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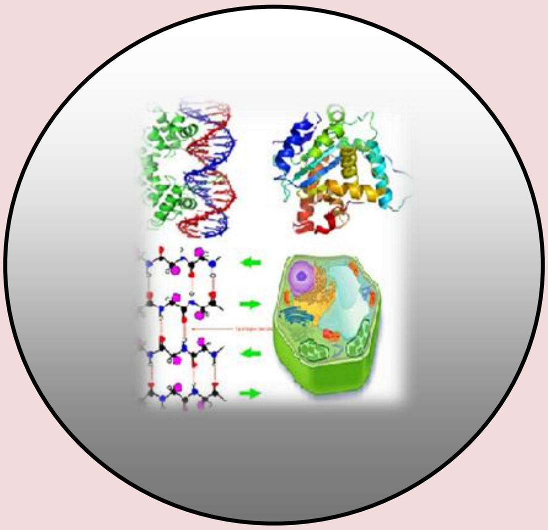

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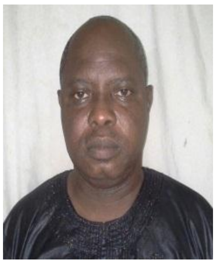

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RESEARCH PAPER

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Assessment of Water Productivity of Sorghum- Kenaf- Okra Intercrop

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ABSTRACT
The water supply for the cultivation of sorghum, kenaf and okra intercrop was investigated in Southwest, Nigeria during the 2015 and 2016 cropping seasons. The experiment comprises of two varieties of sorghum [Farin-dawa (white) and Janare (red)], one variety of kenaf (Cuba 108) and one variety of okra crops (NHAe 47-4). Selected indices, such as water use efficiency (WUE), water equivalent ratio (WER) and land equivalent ratio (LER) were calculated to compare the intercropping efficiency of land and water use to sole crops. The results showed that WUE of crops in intercrop ranged from 2.5 to 6 Kg/ha mm, LER in intercropping patterns ranged from 0.58 to 1.32 and WER ranged from 1.00 to 2.10. Okra performed excellently well in water utilization efficiency WUE, WER and LER in its intercrop with sorghum cultivars (red and white) and kenaf producing the highest yield in intercrop than other crops in mixtures. 2-tier intercrop performed better than 3-tier intercrop irrespective of mixture and resources utilization. Mono-cropping performed better than intercropping in water utilization efficiency and yield, suggesting higher productivity in monoculture over intercrop. However, water supply in rain-fed agriculture was confirmed to be efficient for sorghum- kenaf –okra intercrop in Nigeria.
Key words: WUE, WER, LER, Intercrop, Crop and Efficiency.

INTRODUCTION
Water saving agriculture' approaches whether in irrigated or rainfed production is fast becoming necessary in sustainable crop production particularly in this era of climate change. This is more so that there has been competition in fresh water usage for domestic, industrial, agricultural and environmental purposes. Globally, agriculture activities in particular crop production dominates the use of freshwater and accounts for some 70% of withdrawals from water resources (FAO 2012) as a result of increasing demand for food due to a rapidly growing world population. However, in marked contrast to domestic and industrial fresh water withdrawals, most of the water withdrawn by agriculture is lost in evaporation and transpiration. Hence, there is need for urgent improvement of productivity per unit of water consumed in agriculture. This can be achieved by developing crops that require less water to produce sufficient yield, through understanding the physiological mechanisms that determine growth and water loss, and plant response to reduced water availability. Olasantan, 2005 reported that one of the reasons majority of the traditional farmers in the tropics often practice intercropping system is to reduce evaporative water losses. Amujoyegbe *et al.*, 2013 in their work further iterated that improved crop yields and water productivity can be accomplished through *in-situ* water management, and by managing soil evaporation. They suggested that, management can be targeted at maximizing the plant water uptake capacity, which involves practices of crop and soil management to increase root water uptake of which intercropping system is crucial, provided demands for component crops are well understood.

Intercropping fiber crop with legumes and cereals has been shown to give higher returns than sole cropping (Liu, *et al.*, 2016). Thus, for sustainable agricultural production, researchers all over the world and in Nigeria in particular have not relented on their efforts at investigating both the positive and negative effects of intercropping. Kenaf cultivation and production is said to be suitable for the agronomic conditions in Nigeria (Adeniyan *et al.*, 2015) and it is gradually gaining relevance in the intercropping system in some part of the country because of its economic potential and role in the cottage fiber industry. The crop prefers area of rainfall of 500-600 mm over 4-5 months with wet and dry periods. Kenaf may be useful in alleviating global warming not only because of its absorbing potential for carbon dioxide gases due to its rapid growth rate but also its absorption rate is five time that of forest (Li *et al.*, 2012). The usual time for planting kenaf in Nigeria coincides with that of maize, cowpea, sorghum, groundnut among others (Adeniyan *et al.*, 2015). Research into kenaf with other food crop has been extensive in Nigeria (Adeniyan *et al.*, 2015), Raji, 2015) and Agbaje *et al.*, 2016). However, there are few types of research on the water consumption characteristics and water utilization efficiency of kenaf in intercrop currently. For these reasons, the objective of this research was to investigate the influence of sorghum- kenaf- okra intercropping to the increasing utilization efficiency of soil resource and field water resource.

MATERIALS AND METHODS

Description of study area

The research was conducted at the Teaching and Research farm of Federal University of Agriculture along Alabata road, Abeokuta (7° 15'N, 3°25'E) in Odeda Local Government Area of Ogun State, South Western Nigeria (Fig. 1) during the 2015 and 2016 cropping seasons. The study area is characterized by a tropical climate with distinct wet and dry seasons with bimodal rainfall pattern and mean annual air temperature of about 30°C. The actual rainfall totals during the 2015 and 2016 cropping season were 1177.2 and 1201.6 mm, respectively. However, the area is characterized by rainfall variability which is not limited to seasonal fluctuations but also includes year to year variability in the onset, cessation and duration of the rains which are also characterized by dry spells of unpredictable magnitude that may last from a few days to more than three weeks. The soil at the experimental site was categorized as a well-drained tropical ferruginous soil (A horizon of an Oxic Paleudulf of Iwo series) with 83% sand, 5% silt and 12 % clay with a pH of 6 (Olasantan, 2005).

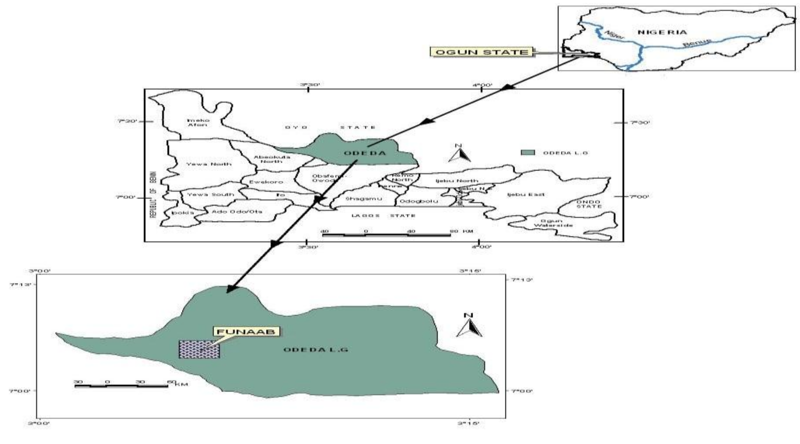

Figure 1. Location of University of Agriculture, Abeokuta within Odeda Local Government Area in Ogun State, Southwestern Nigeria.

Experimental design and field measurement

The experimental site comprised gross plot sizes of 45 m by 25 m were cleared, stumped and ridged manually with the use of cutlass and hoe during the late May which marked the early cropping seasons in the study area. Plot size was 5 m wide and 3 m long, with a walk-path of 1 m. Two cultivars of sorghum {Farin-dawa (white) and Janare (red)}, kenaf cultivar (Cuba 108) and okra crops (NHAe 47-4) were sown per hole in their respective plots at depth of 2.5 cm after the full establishment of rains on June 9, 2015 and June 29, 2016. Four seeds of sorghum and kenaf, two seeds of okra were dibbled in each plot 3 - 5 cm deep. The excess seedlings were thinned out at 20 days after sowing so as to maintain the required plant population. The seedlings were thinned to two plants per stand for sorghum and kenaf, and one plant per stand for okra. The inter row spacing of kenaf, sorghum and okra in sole were 0.75, 0.90 and 0.90 m, respectively. While the intra row spacing in kenaf, sorghum and okra in sole were 0.60, 0.60 and 0.30 m, respectively.

All the selected crops in mixture have both inter and intra row spacing as 0.9 m. A mixture of Punch and Karate herbicides was applied at the rate of 4 ml/l on equal basis and all plots were regularly weeded using traditional hoe with no fertilizer application. During each of the phenological stages, daily observation of air temperature (^oC), wind speed at a height of 2m (ms^{-1}), rainfall (mm) were made at meteorological enclosure adjacent to the experimental field. Other climatic parameters measured consumptive water used by the crop (ET) in mm is using soil water balance computation throughout the growing season (Brito, *et al*., 2011). The soil water balance equation is given as:

ET = IR + ER + ΔS + GW

In the formular, IR and ER are irrigation water and effective rainfall (mm), while ΔS and GW are change in soil moisture content and ground water contribution (mm). The sum of IR and GW during the period of this experiment was assumed to be zero. Ground water contribution was assumed to be zero because water table of the study area is far below the root zones of the experimental crops. For practical purposes, the GW was taken as zero when the ground water table is 3m below the soil surface. Irrigation was not applied throughout the growing season. The Soil moisture content was determined using the TDR (TDR 100) method mentioned in Agnieszka *et al.* (2012). The TDR contains two long probes which are buried into the soil to determine the instantaneous soil water content. Perforated PVC pipe access tubes measuring 4 inches in diameter was inserted to depths of 15 cm per plot for easy access of TDR.

The Effective rainfall (ER) is that part of rainfall that is added and stored in the soil root zone and can be utilized by crops (Farmwest, 2013). This was estimated using FAO/AGLW method as given below:

ER = 0.6 × monthly rainfall – 10 (when rainfall is < 70mm)

ER = 0.8 × monthly rainfall – 24 (when rainfall is > 70mm)

Viets (1962) defined water use efficiency (WUE in kg/ha/mm) as the ratio of crop production to that of evapotranspiration. WUE is represented mathematically as:

$$WUE = Y/_{ET}$$

Where the grain yield (Y) is measured in kg/ha

The assessment of water utilization efficiency of the intercropping population was achieved following the method of Li.*et al.* (2012) for the determination of Water Equivalent Ratio (WER) as shown:

$$WER = WER\ (A) + WER\ (B) = \frac{WUE(int.A)}{WUE(mono.A)} + \frac{WUE(int.B)}{WUE(mono.B)}$$

Where:

WER = Water Equivalent Ratio

WER (A) and WER (A) = Water Equivalent Ratio of crop A and B

WUE (int. A) and WUE (int. B) = Water Use Efficiencies of crop A and B in intercrop

WUE (mono. A) and WUE (mono. B) = Water Use Efficiencies of monoculture of crop A and B.

The WER quantifies the amount of water that would be needed in single crops to achieve the same yield as produced with one unit of water in intercrop. If the $WER > 1$, it suggests that the water utilization efficiency of intercropping is higher than that of monoculture. If $WER < 1$, it shows that water utilization efficiency of intercropping is lower than that of monoculture.

Furthermore, the Land equivalent ratio (LER) was calculated according to citation of Amanullah *et al*. (2016) as follows:

$$LER = \frac{Y_A}{S_A} + \frac{Y_B}{S_B} + \frac{Y_C}{S_C} \text{ -- } (4)$$

Where

LER = land equivalent ratio

Y_A Y_B and Y_C = individual crop yield in intercropping

S_A S_B and S_C = yield of the respective crops in sole (pure stand)

According to Amanullah *et al*. (2016), like in the definition of *LER*, the LER is a standardized index that is defined as the relative area required by sole crops to produce the same yield as intercrops. The LER is the ratio of land required by pure (sole) crop to produce the same yield as that of intercrop. LER value greater than 1 show that intercropping is significant (i.e. intercropping has a yield advantage,) while LER value less than 1 indicates that intercropping has no significant effect (there is yield disadvantage from intercropping) and when LER = 1, there is no advantage to intercropping.

RESULTS AND DISCUSSION

Intercropping is a traditional agricultural system of crop production practiced by farmers to increase land productivity and improve resources utilization efficiency in particular water supply (Chen *et al*., 2016). This is because water supply significantly influences crop developmental rates and yield. Anyam and Ijoyah (2013), and others have documented that major arable crops in humid, sub-humid and semi-arid regions are produced under mix-intercropping with poor WUE, but widely popularized.

Among such are cassava/maize/egusi melon and sorghum/maize/okra. From our study of potential of water use and productivity of sorghum cultivars in performance in intercrop of Sorghum-Kenaf- Okra during the 2015 and 2016 cropping season as shown in Table 1.It was obvious that he WUE of sorghum cultivars (red and white) in intercrop with okra enhanced the utilization of water effectively than other sorghum planting ways by having the highest WUE(6 and 7Kg/ha mmfor red and white, respectively for both experimental years) and better WER (2.10 in 2015 and 1.8 in 2016 for red and 1.87 in 2105 and 1.6 in 2016 for white) and LER (0.90 in 2015 and 0.85 in 2016 for red and 0.78 in 2105 and 0.90 in 2016 for white). The variation in WUE during the two experimental years could be attributed to the differences in the rainfall amount and other climatic conditions in 2016 cropping season which affects the yield of the component crop(s) in the mixtures.

However, it was obvious in general that intercropping modes of planting does not show advantage of improving the land utilization efficiency since the LER was less than 1 thereby producing lower yield of crop when compared to monocrop. It was further observed that sorghum performed better in sole cropping producing higher yield (1.50t/ha in 2015 and 1.44t/hain 2016 for red and 1.54 t/hain 2105 and 1.42t/hain 2016 for white) than when intercropped. The higher yield recorded in monoculture system could be attributed to competition-free environment, which led to higher leaf area at harvest. The mean grain yields of sole sorghum in the present study were reduced in 2015 and 2016 by 19%, 45% and 60%, and 16%, 43% and 61% as compared to intercropping with okra, kenaf, and kenaf and okra, respectively. Chen *et al*. (2016) reported higher grain yield of sorghum in sole cropping as compared to intercropping sorghum with maize and okra. Also, Adeniyan *et al*. (2015) reported that grain yield of sorghum reduced significantly in intercropped treatment as compared to sole crop. There was also marked difference in the yield of 2-tier and 3-tier mixed cropping systems. The lowest grain yield of sorghum was recorded in the three-tier cropping system (Sorghum- kenaf- okra).

Table 1. Water productivity of sorghum in sorghum-kenaf-okra intercrop in 2015and 2016 cropping seasons.

Treatments	Water useefficieny (WUE in Kg/ha mm)		Water equivalent ratio (WER)		Land equivalent ratio (LER)		Yield (t/ha)	
	2015	2016	2015	2016	2015	2016	2015	2016
White Sorghum	4.50	5.00	0.00	0.00	0.00	0.00	1.54	1.42
Red Sorghum	4.50	5.00	0.00	0.00	0.00	0.00	1.50	1.44
White Sorghum + Kenaf	3.00	3.00	1.17	1.1	0.90	0.82	0.98	0.69
Red Sorghum + Kenaf	2.50	3.00	1.00	1.1	0.84	0.74	0.81	0.63
White Sorghum + Okra	7.00	7.00	2.10	1.8	0.90	0.85	0.98	0.86
Red Sorghum + Okra	6.00	6.00	1.87	1.6	0.78	0.90	0.81	0.92
White Sorghum + Keanf + Okra	4.00	3.5	1.83	1.5	0.84	0.58	0.68	0.40
Red Sorghum + Kenaf + Okra	4.00	3.5	1.83	1.5	0.69	0.63	0.55	0.43

Table 2. Water productivity of kenaf in sorghum-kenaf-okra intercrop in 2015 and 2016 cropping seasons.

Treatments	Water use efficieny (WUE in Kg/ha mm		Water equivalent ratio (WER)		Land equivalent ratio (LER)		Yield (t/ha)	
	2015	2016	2015	2016	2015	2016	2015	2016
Kenaf	6.00	6.00	0.00	0.00	0.00	0.00	2.75	2.01
Kenaf + Okra	8.00	8.00	1.86	1.83	0.74	0.93	1.27	1.22
White Sorghum + Kenaf	3.00	3.00	1.17	1.10	1.20	1.32	1.18	1.11
Red Sorghum + Kenaf	2.50	3.00	1.10	1.10	1.27	1.37	1.23	1.17
White Sorghum + Kenaf + Okra	4.00	3.50	1.83	1.50	1.10	1.10	0.83	0.70
Red Sorghum + Kenaf + Okra	4.00	3.50	1.83	1.50	1.24	1.32	0.99	0.91

Unlike early maturity component crop (okra), sorghum intercropped with kenaf led to higher competition for resources and consequently, reduced the grain yield of sorghum. This might be attributed to lower leaf area index which produced less photosynthates and thereby contributed to less assimilation to different parts. Adeniyan *et al*. (2015) reported significantly lower yield when sorghum was intercropped with maize as compared to sorghum intercropped with okra. Chen *et al*. (2016) observed lowest grain yield when sorghum was intercropped with legumes.

It was also found that sorghum in okra and kenaf mixture utilizes water better than sorghum in sorghum- kenaf mixture, though with less LER and also producing fewer yields. Generally, sorghum performance in kenaf-okra intercrop was relatively consistent with the result of WER > 1 and LER < 1 indicated that the intercropping patterns had same functions and effects in the aspect of water utilization efficiency and utilization efficiency of land. This implies that sorghum performance in intercrop of kenaf-okrahad the potential to increase the utilization water in large extent but not efficient in land utilization, comparing with the single crops.
The water use and land utilization efficiency of kenaf in intercrop with sorghum and okra was also assessed during the 2015 and 2016 cropping season as shown in Table 2.Highest water utilization efficiency WUE was observed in kenaf inokra mixture with 8 Kg/ha mm in both experimental years, while kenaf insorghum cultivars (red and white) in intercrop has fewer WUE of average of 3 Kg/ha mm for both years thereby making okra in mixture enhancing the utilization of water effectively than other kenaf planting ways as in the mixture with sorghum. The kenaf in mixture with okra also produces better WER (1.86 in 2015 and 1.83 in 2016), though with lowest LER (0.74 in 2015 and 0.93 in 2016) and best yield in the intercropping systems (1.27 t/ha in 2015 and 1.22 t/ha in 2016). The low performance in kenaf in sorghum mixture compared to that of kenaf in okra could be attributed to the similarity in kenaf and sorghum maturity types which may increase the intensity and extent of competition for resources. However, it was observed in general that intercropping modes of planting has less WUE ranging from 2.5 – 4.0 Kg/ha mm for both experimental years except for kenaf and okra mixture of 8 Kg/ha mm for both years. Intercropping consistently show advantage of improving the water and land utilization efficiency since both WER and LER were greater than 1, though producing lower yield of crop when compared to monocrop. This indicated that the intercropping patterns had same functions and effects in the aspect of water utilization efficiency and utilization efficiency of land implying that kenaf performance in intercrop of sorghum-okra had the potential to increase the utilization water and land in large extent, comparing with the single crops. It was further observed that kenaf performed better in sole cropping producing higher yield (2.75 t/ha in 2015 and 2.01 t/ha in 2016) than when intercropped. It was also found that kenaf in sorghum and okra mixture also producing least yields.
Okra in intercrop with sorghum and kenaf was assessed for water and land utilization efficiency during the 2015 and 2016 cropping season as shown in Table 3. Okra performed excellently well in water utilization efficiency WUE, WER and LER in its intercrop with sorghum cultivars (red and white) and kenaf. This could be a result of least competition by okra because of its early maturity and senescence. However, It was obvious that kenaf with okra utilizes water and land effectively and produced the highest yield in intercrop than other mixtures. Kenaf inokra mixture has 8 Kg/ha mm in both experimental years and LER (1.86 in 2015 and 1.83 in 2016) and best yield in the intercropping systems (3.40t/ha in 2015 and 2.50 t/ha in 2016). This indicated that okra performed well in intercropping and in monocropping, though better off in monocropping. The higher productivity in monoculture over crop combinations in the can be attributed to lower population in intercrop according to Eastonce and Jestinos (2016).

Table 3. Water productivity of okra in sorghum-kenaf-okra intercrop in 2015 and 2016 cropping seasons.

Treatments	Water use efficieny (WUE in Kg/ha mm		Water equivalent ratio (WER)		Land equivalent ratio (LER)		Yield (t/ha)	
	2015	2016	2015	2016	2015	2016	2015	2016
Okra	15.00	16.00	0.00	0.00	0.00	0.00	4.47	3.61
Kenaf + Okra	8.00	8.00	1.86	1.83	2.00	1.91	3.40	2.50
White Sorghum + Okra	7.00	7.00	2.10	1.80	2.76	2.37	3.16	2.42
Red Sorghum + Okra	6.00	6.00	1.70	1.60	2.63	2.24	3.10	2.30
White Sorghum + Kenaf + Okra	4.00	3.50	1.83	1.50	2.55	2.49	2.07	1.70
Red Sorghum + Kenaf + Okra	4.00	3.50	1.83	1.50	2.26	2.35	1.80	1.61

CONCLUSIONS

Though water supply remains the most critical factor to improve the productivity of crops in the tropics, one of the reasons for improving LER and WER is that intercropping makes better use of one or more agricultural resources both in time and in space, such as greater interception of sunlight and more efficient conversion of the intercepted radiation (Li *et al*., 2012), more efficient root distribution in space plays, mutually beneficial effects of allelopathy or phenological characteristics (Chen *et al*., 2016), and so on. Okra in mixture with other selected crops has high water utilization efficiency while kenaf with sorghum irrespective of cultivar has the least water utilization efficiency. This study suggested that the higher water efficiency okra with either kenaf or sorghum intercropping system is as a result of high water use.

In general, kenaf and sorghum in mixture requires more water than okra in mixture under normal rain-fed conditions, so how to balance the need of crops for water from farmlands by creating an intercropping population between okra and sorghum or/and kenaf is important. And, there are some other effective regulation measures to achieve optimization effect of soil moisture, e.g. tillage, irrigation and rational density (Ogbazghi *et al*., 2016; Liu *et al*., 2016), so the benefit potential of intercropping will be greater if combined with these methods.

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