water stress throughout the crop cycle (ETR/ETM <1), but more pronounced during the vegetative stage. Drainage showed strong positive values during the vegetative stage, but negative values during the flowering and fruiting-harvest stages, indicating capillary upwelling of water.This will help producers to use cultural practice which increase soil water availability under pineapple crop.

ACKNOWLEDGEMENTS

The authors would like to thank the Rectorate of University of Abomey-Calavi (UAC) for its material and financial support through Research Competitive Fund Program (CRFP/UAC). (CRFP/UAC).

REFERENCES

[1]. FAO (Food and Agriculture Organization), Synthèse des documents d'information technique, Sommetmondial de l'alimentation, Rome, 1996.
[2]. D.D.A.A.Arinloyè,*Governance, marketing and innovations in Beninese pineapple supply chains*,Wageningen University, Wageningen, NL, Thesis, 2013, 194 p.
[3]. FAO, Intergovernmental group on bananas and tropical fruits, Yaoundé, Cameroon, 2011.
[4]. M.K.V.Carr, The water relations and irrigation requirements of pineapple (*Ananas comosus* var. *comosus*), Experimental Agriculture 48 (4), 2012, 488-501.
[5]. INSAE (Institut National de la Statistique et de l'Analyse Economique), Dynamique des filières
[6]. d'exportation au Bénin, Bénin, 2009, 56 p.
[7]. J.C. Cushman, Crassulacean acid metabolism: recent advance and future opportunities, FunctionalPlant Biology 32 (1), 2005, 375–380.
[8]. D.P.Bartholomew, E.Malézieux, G.M.Sanewski, and E.Sinclair, in: D.P.Bartholomew, R.E.Pauli, and K.G. Rohrbach (Eds.),*Inflorescence and fruit developmentand yield, The Pineapple Botany, Production and Uses*, (Wallingford, UK, CAB International, 2003) 342-366.
[9]. E.Malézieux, F.Côte, andD.P.Bartholomew,in: D.P.Bartholomew, R.E.Pauli, and K.G.Rohrbach (Eds.),*Crop environment, plant growth and physiologyThe Pineapple Botany, Production and Uses*, (Wallingford, UK, CAB International, 2003).
[10]. Anon, Soil and moisture conservation in coconut lands, Cover crops and mulching, Coconut Bulletin,7(1/2), 1990, 21–27.
[11]. D.L.Tanaka, andR.L.Anderson, Soil water storage and precipitation storage efficiency of conservation tillage systems, Journal of soil and water conservation, 26, 1997, 363–367.
[12]. O.L.Sintondji, *Impact du paillage d'un sol ferrallitique avec senna siamea sur le bilan hydrique et sur l'efficacité de l'engrais minéral NPK 14-23-14*, Université d'Abomey-Calavi, Faculté des Sciences Agronomiques, Thèse d'Ingénieur Agronome, 1998, 163 p.
[13]. R.Mrabet, Differential response of wheat to tillage management systems in a semiarid area of Morocco, Field Crops Research 66, 2000, 165–174.
[14]. B.Z.Boli, E.Roose, B.Bepaziem, K.Sanon, andF.Waechter. Effets des techniques culturales sur le ruissellement, l'érosion et la production de coton et maïs sur un sol ferrugineux tropical sableux, CahierOrstom séries Pédologie, 18 (2), 1993, 309-325.
[15]. FAO, Introduction à la gestion conservatoire de l'eau, de la biomasse et de la fertilité des sols (GCES), Bulletin pédologique, Montpellier, France, 1994.
[16]. D.A.Fatoumbi, *Analyse comparée de la rentabilité de la production du maïs et de l'ananas dans la commune d'Allada au Sud Bénin*. Université d'Abomey-Calavi, Mémoire de licence professionnel en économie, 2011, 60 p.
[17]. C.V.Doto, K.E.Agbossou andB.Ahamide, Etude de la consommation en eau et du rendement d'une culturede soja sur un sol ferrallitique au Sud-Bénin, Troisième colloque des sciences, culture et technologies de l'Université d'Abomey-Calavi, Bénin, 2012, 239-268.

[18]. R.Kabalan, Consommation en eau et productivité d'une culture du soja à la bekaa, INRA, 1998, 30 p.
[19]. C.K.Agossa, Contrôle du ruissellement et de l'érosion par l'amélioration des techniques de lutte anti-érosive dans le bassin versant de DRA, commune de DJIDJA, Université d'Abomey-Calavi, Faculté desSciences Agronomiques, Thèse d'Ingénieur Agronome, 2005, 87 p.
[20]. N.Aho, etD.K.Kossou, Précis d'Agriculture Tropicale, bases et éléments d'applications Ed Flamboyant,Cotonou, Bénin, 1997.
[21]. D.Hillel, L'eau et le sol, Principes et processus physiques, Accadémie press, New-York, 1974.
[22]. A.Musy, et M.Soutter, Physique du sol, Presses Polytechnique et universitaire Romandes, Centre Midi, CH-10-15 Lausanne-suisse, 1991.
[23]. P.E.Rijtema, and A.Aboukhaled, Crop Water use. In: FAO regional office for the near East (Eds.), Research on crop Water use salt affected soils and drainage in the Arab Republic of Egypt, 1975.
[24]. J.Doorenbos, et A.H.Kassam, Réponse des rendements à l'eau, Bulletin d'irrigation et de drainage N°33 FAO, Rome, 1987.
[25]. M.M.Hanafi, S.M.Shahidullah,M. Niazuddin, Z.Abd Aziz, and C.H.Mohammud, Crop water requirement at different growing stages of pineapple in BRIS soil, Journal of Food, Agriculture and Environment, 8(2), 2010, 914 – 918.
[26]. R.Nicou, etJ.L.chopart, Travail du sol et propriétés physiques du sol en zone semi-aride ouest-africaine,1992.
[27]. Z.Kouyate, etG.W.Wendt, Gestion de l'eau et de la fertilité du sol au Mali, Soil Water Balance in the Sudano-Sahelian Zone, 199, 2001, 339-344.
[28]. M.Yemefack, L.Nounamo, N.Rosaline, and P.Bilong, Influence des pratiques agricoles sur la teneur en argile et autres propriétés agronomiques d'un sol ferrallitique au sud Cameroun, Tropicultura, 22(1),2004, 3-10.
[29]. L.Roca-Pérez, C.Martínez, P.Marcilla, and R.Boluda, Composting rice straw with sewage sludge and compost effects on the soil-plant system, Chemosphere, 75, 2009, 781-787.
[30]. J.L.Hatfield, T.J.Sauer andJ.H.Prueger, Managing soils to achieve greater water use efficiency, Agronomy Journal, 93, 2001, 271-280.
[31]. M.Tejada, J.L.Gonzalez, Crushed cotton gin compost on soil biological properties and rice yield, European Journal of Agronomy, 25, 2006, 22-29.
[32]. G.A.Agbahoungba, Dynamique de la matière organique d'acacia auriculaeformis (cunn. a.) ex benth.(mimosaceae) et influence de la fertilisation organique et minérale dans les systemes agroforestiers d'acacia à base de maïs zea mays l. (poaceae), dans le sud du Benin, Université de Cocody-Abidjan, Thèse de doctorat, 2007, 276 p.
[33]. M.K.Eusufzai, K.Fujii, andI.Iiyama, Decomposition of Surface Applied and Buried Residue Biomass, Geological Society of America Abstracts with Programs, 40(6), 2008 358-365.
[34]. P.V.Azevedo, C.B.de Souza, B.B.da Silva, andV.P.R.da Silva, Water requirements of pineapple cropgrownin a tropical environment, Agricultural Water Management, 88, 2007, 201-208.
[35]. R.Poss, Transferts de l'eau et des éléments minéraux dans les terres de barre du Togo, Conséquences agronomiques, Université Paris 6, France, Thèse de Doctorat, 1991, 335 p.