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Biological and water-use efficiencies of sorghum-groundnut intercrop

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ABSTRACT
In order to compare water-use efficiency of sole crops and intercrops, 2 experiments were conducted in 2 consecutive years with sorghum (*Sorghum bicolor* L. Moench) and groundnut (*Arachis hypogaea* L.) on a loamy, Grossarenic Paleudult. In a randomized block, split-plot design, sorghum (SS), groundnut (GG), sorghum/groundnut intercrop (SG) were subjected to 4 replicates of 4 water managements as main treatments (trt): (1) Optimum irrigation, (2) deficit irrigation allowing stress on sorghum, or (3) on groundnut, (4) rainfed. All crops were seeded in rows at a density of 256000 (SS), 160000 (GG), 256000 + 160000 (SG, year 1), 157000+102000 (SG, year 2) plants/ha. Soil water status was monitored and ET calculated all over the growing seasons. Dry matter (DM) and grain yields (GY) were determined at physiological maturity for each crop. Sorghum GY was very high, ranging from 3.55 (trt 4) to 8.03 (trt 1) Mg/ha in sole crop, and from 2.71 to 6.27 Mg/ha in intercrop. Groundnut GY was very high in sole crop (3.76 to 6.54 Mg/ha), but was very depressed in intercrop (0.13 to 3.26 Mg/ha). Mean Total Land Equivalent Ratio (TLER) was 1.14 for DM and 1.11 for GY, showing a 14 and 11% advantages over sole cropping. But these advantages disappeared when the amount of water used was taken into account in the Total Land Water Use Equivalency Ratio (TLWUER). The overall mean TLWUER were 1.01(irrigation) and 0.99 (seasonal ET) for DM, 0.98 and 0.96 for GY, indicating no advantage of intercropping over sole cropping. Nevertheless, based on water use ratios, intercropping was more water use efficient than sole crops. The contrasting results between the TLER and TWUER may imply that the yield advantage of intercropping was not attributable to its overall improved water use ratio but rather to its higher seasonal water use.
Key words: Intercropping, Biological efficiency, Water use efficiency, TLER, TLWUER.

INTRODUCTION

Some of the suggested advantages of intercropping include greater yields, greater stability of yields over different seasons or environmental conditions, and better use of available resources [1]. A common assumption about crop mixtures is that different species would complement each other through their differential use of natural resources [1]. Thus, competition would be more severe between like plants than between unlike plants. Yield advantages from intercrops could arise in two ways. Component crops may have different durations of growth cycles or different growth patterns, and thus have peak demands on resources at different times.

It has been shown that intercrops of grain sorghum and groundnut achieved larger relative yield advantages when grown under drought than they did when kept well-watered [2, 3, 4, 5]. The authors suggested that the sorghum-groundnut mixture may combine both temporal and spatial complementarities. In other words, the mixture would use resources such as water more efficiently both in time and in space as compared to sole cropping.

This viewpoint is not shared by [6] and [7] who suggested that intercropping would in fact be less water-use efficient and would seldom outyield the best monocropping. Plant species, instead of being complementary in their use of available resources, actually compete for the same basic resources of light, carbon dioxide, soil water and nutrients. The photosynthetic rate of a full canopy of leaves of high physiological capacity and arranged in an optimal way can be maximized with a single species, and it cannot be improved by introducing a species with inferior traits [7]. Similarly, complementation of species with deep rooting and those with shallow roots cannot exceed in nutrient and water extraction a single species capable of exploring the entire profile. Furthermore, mixed cropping is generally practiced in primitive systems where soil nutrients are strongly limiting. In such conditions, plant growth is generally poor and there is little competition for light. Loomis' analysis [7] implicitly implies that the often reported yield advantages of intercropping over sole cropping may result from a poor management of sole cropping rather than a better or more efficient use of available resources by intercrop systems. In order to assess any advantage, it is therefore critical that both cropping systems be grown under their respective optimum agronomic and environmental conditions.

The apparent conflicting biological efficiency of intercropping may also be due to the conceptual basis on which the sole cropping versus intercropping comparisons are made [8, 9]. Willey [10] pointed out that one of the most problematic areas of intercropping research is the quantitative evaluation of the advantages provided by any given intercropping system. The conventional approach has been to use relative yields which can be added- even though the component crops may be of different kinds - to form a relative yield total on a per plant basis [11] or the land equivalent ratio (LER) on a land area basis [1]. The latter is defined as the relative land area required as sole crops to produce the yields achieved in intercropping. For two crops A and B, total LER can be expressed as

$$TLER = \frac{Y_{IA}}{Y_{AA}} + \frac{Y_{IB}}{Y_{BB}} \quad (1)$$

Where Y_{IA} and Y_{AA}, Y_{IB} and Y_{BB} are the respective yields of intercropping and sole cropping for the two crops.

A TLER > 1 would indicate a yield advantage of intercrop over sole crops, thus an intercrop land-use advantage. But the LER concept is commonly criticized because it gives no indication of absolute yields. Willey [10] proposed that absolute yields be used to compare intercropping and sole cropping.

Hiebsch & McCollum [8] proposed an area-time equivalency ratio (ATER) developed by integrating the time factor into the land equivalent ratio concept to account for differential duration of growing cycles between pure stands and intercrop:

$$ATER = \frac{Y_{IA}.T_{AA}}{Y_{AA}.T_{AB}} + \frac{Y_{IB}.T_{BB}}{Y_{BB}.T_{AB}} \quad (2)$$

Where T_{AA} and T_{BB} are the durations of crop cycle in pure stands of crops A and B, respectively, T_{AB} is the total duration required to grow the component crops A and B in the mixture.

After reviewing earlier experiments, Hiebch & McCollum [8] did not find any significant yield advantage of intercropping over sole cropping, based on the ATER concept.

The resource capture principles may also be applied to water by breaking its utilization down into capture and conversion efficiency components. The quantity of dry matter produced (DM) depends on the quantity of water captured and the efficiency with which it is used to produce dry matter [12, 13]. The ratio of dry matter production to water transpired, expressed on a unit leaf area or land area basis, is known as the water use ratio (e_w). Dry matter production may be expressed as $DM = e_w \Sigma E_w$, where ΣE_w represents cumulative water use or transpiration. Morris & Garrity [12] reviewed many intercropping experiments and concluded that total water use by intercrops is little different from monocrops. However, water utilization efficiency by mixtures greatly exceeds that by sole crops. The beneficial effect of intercropping may originate from improvements in e_w through several mechanisms, rather than from seasonal water use [13]. The relationship between biomass and transpiration was found to remain constant under a wide range of conditions [14], but Steduto & Albrizio [15] reported a great variability in e_w due to variability in environmental, namely climatic conditions, thus making comparisons difficult. This calls for a need to normalize e_w for climate.

In order to compare water-use efficiency of sole crops and intercrops, two experiments were conducted in two consecutive years with sorghum (*Sorghum bicolor* L. Moench) and groundnut (*Arachis hypogaea* L.) at the Irrigation Research and Education Park (IREP) of the University of Florida in Gainesville.

MATERIAL AND METHODS

Experimental site, crops and experimental design

The soil of the experimental site is a level, well-drained Millhopper fine sand (loamy, hyperthermic Grossarenic Paleudult) with an underlying argillic horizon starting at 120 - 190 cm depth. The sorghum crop was the bird-resistant Northrup King Savanna 5 hybrid, while the groundnut varieties were the Florunner (year 1) and the Southern Runner (year 2).

The layout was a randomized block, split-plot design with four water managements as main treatments and four cropping systems as sub treatments, in four replications. Each main plot was 14 m x 14 m in size, divided into four 7 m x 7 m subplots planted to sorghum, groundnut, sorghum-groundnut intercropped, and maize. Maize results will not be reported in this paper. Sole crops were planted in 60 cm rows at a density of 256000 plants/ha (sorghum) and 160000 plants/ha (groundnut). In sorghum-groundnut intercrop, both crops were seeded in 60 cm alternate rows (year 1) with half the intra-row spacing of sole crops, resulting in an additive intercrop series (100% of each sole crop on 50% of the land area). In year 2, two paired rows of sorghum 30 cm apart were alternated with two paired rows of groundnut 45 cm apart. The distance between sorghum and groundnut rows was 60 cm, resulting in a density of 157000 p/ha for sorghum (61.3% of sole sorghum density occupying about 46% of land area) and 102000 p/ha for groundnut (63.8% of sole groundnut density sown on 54% of land area).

Prior to planting, the seedbed preparation involved ploughing, incorporation of 0-10-20 (N-P_2O_5-K_2O) fertilizer containing 0.06% B, 0.06% Cu, 0.36% Fe, 0.15% Mn and 0.014% Mo as top dressing at a rate of 830 kg/ha, and of Furadan at a rate of 43 kg/ha, and then disking. Ammonium nitrate was applied in bands along sorghum rows as side dressing in three split applications at 16, 36 and 56 days after sowing (DAS), resulting in a total of 250 kg N /ha; 900 kg/ha of gypsum were broadcast on groundnut crop at 45 DAS as source of calcium to promote pod filling. All crops were properly cared for against weeds, pests and diseases during the growing seasons. An area of 4.88 m^2 was sampled in each subplot to estimate crop yield at physiological maturity, 102 and 134 DAS in year 1 for sorghum and groundnut, respectively. In year 2, sorghum was harvested at 102 DAS (treatment 1), 107 DAS (treatment 2), 126 DAS (treatments 3 and 4), and groundnut at 160 and 203 DAS for all the treatments.

Water Management

The four water treatments were

1. Optimum water management in which irrigation was applied to prevent any visible stress on crops. Water application was triggered whenever soil water pressure at 15 and/or 30 cm depths was less than -20 kPa;
2. Irrigation after two days of visible wilt on sorghum or when soil water pressure at 15 and/or 30 cm depths was less than -50 kPa in sole sorghum subplots;
3. Irrigation after two days of visible wilt on groundnut or when soil water pressure at 15 and/or 30 cm depths was less than -50 kPa in sole groundnut subplots; and
4. Rainfed, except when all treatments were irrigated early in the season for crop establishment.

Seasonal irrigation amounts decreased from treatment 1 to 4. The strategy used in irrigation scheduling was to partly replenish soil profile within the root zone during periods of deficit rainfall (when rainfall was less than crop ET) in order to take advantage of any unexpected precipitation. Irrigation water was applied early in the morning when winds were calm, using a solid-set impact sprinkler system. Quarter circle sprinklers located at each corner of 14 m x 14 m plots gave a full two-sprinkler overlap along the plot edges and a four-sprinkler overlap in the centre, resulting in an uneven water distribution. Only the central square of each plot (5.6 m x 5.6 m) in which the rate of irrigation application had a coefficient of uniformity of 97.21% was used for water budget measurements.

One neutron access tube (inserted down to the top of the argillic horizon) and a set of ten tensiometers (at 15, 30, 45, 60, 75, 90, 105, 120, 135 and 150 cm depths) were installed in each subplot, 15 cm off the 4th crop row from the plot centre. Soil water content data were collected every other day using a TROXLER 1651 neutron probe. Tensiometers were read every day with a SOIL MEASUREMENT SYSTEMS tensimeter.

Daily actual ET was calculated for each profile using the soil water balance method and mean values computed for each water treatment [16].

Statistical analysis

Dry matter, grain yield, Land Equivalent Ratio (LER), and water use ratio data were analyzed using the MEANS procedure in SAS [17]. The 95% confidence interval was also calculated. Student's paired-difference t-test was used to compare LER to LWUER means and the null hypothesis was rejected at the 0.05 probability level.

RESULTS

The amounts of seasonal water use and yield components for the two crops and cropping systems are presented in tables 1 and 2. Sorghum and groundnut grain yields were reported at 13 % and 7 % water content by weight, respectively, whereas dry matter yields were expressed at 0 % water content for both crops. The higher sorghum yields observed in year 2 are due to early planting (13 April vs. 20 June) for which the peak growth periods of the crop coincide with the high solar radiations of the months of June and July in the region, whereas groundnut greater yields were due to the combined effects of early planting and a longer growing season. Southern runner groundnut has a more indeterminate growth habit and is more resistant to *Cercospora* leafpot than the Florunner. This gave room for a longer growth period and two harvest dates in the former (160 and 203 days after sowing as against 134 for Florunner). Significant yield increases were obtained by delayed harvest. Year 2 was drier than year 1, and therefore resulted in higher amounts of seasonal irrigation water in all the treatments. Sorghum above-ground dry matter production responded poorly to irrigation during year 1 because of the fairly well distributed rainfalls throughout the season; grain yield did not respond at all. The situation was quite different the following year where the decrease in irrigation frequency from treatment 1 to 4 resulted in increasing crop water stress in the same order. Grain yield was more affected by the stress than total above-ground biomass. Intercropping strongly depressed groundnut yield in both years. The biggest decreases were observed in year 1 where the best groundnut yield in the mixture was 400 kg grain /ha as against 5040 kg /ha for sole groundnut. Total LER based on dry matter varied from 1.01 to 1.07 (yr 1), 1.06 to 1.28 (yr2) with respective means of 1.05 and 1.14, and an overall mean of 1.14 (Table 3). The overall TLER mean for grain yield was equal to 1.11 (Table 4). Both TLER (DM and grain) were significantly different from 1 (p-value of 0.0007 and 0.0136 respectively), indicating a 14% (dry matter) and 11% (grain yield) advantages over sole cropping.

Table 1: Yields of grain sorghum subjected to 4 water treatments (trt) and 2 cropping systems

Trt(yr) --	Cropping System	Irrigation (mm)	Seasonal ET (mm)	Dry matter[a] (Mg/ha)	Grain yield[a] (Mg/ha)
1(1)	Sole	239	410	16.78 ± 1.11	6.25 ± 0.77
1(1)	Intercrop	239	426	15.48 ± 1.25	6.27 ± 0.46
1(2)	Sole	368	419	16.90 ± 1.01	8.03 ± 0.66
1(2)	Intercrop	368	432	13.28 ± 1.18	6.26 ± 0.91
2(1)	Sole	117	420	15.76 ± 2.65	6.36 ± 0.44
2(1)	Intercrop	117	422	15.08 ± 0.64	6.11 ± 0.51
2(2)	Sole	241	407	17.18 ± 2.53	7.14 ± 0.55
2(2)	Intercrop	241	411	11.05 ± 1.75	4.99 ± 1.01
3(1)	Sole	117	420	15.75 ± 2.64	6.36 ± 0.45
3(1)	Intercrop	117	422	15.07 ± 0.65	6.10 ± 0.52
3(2)	Sole	237	482	13.55 ± 3.11	4.58 ± 1.60
3(2)	Intercrop	237	523	10.25 ± 3.67	4.04 ± 2.45
4(1)	Sole	47	383	14.68 ± 2.76	6.32 ± 0.35
4(1)	Intercrop	47	397	13.12 ± 4.55	5.74 ± 1.55
4(2)	Sole	100	396	11.72 ± 2.34	3.55 ± 1.00
4(2)	Intercrop	100	370	8.00 ± 1.61	2.71 ± 0.71

[a] Mean ± Confidence interval at 95% probability level.

Table 2. Yields of groundnut subjected to 4 water treatments (trt) and 2 cropping systems

Trt(yr) --	Cropping System	Irrigation (mm)	Seasonal ET (mm)	Dry matter[a] (Mg/ha)	Grain yield[a] (Mg/ha)
1(1)	Sole	309	434	11.96 ± 0.91	5.04 ± 0.57
1(1)	Intercrop	309	418	1.08 ± 0.65	0.13 ± 0.16
1(2/1)*	Sole	481	536	13.51 ± 1.42	4.50 ± 0.86
1(2/1)	Intercrop	481	608	6.66 ± 2.52	1.95 ± 0.22
1(2/2)	Sole	511	617	18.19 ± 5.37	6.54 ± 2.83
1(2/2)	Intercrop	511	692	9.62 ± 1.16	3.26 ± 0.24
2(1)	Sole	137	428	11.45 ± 2.03	4.68 ± 0.77
2(1)	Intercrop	137	405	1.28 ± 0.25	0.21 ± 0.02
2(2/1)	Sole	345	579	13.90 ± 3.03	4.92 ± 0.97
2(2/1)	Intercrop	345	656	5.79 ± 1.11	1.40 ± 0.38
2(2/2)	Sole	375	632	15.50 ± 3.73	6.47 ± 0.84
2(2/2)	Intercrop	375	678	8.47 ± 0.61	3.24 ± 0.01
3(1)	Sole	137	427	11.64 ± 2.23	4.56 ± 0.78
3(1)	Intercrop	137	406	1.30 ± 0.23	0.23 ± 0.05
3(2/1)	Sole	280	531	12.42 ± 2.89	4.58 ± 0.70
3(2/1)	Intercrop	280	579	4.75 ± 1.70	1.06 ± 0.25
3(2/2)	Sole	310	604	16.42 ± 6.19	6.45 ± 2.74
3(2/2)	Intercrop	310	627	7.93 ± 2.63	2.97 ± 0.36
4(1)	Sole	47	405	12.59 ± 1.71	4.73 ± 0.46
4(1)	Intercrop	47	388	1.96 ± 0.68	0.40 ± 0.35
4(2/1)	Sole	100	438	9.86 ± 1.46	2.75 ± 0.49
4(2/1)	Intercrop	100	442	3.94 ± 0.98	0.67 ± 0.18
4(2/2)	Sole	130	498	10.31 ± 2.08	3.76 ± 1.31
4(2/2)	Intercrop	130	506	4.58 ± 1.29	1.01 ± 0.48

[a] Mean ± Confidence interval at 95% probability level; * 1(2/1) = trt 1, yr 2, groundnut harvest 1

In order to account for both the land area and the seasonal amount of water used, a new biological efficiency index was introduced and defined as follows:

$$TLWUER = \frac{Y_{IS}.W_{SS}}{Y_{SS}.W_{SG}} + \frac{Y_{IG}.W_{GG}}{Y_{GG}.W_{SG}} \quad (3)$$

where TLWUER is the total land-water use equivalency ratio, Y_{IS} and Y_{SS} are sorghum yields, Y_{IG} and Y_{GG} are groundnut yields in intercrop and in pure stands, respectively; W_{SS}, W_{GG} and W_{SG} are the seasonal water use (irrigation or evapotranspiration) for sole sorghum, sole groundnut and sorghum-groundnut intercrop, respectively. It is worth noting that TLWUER implicitly includes a time factor through its water-use component.

Crop yields and the amount of water consumed through irrigation or crop evapotranspiration (ET) were used to calculate the various biological efficiency indices. Tables 3 and 4 compare the conventional TLER values with the corresponding TLWUER for the four water treatments and the two growing seasons, using the Student's paired-difference t-test [17]. Significant improvements in groundnut yields and LER were attained by extending the growing cycle of the crop to 203 days. Water use efficiencies of the 2 crops based on seasonal ET and dry matter yield or grain yield are given in tables 5 and 6. The values are expressed in g of dry matter or grain produced per m^2 of land per mm of water evapotranspired [12]. Sorghum DM water use efficiency ranged between 2.96 and 4.09 g DM m^{-2} mm^{-1} for sole crop (average 3.68), 1.96 and 3.63 for intercrop (average 3.00). The corresponding values for sorghum grain were 0.90-1.92 (aver. 1.46), 0.73-1.47 (aver. 1.25), showing a significant advantage of sole cropping over intercropping. This trend was confirmed with sole groundnut showing a systematic WUE advantage over intercropping.

Table 3: Dry Matter-based Biological Efficiency Indices for the Sorghum-Groundnut Intercrop.

Trt (yr)	Crop	LER	$LWUER_{IRR}$ (1)	$LWUER_{ETC}$ (2)
1(1)	IS	0.92	0.71	0.89
1(1)	IG	0.09	0.09	0.09
1(1)	Total	1.01	0.80	0.98
1(2)	IS	0.79	0.60	0.54
1(2)	IG	0.49/0.54[a]	0.49/0.54	0.44/0.48
1(2)	Total	1.28/1.33	1.09/1.14	0.98/1.02
2(1)	IS	0.96	0.82	0.95
2(1)	IG	0.11	0.11	0.12
2(1)	Total	1.07	0.93	1.07
2(2)	IS	0.64	0.45	0.40
2(2)	IG	0.42/0.55	0.42/0.55	0.37/0.52
2(2)	Total	1.06/1.19	0.87/1.00	0.77/0.92
3(1)	IS	0.96	0.82	0.95
3(1)	IG	0.11	0.11	0.11
3(1)	Total	1.07	0.93	1.06
3(2)	IS	0.76	0.64	0.63
3(2)	IG	0.38/0.49	0.38/0.49	0.35/0.47
3(2)	Total	1.14/1.25	1.02/1.13	0.98/1.10
4(1)	IS	0.89	0.89	0.86
4(1)	IG	0.16	0.16	0.16
4(1)	Total	1.05	1.05	1.02
4(2)	IS	0.68	0.68	0.61
4(2)	IG	0.40/0.45	0.40/0.45	0.40/0.44
4(2)	Total	1.08/1.13	1.08/1.13	1.01/1.05
Mean Total (SE)	--	1.14 (0.03)	1.01 (0.03)	0.99 (0.02)
t-test (Ho: Mean=1.0)		0.0007***	0.658	0.885
t-test (Ho: LER=LWUER)		--	0.0002***	0.0021**

[a] 1st/2nd groundnut harvest;***=significant at $p\leq0.001$; **=significant at $p\leq0.01$; (1) =Irrigation; (2)=Crop ET

Table 4: Grain Yield-based Biological Efficiency Indices for the Sorghum-Groundnut Intercrop.

Trt (yr)	Crop	LER	$LWUER_{IRR}$ (1)	$LWUER_{ETC}$ (2)
1(1)	IS	1.00	0.78	0.96
1(1)	IG	0.03	0.03	0.03
1(1)	Total	1.03	0.81	0.99
1(2)	IS	0.78	0.60	0.54
1(2)	IG	0.43/0.53[a]	0.43/0.53	0.38/0.47
1(2)	Total	1.21/1.31	1.03/1.13	0.92/1.01
2(1)	IS	0.96	0.82	0.96
2(1)	IG	0.05	0.05	0.05
2(1)	Total	1.01	0.87	1.01
2(2)	IS	0.70	0.49	0.43
2(2)	IG	0.28/0.50	0.28/0.50	0.25/0.47
2(2)	Total	0.98/1.20	0.77/0.99	0.68/0.90
3(1)	IS	0.96	0.82	0.95
3(1)	IG	0.05	0.05	0.05
3(1)	Total	1.01	0.87	1.00
3(2)	IS	0.88	0.75	0.73
3(2)	IG	0.23/0.49	0.23/0.49	0.21/0.47
3(2)	Total	1.11/1.37	0.98/1.24	0.94/1.20
4(1)	IS	0.91	0.91	0.88
4(1)	IG	0.08	0.08	0.08
4(1)	Total	0.99	0.99	0.96
4(2)	IS	0.76	0.76	0.68
4(2)	IG	0.24/0.36	0.24/0.36	0.24/0.36
4(2)	Total	1.01/1.12	1.01/1.12	0.92/1.04
Mean Total (SE)		1.11 (0.04)	0.98 (0.04)	0.96 (0.03)
t-test (Ho: Mean=1.0)		0.0136*	0.682	0.334
t-test (Ho: LER=LWUER)		--	0.0002***	0.0017**

[a] 1st/2nd groundnut harvest;***=significant at p≤0.001; **=significant at p≤0.01;*=significant at p≤0.05
(1) =Irrigation; (2)=Crop ET

Table 5: Water use ratios, e_w (g Dry Matter m^{-2} mm^{-1} ET) for sole sorghum (SS), sole groundnut (SG) and sorghum-groundnut intercropped (IS & IG)

Trt (yr)	SS	IS	SG	IG
1(1)	4.09	3.63	2.75	0.26
2(1)	3.75	3.57	2.67	0.32
3(1)	3.75	3.57	2.72	0.32
4(1)	3.83	3.30	3.11	0.50
1(2)	4.03	3.07	2.52/2.95[a]	1.09/1.39
2(2)	4.22	2.69	2.40/2.45	0.88/1.25
3(2)	2.81	1.96	2.34/2.72	0.82/1.26
4(2)	2.96	2.16	2.25/2.07	0.89/0.90
Mean (SE)	3.68 (0.18)	3.00 (0.21)	2.58 (0.08)	0.82 (0.03)
t-test (Ho: Sole=Intercrop)		0.0001***	--	0.001***

[a] 1st/2nd groundnut harvest; *** Significant at p≤0.001.

Table 6: Water use ratios, e_w (g Grain Yield m^{-2} mm^{-1} ET) for sole sorghum (SS), sole groundnut (SG) and sorghum-groundnut intercropped (IS & IG)

Trt (yr)	SS	IS	SG	IG
1(1)	1.52	1.47	1.16	0.03
2(1)	1.51	1.45	1.09	0.05
3(1)	1.51	1.45	1.07	0.06
4(1)	1.65	1.44	1.17	0.10
1(2)	1.92	1.45	0.84/1.06[a]	0.32/0.47
2(2)	1.75	1.21	0.85/1.02	0.21/0.48
3(2)	0.95	0.77	0.86/1.07	0.18/0.47
4(2)	0.90	0.73	0.63/0.75	0.15/0.20
Mean (SE)	1.46 (0.13)	1.25 (0.11)	0.96 (0.05)	0.23 (0.04)
t-test (Ho: Sole=Intercrop)		0.0001***	--	0.0003***

[a] 1st/2nd groundnut harvest; *** Significant at p≤0.001.

DISCUSSION AND CONCLUSION

Total LER values found in this experiment, though low, are consistent with those reported by many researchers, including [18], [19], [20], [21], [22]. The highest TLER values came about when the dominated crop (groundnut) suffered less from the competition and was able to substantially increase its partial LER. Water management did not have any significant influence on TLER, except for the rainfed treatment that exhibited the lowest grain TLER in year 1 because groundnut yield was more depressed in the mixture than in sole stand. Groundnut partial dry matter LER increased systematically with increasing water stress in year 1, while sorghum had its highest LER in treatments 2 (deficit irrigation with stress on sorghum) and 3 (deficit irrigation with stress on groundnut). The situation was reversed in year 2 where groundnut LER systematically decreased from treatment 1 to 4, while sorghum LER was highest in treatment 1 (0.79), followed by treatment 3 (0.76), 4 (0.68), and lastly 2 (0.64). The trends described above were similar for groundnut harvestable yield in both cropping seasons. The difference in groundnut crop behaviour in year 1 and 2 is probably due the change in crop variety, plant density and planting geometry. Groundnut performed better in year 2 than in year 1. The trends in partial LER variation were more shuffled for sorghum in both years.

The yield advantage indicated by the TLER concept disappeared when we integrated the amount of water used by the various crops. The dry matter-based total land water-use equivalency ratios (TLWUER) ranged from 0.80 to 1.05 for irrigation, and from 0.98 to 1.07 for seasonal ET in year 1. The respective ratios varied from 0.87 to 1.13 and from 0.77 to 1.10 during the second year. The overall mean TLWUER were 1.01(irrigation) and 0.99 (seasonal ET) based on dry matter, 0.98 and 0.96 based on grain yield, indicating no advantage of intercropping over sole cropping. This was confirmed by the t-test (Ho: mean=1.0) which was not significant (Tab. 3 & 4.), and showed that all the 4 mean TLWUER were not statistically different from 1.0. Moreover, the t-test comparing TLER to TLWUER indicates that TLER is greater than TLWUER in all the 4 cases, with p-values ranging 0.0021 to 0.0002. Similar results were reported by Hiebsch & McCollum [8] using the Area-Time equivalency ratio (ATER) concept.

Comparing water use ratios (e_w) of sole versus intercrops revealed that sole crops sorghum and groundnut were systematically more water use efficient than intercropping. The differences in water use ratios between sole and intercrops were very highly significant (p-value $\leq$ 0.001). The values found for sole sorghum and groundnut compare well with those reported by Black & Ong [13], Steduto & Albrizio [15] and Azim-Ali et al.[23]. The contrasting results between the TLER and TWUER may imply that the yield advantage of intercropping was not attributable to the overall e_w improvements in the mixture, but rather to the differential seasonal water use of the two cropping systems.

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