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Soil moisture storage and water-use efficiency of maize planted in succession to different fallow treatments**

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Abstract. Soil water storage and crop water use efficiency (WUE) were monitored in a randomised complete block design experiment set up on a 0.7 ha field plot with treatments that consisted of five fallow treatments, namely Guinea grass (*Panicum maximum* Jacq.PAF), Kaliko plant (*Euphorbia heterophylla* Linn. EUF), tropical kudzu (*Pueraria phaseoloides*(Roxb) Benth.(PUF), native fallow without fertilizer (NNF), and native fallow with fertilizer applied during subsequent cropping (NFF). The fallow crops were ploughed under and cultivated to maize (*Zea mays*) in the subsequent season and the water storage and crop water use efficiency were monitored. Fluctuations in soil water storage were found to be dependent on rainfall and soil profile characteristics. The amount of water stored in the soil was consistently the highest under NNF (25%) and the least under PUF (19%). Maize dry matter yield (0.46 - 3.38 t ha^{-1}) and WUE (0.011 t ha^{-1} mm^{-1} - 0.030 t ha^{-1} mm^{-1}) were the highest at 29 days after planting (29 DAP) and at 45 DAP under TPU. At 75 DAP dry matter yield for EUF improved (8.88 t ha^{-1}), while NFF was the highest (10.12 t ha^{-1}). Water use efficiency calculated in terms of grain yield (WUE-GY) having a value of 0.018 t ha^{-1} mm^{-1} was found to be the highest under NFF, followed by the results from EUF and PUF (0.015 t ha^{-1} mm^{-1}), while NNF (0.011 t ha^{-1} mm^{-1}) was significantly (p 0.05) the lowest. Short fallow with *Pueraria phaseoloides,* therefore, appeared to be an attractive alternative for sustaining the water use efficiency of continuously cropped farmlands.

Keywords: water use efficiency, maize, *Pueraria phaseoloides*, *Panicum maximum*, *Euphorbia heterophylla,* fallow, TDR

INTRODUCTION

Soil water utilization is an important limiting factor to crop production. The knowledge of available water storage is very important in efficient management of soil and water. A study of water storage, a component of field water cycle, makes consideration of field water balance necessary. The water balance of a field is an itemized statement of all gains (rainfall and irrigation), losses (evapotranspiration, run-off and drainage) and changes of storage of water occurring in specified boundaries during a specified period of time. Efficient management of soil moisture storage can thus be achieved by manipulating the field water balance. This involves monitoring and controlling different soil water flow processes, including infiltration, redistribution, drainage, evaporation and water uptake by plants. Organic matter plays a prominent role in controlling these physical processes.

There is a growing interest in improving indigenous techniques to increase productivity so as to encourage adoption by farmers. Aboyade (1990) suggested that efforts be directed at bridging the gap between indigenous and global knowledge systems as a way to enhance transfer, acceptance and adoption of modern knowledge systems. While fallow had been reported to improve soil physical, chemical and biological attributes (Aina, 1979; Hauser and Asawalam, 1998), long fallow (more than 5 years) is becoming obsolete as a result of demographic pressure giving way to short fallow (2 to 3 years). Short fallow is practiced through a cropped fallow system. Some species of fallow crops have proved effective (Adediran *et al.*, 2003; Aina, 1979), while others are being investigated.

Maize is an important staple food that is widely eaten in both raw and processed forms in Nigeria. It constitutes a major source of basal energy in livestock feed industries. The

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fact that maize is sensitive to water stress typical of post-rainy season has been reported (Hulugalle and Lal, 1986). Agele (2002) also noted that soil water reserve was not sufficient to meet crop evapotranspirative demand for maize in the post rainy season in south western Nigeria. This study was aimed at comparing the influence of different fallow treatments on soil water storage and water use efficiency under post fallow maize.

MATERIALS AND METHOD

The field experiment was carried out at Obafemi Awolowo University, Teaching and Research Farm (T&RF), Ile-Ife (latitude 7°25′ N, and longitude 4°39′E), Nigeria. It is located in the rainforest ecosystem in the south-western region of Nigeria, with a mean annual rainfall of about 1400 mm which is bimodally distributed with peaks in June and September. Average annual insolation/radiation is 18.7 MJ m^{-2} day^{-1}. The soil - derived from coarse grained granite and gneisses – is classified at series level as Iwo series (Periaswamy and Ashaye, 1982) and as Oxic Tropudalf according to the USDA system (Soil Survey Staff, 1992). The soil is well drained with the surface texture varying from sandy loam to sandy clay loam. It is located on a 1-2 % slope.

The experimental field was 0.7 ha and was cleared, ploughed and planted to maize in late season of 2003 (October, 2003) to homogenize the soil before planting fallow crops. Thereafter, in early season of 2004, the field was laid out in randomised complete block design (RCBD). Each plot was 10 x 15 m with 5 m hedgerows between blocks and 3 m hedgerows separating the treatments within each block. The treatments were: NNF (native fallow), NFF (native fallow with addition of fertilizers during cropping), PAF (*Panicum maximum* J.), EUF (*Euphorbia heterophyllum* L.), and PUF (*Pueraria phaseoloides* B.). The treatments were replicated four times. The fallow species were ploughed under in September, harrowed and thereafter sown to early maturing maize variety (TZR-Y) the same month of September, 2004. An electronic rain gauge was installed in the middle of the field and used in complement with an automated weather station which was located about 150 m away from the field plot. Post-planting weeding was carried out using both Atrazine applied at the rate of 150 g 15 l^{-1} as pre-emergence herbicide and gramozone applied at the rate of 75 cl 15 l^{-1} as post-emergence herbicide. Single dose of fertilizer (NPK 15:15:15) was also applied to the NFF plots by side dressing at the rate of 333 kg ha^{-1}. The crops were harvested on December 8th, 2004.

Access pipes made of 10 cm diameter PVC tubes were installed at two locations (5 m apart) per experimental plot and the volumetric moisture content was determined with a portable time domain reflectometry (TDR100 by Spectrum Technologies, Illinois, USA) device. Soil moisture content was determined at different depths, at 12 cm intervals, from soil surface to the depth of 60 cm representing the rooting depth of maize.

The water balance equation for the root zone used is represented as (Hartmann, 1998):

$$(P+C) - (R+D+ET) = \quad S$$

where: P+C – gains, R+D+ET – losses, S – changes in storage, P is rainfall (mm) obtained through the electronic rain gauge, C is capillarity which is assumed negligible in this study, R is run off (mm) which was assumed zero since erosion was negligible on the plots with <2% slope. Drainage component D was also considered negligible being a post-rainy season planting. The potential evapotranspiration (ETo) was computed from the obtained climatic data as based on the FAO method (Allen *et al.*, 1998), while the crop evapotranspiration (ETc) was computed from the water balance equation. The above-ground shoot biomass at 29 days after planting (DAP), at tasselling (45 DAP) and at maturity (75 DAP) were sampled at three (3) locations per plot to determine dry matter yield. Crop water use efficiencies were computed on dry matter basis at 29 DAP, 45 DAP and 75 DAP and yield basis at harvest. The data collected were analysed using the ANOVA and GLM subroutines of SAS package (SAS Institute, 1988) based on the experimental design.

RESULTS AND DISCUSSION

Soil water storage

Table 1 presents the climatic information during the year of study (2004). Soil moisture increased down the profile under all treatments (Fig. 1) and was more dependent on rainfall than on treatments. Soil water at various depths was consistently the lowest under Pueraria fallow compared to the others, while the native fallow plots consistently had the highest moisture contents at depths. This trend is reflected in the moisture storage (Fig. 2) of the soils where Pueraria treatments also consistently had the lowest volume of water stored compared with the other treatments. This effect became more prominent with progressive maize crop maturity. Soil under Pueraria showed a comparatively pronounced decrease in water storage starting from 9th November (48 DAP) which coincided with the onset of tasselling. High level of water demand by maize (Plaut, 1995), soybean (Choi *et al.*, 1996; DeBruyn *et al.*, 1995), *Capsicum anuum* L. (Beese *et al.*,1982) and *Capsicum chinense* Jacq (Jaimez *et al.*, 2000) at reproductive stage has been reported. The reason for low soil moisture storage under Pueraria treatment may be explained by higher maize biomass and the consequent high demand for water by maize on the Pueraria plots. A similar result was observed by Zougmoré *et al.* (2004) in Burkina Faso under organic

Table 1. Mean monthly climatic information for the period under study (2004)

Month	Temp. max. (°C)	Temp. min. (°C)	Humidity (%)	Wind speed (km h^{-1})	Sunshine (h)	Solar rad. (MJ m^{-2} d^{-1})	ETo (mm d^{-1})
January	32	20.2	56.0	71	5.6	16.3	3.71
February	33.7	23.5	78.0	104	4.3	15.3	3.79
March	33.6	24.6	71.0	159	6.9	20.1	5.44
April	31.9	24.9	73.4	154	7.0	20.3	5.18
May	31.5	25.5	71.0	126	7.1	19.8	4.96
June	29.4	26.4	78.2	128	7.1	19.3	4.46
July	27.1	25.1	82.7	139	7.1	19.5	4.15
August	27.5	25.5	80.0	140	7.0	19.9	4.36
September	28.7	24.7	85.6	118	6.9	20.0	4.36
October	29.9	25.9	80.3	99	6.8	19.2	4.39
November	31.7	23.1	68.0	72	6.7	18.0	3.96
December	31.4	17.6	63.0	105	6.7	19.0	3.85
Average	30.7	27.0	73.8	114.6	6.6	18.7	4.36

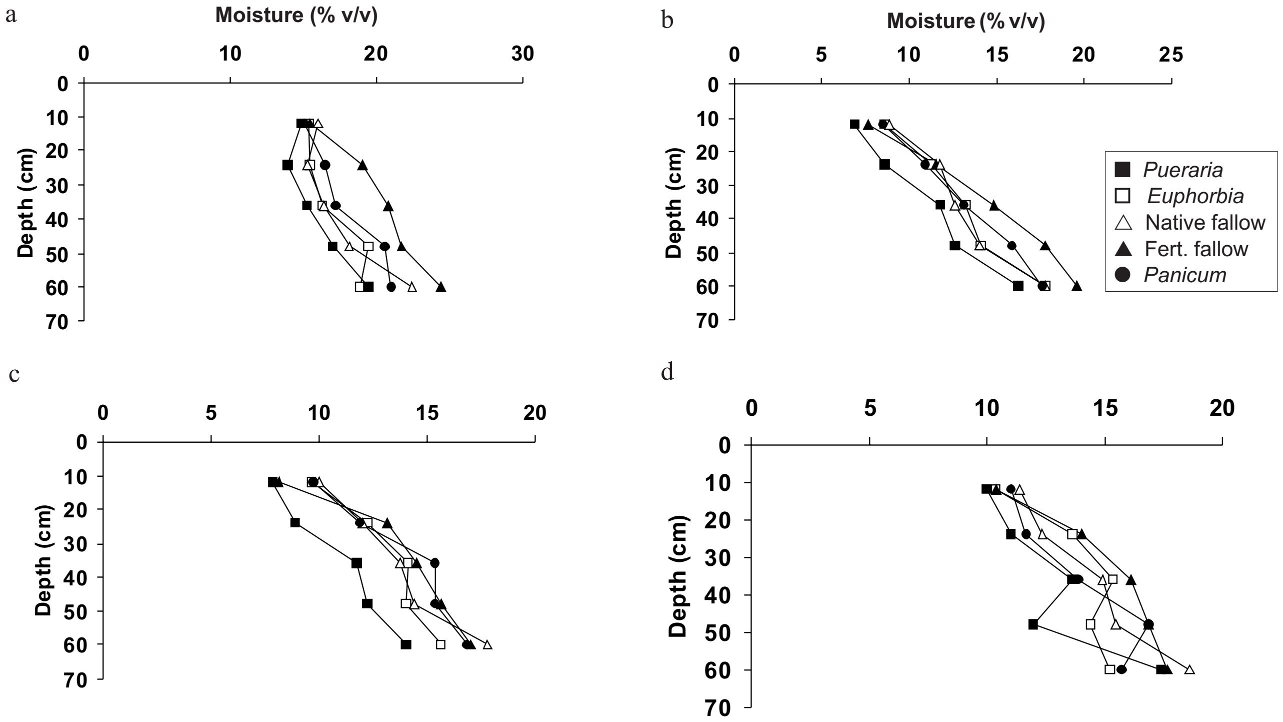

Fig. 1. Moisture distribution with depth at different sampling dates: a – 3rd, b – 9th, c – 17th, and d – 24th in the November of 2004.

material treated plots which had less moisture stored due to more evapotranspirative demand of the more vigorous crops on organic matter treated soils. According to Vetterlein and Marschner (1994), an important relationship between nutrient supply and soil water balance is an increase in plant shoot size, due to improved nutritional status and, thereby, increase in the water requirement of the crop. Also the modification of soil structure by *Pueraria*, resulting in improved drainage, might have also contributed to this trend. This corroborated the findings of Salako *et al.* (1999) who observed that a continuously cropped subplot under Pueraria system had consistently more stable aggregates.

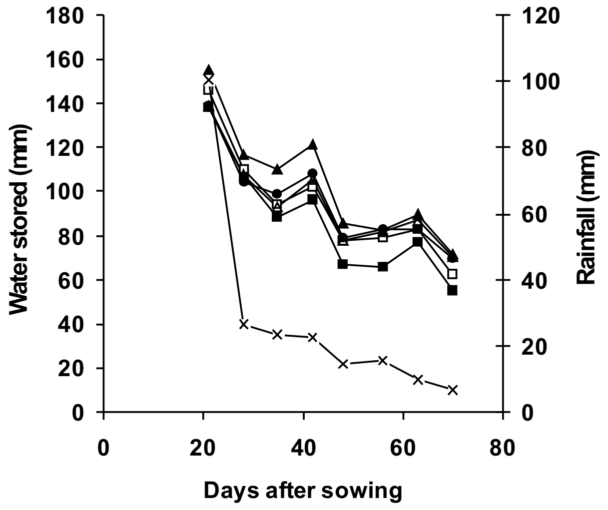

Fig. 2. Total moisture stored in the root zone at different periods of the growing season. Explanations as in Fig. 1, × – rainfall.

As shown in Fig. 2, fluctuations in soil moisture storage were mainly influenced by the rainfall pattern. This was in agreement with the observation of Bullied and Martin (1999) who noted that soil water content between the early August period and late fall were related to precipitation, with greater recharge associated with higher precipitation levels. Narain *et al.*, 1998, shared a similar view when they reported that profile moisture was much better during the post-monsoon winter season than the in the pre-monsoon summer period. There was no significant difference in soil moisture storage among the treatments except between 40 and 50 DAP when *Pueraria* plots stored the least water.

Crop evapotranspiration and water balance

The crop evapotranspiration (ETc) of maize as computed from the water balance equation is presented in Table 2. As shown in Fig. 3, there was no significant (p 0.05) difference in the ETc values under the different treatments at the initiation of the study, but from about 50 DAP onwards the Pueraria and the native fallow treatments had consistently higher ETc compared to other treatments. The ratio of ETc to ETo is an indication of crop water demand (Kozak *et al.*, 2006). A higher value of ETc compared to ETo value is an indication of a condition of water stress. In Table 2, the water stress index was below 100 % on most of the indicated dates, under all treatments. However, Fig. 4 reveals some days in which the ETo was less than ETc for all the treatments at 25 and 45-48 DAP.

Dry matter yield and crop water use efficiency

At the earlier stage of growth (up to 45 DAP), Pueraria fallow gave the best yield and came next to the native fallow plot with fertilizer applied (NFF) with the highest yield at 75

T a b l e 2. Soil water balance during the late planting season (2004)

Treatments	Date	Rainfall	S	ETc	ETo	Stress index*
Pueraria	13/10	18.6	-1.80	20.60	81.06	25.41
	20/10	10	-1.20	11.20	36.01	31.10
	27/10	12	-24.30	36.30	34.73	104.52
	3/11	20	8.10	11.90	33.53	35.49
	9/11	30	-29.25	29.25	34.5	84.78
	17/11	13	-1.65	14.65	44.12	33.20
	24/11	13	11.10	1.90	35.85	5.30
	30/11	0	-21.90	21.90	28.32	77.33
Euphorbia	13/10	18.6	0.75	18.05	81.06	22.27
	20/10	10	-5.70	15.70	36.01	43.60
	27/10	12	-17.70	29.70	34.73	85.52
	3/11	20	8.10	11.90	33.53	35.49
	9/11	30	-24.60	24.60	34.5	71.30
	17/11	13	7.75	12.25	44.12	27.77
	24/11	13	4.05	8.95	35.85	24.97
	30/11	0	-20.25	20.25	28.32	71.50
Native fallow	13/10	18.6	-2.25	21.05	81.06	25.97
	20/10	10	0.60	9.4	36.01	26.10
	27/10	12	-13.50	15.4	34.73	44.34
	3/11	20	11.10	8.9	33.53	26.54
	9/11	30	-36.00	66.0	34.5	191.30
	17/11	13	-3.67	16.6	44.12	37.62
	24/11	13	7.95	5.05	35.85	14.09
	30/11	0	-18.45	18.45	28.32	65.15
Fertilized fallow	13/10	18.6	-1.15	19.45	81.06	23.99
	20/10	10	-10.50	20.50	36.01	56.93
	27/10	12	-20.40	32.40	34.73	93.29
	3/11	20	12.45	17.55	33.53	52.34
	9/11	30	-27.75	27.75	34.5	80.43
	17/11	13	3.60	9.40	44.12	21.31
	24/11	13	5.70	7.30	35.85	20.36
	30/11	0	-17.10	17.10	28.32	60.38
Panicum	13/10	18.6	-0.50	19.30	81.06	23.81
	20/10	10	3.60	6.4	36.01	17.77
	27/10	12	-15.30	27.30	34.73	78.61
	3/11	20	9.75	10.25	33.53	30.57
	9/11	30	-29.25	59.25	34.5	171.74
	17/11	13	3.90	9.1	44.12	20.63
	24/11	13	-0.15	13.15	35.85	36.68
	30/11	0	-13.20	13.20	28.32	46.61

*Stress index = (ETc/ETo) 100.

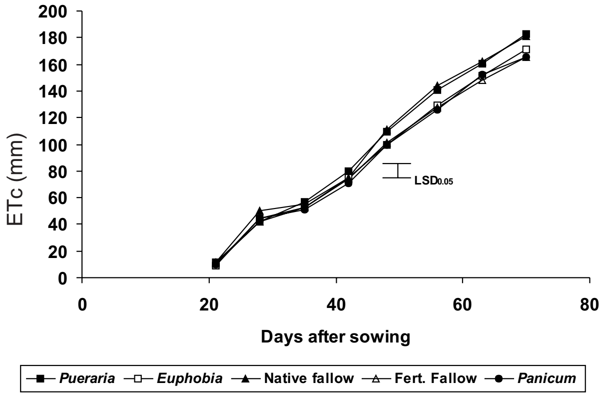

Fig 3. Cumulative crop evapotraspiration (ETc) for maize.

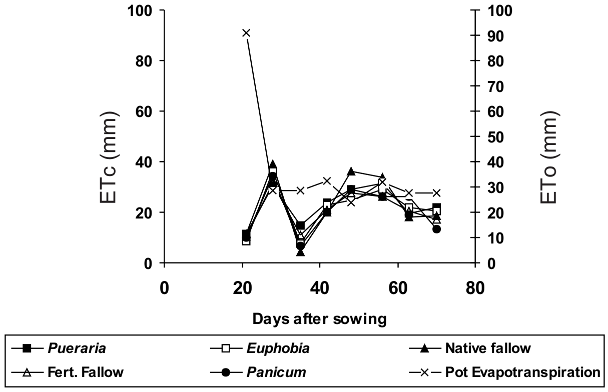

Fig 4. Comparison of potential evapotranspiration (ETo) with actual crop evapotranspiration on different days after sowing.

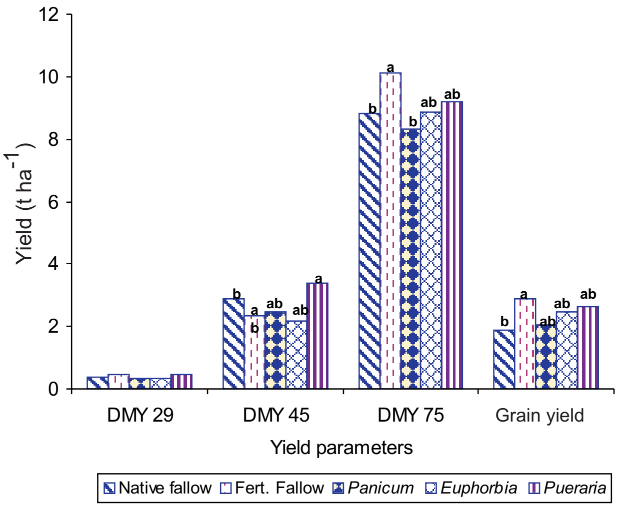

Fig 5. Maize crop water use efficiency under different fallow treatments. (Bars carrying the same letters are not significantly different at p 0.05 according to Duncan's multiple range test while those without letters are not significantly different).

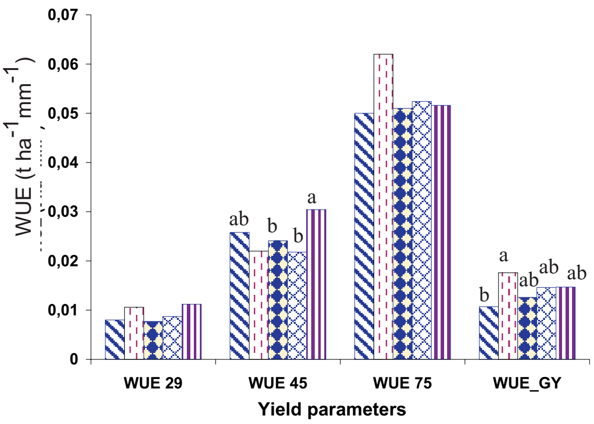

Fig. 6. Water use efficiencies of maize in response to different fallow treatments at 29 (WUE 29), 45 (WUE 45), 75 (WUE 75) days after planting and at grain harvest (WUE-GY). (Bars carrying the same letters are not significantly different at p 0.05 according to Duncan's multiple range test while those bars without letters are not significantly different). Explanations as in Fig. 3.

DAP (Fig. 5). The result observed for grain yield followed a similar trend as that obtained with dry matter yield at maturity (Fig. 5). The highest value was observed under fertilized fallow (2.87 t ha^{-1}), followed by Pueraria fallow (2.63 t ha^{-1}) and then by the other fallow treatments. Apart from the thick ground cover that conserved soil moisture by reducing evaporation and improved the soil organic matter status, Pueraria is a legume and is known to fix nitrogen, which improves nutrition in the soil. This supported the view of Narain *et al*. (1998) who explained that yield relies on the synergy between water availability and soil nutrient status. The highest value of about 10.12 t ha^{-1} under fertilized fallow, NFF, observed at DMY 75, was primarily due to the single dose fertilizer application, administered close to tasselling. Positive response of crops, including maize, to fertilizer has been well reported (Aduayi and Ekong, 1981; De Barros, 2002; Gaiser *et al*., 2004).

Crop water use efficiency is computed as the grain (WUE-GY) or dry matter yield (WUE-DMY) per mm of water used *ie* cumulative ETc. There was no significant difference in WUE among the treatments. There was, however, a consistently highest WUE recorded under *Pueraria* treatments at 29 DAP and 45 DAP compared to the other treatments (Fig. 6). The *Euphorbia* treatments had the least WUE at 45 DAP but competed with *Pueraria* and *Panicum* at maturity, while TNF was the least. At maturity, TFF was highest. Nutrient deficiencies can reduce water use efficiency due to reduced yield potential and greater soil evaporation (Fisher and Turner, 1978). Under similarly rainfed conditions, Onken and Wendt (1989) found a positive effect of increasing N on grain WUE of four sorghum genotypes.

Water and nutrient availabilities were found to interact to increase WUE until water becomes limiting, at which point further nutrient input did not increase WUE. In this case the highest dry matter WUE recorded under *Pueraria* may be attributed to both physical and chemical improvements of soil properties under this treatment. The N supplying ability of *Pueraria* by the N-fixing bacteria in its root noodles is well reported.

The water use efficiency on the basis of grain yield WUE-GY (0.018 t ha^{-1} mm^{-1}), on the other hand, showed fertilized fallow to be significantly (p 0.05) higher followed by cropped fallow species (with TPU and TEU having an equal edge), while native fallow (0.011 t ha^{-1} mm^{-1}) was least significant. Apart from increasing yield as mentioned earlier, fertilizer has been reported to allow rapid growth of the canopy that shades the soil surface, thereby reducing the proportion of the total water that is evaporated (Cooper *et. al*., 1987). More soil water and nutrient uptake will therefore be available for grain production. This is in agreement with the experiments conducted with millet in Niger (Gregory, 1988), sorghum (Hunderkar *et al*., 1999; Zaongo *et al.*, 1997) and maize (Vegh *et al*., 1998).

CONCLUSIONS

1. The soil water storage observed in this study was influenced by rainfall distribution while the treatments imposed had an insignificant effect.

2. Maize grown on plots that were previously under native fallow followed by fertilizer application performed best in terms of dry matter and grain yield and water use efficiency.

3. When the economic cost of production is considered along with adverse side effects of inorganic fertilizer, short fallow with *Pueraria phaseoloides* appeared to be an attractive alternative to economically sustaining the water use efficiency of continuously cropped farmlands.

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