EFFECTS OF CROP RESIDUE-MULCH ON CROP EVAPOTRANSPIRATION AND WATER USE EFFICIENCY OF SORGHUM AND MILLET IN MAIDUGURI, SEMI-ARID NIGERIA.

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ABSTRACT
A one-year research was conducted under rain-fed conditions at two sites to determine the effects of different rates of rice bran-mulch on crop evapotranspiration and water use efficiency of sorghum and millet in Maiduguri, Semi-arid North-east Nigeria. The experiment was laid out in a split-plot design with test crops as the main-plot, and residue rates as the sub-plot treatments, giving a total of 6 treatments, replicated four times. Profile moisture content (0 – 200 cm depth) was determined using calibrated neutron probe, and gravimetrically (0 – 30 cm depth only). Grain yield was determined at crop maturity. Seasonal crop evapotranspiration, crop water use efficiency and rainfall use efficiency were estimated. Data collected were subjected to statistical analysis (ANOVA). The differences in seasonal crop evapotranspiration, crop water use efficiency and rainfall use efficiency observed between sorghum and millet at the two sites could be attributed to inherent differences between the two crops. Fifteen t/ha mulch rate resulted in significantly lower ($P \leq 0.05$) seasonal crop evapotranspiration than both 0 and 10 t/ha mulch rates by 17.68 mm and 11.30 mm, respectively. Both crop type and mulch treatment did not significantly affect crop evapotranspirational water use efficiency and rainfall use efficiency.
Keywords: Crop residue mulch, sorghum, millet, crop evapotranspiration, water use efficiency and Semi-arid Nigeria.

INTRODUCTION
Under rain-fed agricultural systems in the Semi-arid zone, characterized by low, variable and undependable rainfall, increases of crop yield per unit area depends on the most efficient use of the limited rainfall (Sivakumar and Wallace, 1991). The onset, cessation and distribution of the rains, as well as the prolonged dry spells which usually occur during the growing season adversely affect crop growth and yields (Fajemisin, 1991). Studies have shown that in Semi-arid tropics, seasonal distribution of rainfall and the rate at which it is lost by evaporation are more serious constraints to agricultural production than low annual rainfall (Monteith, 1991; Sivakumar and Wallace, 1991).

In the Semi-arid North-east Nigeria, temperature is quite high, and potential evapotranspiration rates exceed annual rainfall by a factor of 2-3 or more in most of the months, except during the rainy season (De, 1991; Laryea, 1992; Carter, 1995). The soils are generally sandy in nature, poorly structured and inherently low in fertility, organic matter content and water holding capacity (Yandev and Sachan, 1985; Rayar, 1988; Chiroma, 1996). These unfavourable soil and climatic conditions in Semi-arid regions have been noted to have serious negative impact on rain-fed agriculture (Grema and Hess, 1994).

Studies carried out in Semi-arid Northeast Nigeria have shown that management practices such as incorporation of crop residues and mulching conserve rainfall and improve water use by crops (Alhassan, *et al.*, 1998; Chiroma, 2004; Chiroma, *et al.*, 2003). The presence of crop residue-mulch on the soil surface has been reported to decrease the evaporation of soil water, retard surface runoff, enhance infiltration and improve soil capacity to store water for crop use (Odofin, 2005b; Sow, *et al.*, 1997; Chiroma, *et al.* 2003; Rao, *et al.*, 1998). Enhancement of crop water use efficiency, growth and yield in Semi-arid regions have been achieved with use of crop residues. The application of crop residues improved soil physical condition (Chiroma, 2004; Alhassan, *et al.*, 2008) and conserved soil moisture (Rao, *et al.*, 1998; Odofin, 2005a and b). Despite the importance of crop residues in the improvement of soil conditions, the competing use of crop residues as animal feeds, fuel, bedding and construction materials have limited their use for soil and water conservation purposes. Rice bran faces less competition, especially, as livestock feed, and could effectively be used as mulching material. The rates of residues (wheat straw and wood shavings) applied in the study area range between 4 and 10 tons/ha (Chiroma, *et al.*, 2005; Chiroma, 2004).

Sorghum (*Sorghum bicolor* (L.) Moench) and millet (*Pennisetum glaucum* (L) Br.) are important crops in Semi-arid regions of Nigeria, Ghana and Ethiopia amongst others, primarily as major staples (Chiroma, *et al.*, 2003; Ojeniyi, *et al.*, 2009). They are usually grown as sole crops, or intercropped with cereal legumes such as cowpea and groundnuts. Sorghum and millet are mainly grown for their grains. In Semi-arid regions, these two crops are only grown once a year under rainfed condition.

The low and erratic distribution of rainfall in Semi-arid regions coupled with high evapotranspiration rates and poor soil conditions imply that crops grown in such environments are often exposed to varying levels of water stress and inadequate soil nutrient availability. In the Semi-arid regions, an appreciable amount of rainfall in an average year is lost as direct evaporation from the soil. This huge amount of water could be conserved and used productively for the growing of crops without necessary increases in rainfall amounts. In view of the above soil and climatic constraints to crop production, a major challenge for improving crop yields without increases in rain water supply is to minimize evaporation, make efficient use of the limited rainfall, enhance infiltration and utilization of the stored water by crops. The focus of this study, therefore, is to employ a residue management practice that would minimize evaporative losses and make efficient use of scanty rainfall.

MATERIALS AND METHODS

Description of the Study Area

The study was carried out at two sites within the University of Maiduguri, Borno State, Nigeria. Site 1 is located at 11° 49′ N, 13° 13′ E and 324 m above mean sea level, while Site 2 is located at 11° 49′ N, 13° 12′ E and 327 m above mean sea level. The two sites had been set aside exclusively and found suitable for teaching and research purposes over a long period of time.

The climate of the study area is the seasonal wet-dry, Semi-arid type. The annual rainfall ranges between 600 and 900 mm as observed during a ten-year period, 2000 to 2009 (Department of Meteorological Services, Maiduguri). Onset of rainfall on the average occurs in mid-June, while cessation occurs towards the end of September. Also, temperature of the study area could be as low as between 18 and 20 °C during the harmattan period, and as high as between 38 and 42 °C during the peak period of the dry season, between January and April (Department of Meteorological Services, Maiduguri). Furthermore, potential evapotranspiration usually exceeds rainfall for about 8 to 9 months during a given year (Grema and Hess, 1994) except during the rainy periods.

The soils of the study area are developed from aeolian sand deposit. Studies carried out in the study area shows a deep (0- 200 cm) sandy loam soil at Site 1, whereas at Site 2, 0 – 63, 63 – 100 and 100 - 200 cm depths indicated sandy loam, sandy clay loam and sandy loam texture, respectively (Eze, 2015).

Treatments and Experimental Design

The experiment comprised of two test crops (sorghum and millet) and three rates (0, 10 and 15 tons/ha) of rice bran residue laid out in a split-plot design, replicated four times. The 0 ton/ha treatment (Control) represents the common cultural practice in the study area, while residue application rates (10 and 15 tons/ha) represent the introduced technology.

Agronomic Practices

The edges of the plots measuring 8 m x 4 m were bunded to prevent runoff and run-on. Rice bran was uniformly applied on the soil surface. Five to six Apron star treated sorghum (var. ICSV III) and millet (var. LCIC MV-2 (LCIC 9702)) seeds were hand-sown per hole on the flat. Sorghum seeds were sown at a spacing of 40 cm within rows and 75 cm between rows, while millet seeds were sown at a spacing of 50 cm within rows and 75 cm between rows (BOSADP, 1993). The seedlings were thinned to two plants per stand two weeks after planting to give a plant population of about 66,666 and 53,333 plants per hectare for sorghum and millet, respectively. Recommended fertilizer rate of NPK 64:32:30 kg/ha for sorghum and millet was applied uniformly on all the treatment plots in the seed row as side placement and covered up with soil (BOSADP, 1993). Fertilizer sources were Urea (46 % N), Single superphosphate (18 % P_2O_5) and NPK 15:15:15. Because of the sandy nature of the soil profile, two split doses of the N were applied, first at two weeks after planting, following thinning, and second at six weeks after planting as side placement. Removal of weeds was carried out manually using hand-hoe as at and when due. Harvesting was done at physiological maturity (at 12 weeks after planting).

Grain Yield Measurement

Grains obtained from the net plot (6 m^2 and 4.5 m^2 for sorghum and millet, respectively) were weighed after thorough sun-drying following crop harvest. Yield was expressed in kg/ha.

Soil Moisture Content

Access tubes were installed in three replicates of each treatment for the repetitive measurement of soil moisture content at various soil depths. Soil moisture content (volumetric moisture content, θv) was measured weekly using a calibrated neutron probe (Eze, *et al.*, 2007) at 0.1 m interval down to 2.0 m depth (i.e. below the rooting depth) throughout the study period. Volumetric moisture content, θv (cm^3/cm^3) was computed from the model equation obtained from the average calibration curve:

$$\theta v = 0.0666x + 0.0717 \quad \text{.......................(3)}$$

Where x represents count ratio, determined as the ratio of the field test count to the shield count.

Also, gravimetric water content was determined on soil samples collected from the surface, 0 – 15 cm depth and subsurface, 15- 30 cm soil depth. Moist soil samples were collected, weighed and oven-dried at 105 ^{0}C for 48 hours (Brady and Weil, 1999).

Soil Water Balance Studies

Soil water balance was determined from the equation below:

$$\Delta S = P + C - ETcrop - D - R \quad \text{................ (4)}$$

Where, P is rainfall, C is capillary rise from the water table, ETcrop is crop evapotranspiration (water use), D is the drainage out of the root zone and R is runoff (-) or run-on (+) over a specified time period. Since the water table in this area is deeper than 10 m (Grema and Hess, 1994), and the soil is light-textured and possesses a high infiltration capacity, then, capillary rise would be quite negligible. Also, the sides of the plots were raised to prevent run-off/run-on; hence, capillary rise, run-off and run-on could be ignored. Therefore, evapotranspiration or water use was estimated from equation below, after determining the value of each of the factors on the right hand side of the equation (Gregory, 1991):

$$ETcrop = P - \Delta S - D \qquad (5)$$

Drainage (D) occurring below the root zone was determined by the method of Zaongo, *et al.* (1994). The drainage factor, D, that was used in the computation of water use (ETcrop¬) was that occurring between the bottom of the root zone and the measured profile (2.0 m). Drainage below the root zone was estimated as the sum of change in water content between 1.0 m and 2.0 m for sorghum, and 0.9 m and 2.0 m for millet. Some of the water stored above 2.0 m will be lost through drainage as the growing season progresses. Rainfall was measured using manual rain gauge installed at the two sites prior to the commencement of the experiment (Eze, 2015).

Water Use Efficiency

Water use efficiency was determined for both crop (evapotranspirational) and seasonal rainfall. Evapotranspirational water use efficiency (WUE (ETcrop)) was determined as the ratio of grain yield in kg ha^{-1} to seasonal crop evapotranspiration (ETcrop) in mm, while rainfall use efficiency (WUE (P)) was estimated as the ratio of grain yield to seasonal rainfall water supply.

Data Analysis

The data obtained were analyzed statistically (Analysis of Variance) using Statistix 8.0 (2005). Means separation was carried out using Duncan's Multiple Range Test (DMRT) at 5 % significance level.

RESULTS

Seasonal Crop Evapotranspiration and Water Use Efficiency

The seasonal crop evapotranspiration, crop evapotranspirational water use efficiency (WUE (ETcrop)) and rainfall use efficiency (WUE (R)) of sorghum and millet are presented in Table 1. The seasonal crop evapotranspiration, ETcrop (water use) of sorghum and millet was significantly ($P \leq 0.05$) affected by crop type at Sites 1 and 2, and in the combined data. The ETcrop of sorghum was 5, 1 and 3 % significantly higher than that of millet at Sites 1 and 2, and in the combined data, respectively.

Mulch application rate had no significant effect on ETcrop, except at Site 2. The highest mulch application rate resulted in significantly lower ETcrop than both 0 and 10 t/ha mulch rates at Site 2. ETcrop did not differ significantly between 0 and 10 t/ha mulch application rates at Site 2. There was no significant interaction effect of crop type and mulch application rate on ETcrop at Sites 1 and 2, and in the combined data. A similar trend was observed in which crop evapotranspirational water use efficiency (WUE (ETcrop)) and Rainfall use efficiency (WUE (R)) of sorghum and millet were significantly ($P \leq 0.05$) affected by crop type in the combined data only. (WUE (ETcrop)) and (WUE (R)) of sorghum were 37 and 39 %, respectively, higher than those of millet. Mulch treatment and the interaction of crop type and mulch rate had no significant influence on both (WUE (ETcrop)) and (WUE (R)) at Sites 1 and 2, and in the combined data.

At Site 1 in the sorghum plots, crop evapotranspiration was found to be 5.90 % higher than total seasonal rainfall under 0 t/ha mulch treatment, while 10 and 15 t/ha mulch rates resulted in evapotranspiration that were 6.79 and 5.96 %, respectively, higher than total seasonal rainfall, during the growing season. In the millet plots, evapotranspiration under 0, 10 and 15 t/ha mulch treatments were 0.32 %, 1.60 % and 1.31 % high-

Table 1: Effects of crop and mulch on seasonal crop evapotranspiration (mm), crop water use efficiency (kg/ha/mm) and rainfall use efficiency (kg/ha/mm) of sorghum and millet at Maiduguri, 2009.

	Seasonal crop evapotranspiration			Crop water use efficiency			Rainfall use efficiency		
Treatment	Site 1	Site 2	Combined	Site 1	Site 2	Combined	Site 1	Site 2	Combined
A: Crop type									
Sorghum	467.90a	460.52a	464.11a	5.68a	12.87a	9.28a	6.03a	12.35a	9.19a
Millet	445.23b	454.53b	449.88b	5.15a	8.44a	6.79b	5.21a	8.01a	6.61b
SE ±	3.81	0.95	1.87	0.72	1.47	0.41	0.72	1.41	0.38
B: Mulch rate									
0 t/ha	454.20a	465.45a	459.82a	4.86a	10.46a	7.66a	5.01a	10.16a	7.59a
10 t/ha	458.98a	459.07a	459.02a	5.61a	10.61a	8.11a	5.86a	10.19a	8.02a
15 t/ha	456.52a	447.77b	452.14a	5.78a	10.90a	8.34a	5.99a	10.19a	8.09a
SE ±	2.22	4.59	3.60	0.35	0.78	1.47	0.36	0.71	1.32
Interaction									
A x B	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means with the same letter (s) in the columns are not significantly different according to Duncan's Multiple Range Test (DMRT) at 5 % level of probability.

NS: Not Significant

er than total seasonal rainfall. At Site 2, in the sorghum and millet plots, evapotranspiration generally decreased with increasing mulch application rate. Crop evapotranspiration was also observed to be higher than seasonal rainfall.

DISCUSSION

Seasonal Crop Evapotranspiration (ETcrop) and Water Use Efficiency

The difference in seasonal crop evapotranspiration (ETcrop) and water use efficiency observed between sorghum and millet at Sites 1 and 2, and in the combined data, could be attributed to inherent differences between the two crops. At Site 2, water losses from both soil and crops was lower under 15 t/ha mulch application rate compared with both 0 and 10 t/ha mulch rates due to better soil surface cover and higher crop canopy cover. In the Guinea Savanna zone of Nigeria, Odofin (2005a), reported that reduction in evapotranspiration under maize crop resulted from mulching compared with unmulched control (tillage treatments without mulch). Both crop type and mulch application rate had no significant influence on crop and rainfall water use efficiency at the two sites under study.

CONCLUSION

Results from this study showed that the difference in seasonal crop evapotranspiration (ETcrop) and water use efficiency observed between sorghum and millet is attributed to inherent differences between the two crops. Fifteen t/ha mulch application rate gave rise to significantly lower seasonal crop evapotranspiration than 0 and 10 t/ha mulch rates. Also, mulch application rate and the interaction of crop type and mulch application rate did not significantly influence water use efficiency of the two crops. It is suggested that future research should use higher rates of rice bran-mulch to assess its effects on crop performance in the study area.

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