

Mixed Planting with Legumes Modified the Water Source and Water Use of Pearl Millet

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Abstract : In semi-arid areas, pearl millet is an important staple food crop that is traditionally intercropped with cowpea. This study evaluated the water competition between pearl millet and cowpea using deuterated water. At vegetative stage, pearl millet biomass production was lower in the pearl millet-cowpea (PM-CP) combination than in the pearl millet-pigeon pea (PM-PP) and pearl millet-bambara nut (PM-BN) combinations. PM-CP used more water than PM-PP and PM-BN under well-watered conditions; however, all combinations used similar amounts of water under dry conditions. The biomass production, photosynthetic rates, transpiration rates, and midday leaf water potential of pearl millet at early flowering stage were not significantly reduced by mixed planting with cowpea sown two weeks later as compared with single planted pearl millet. When pearl millet and cowpea were sown at the same time, mix planting significantly increased the recovery rates of recently irrigated heavy water in pearl millet, but not in cowpea in both vegetative and early flowering stages. Midday leaf water potential and transpiration rates in pearl millet were lowered by mixed planting but those in cowpea were not. These indicate that the water source of pearl millet is shifted to the recently irrigated and easily accessible water. By contrast, when cowpea was sown two weeks later than pearl millet, this trend was not observed. These results provide new evidence on water competition in the PM-CP intercropping system; cowpea has higher ability to acquire existing soil water than pearl millet when both crops are sown at the same time.

Key words : Competition, Deuterium, Drought, Heavy water, Intercropping, Leaf water potential, Photosynthesis, Stable isotope.

Pearl millet is an important cereal crop in semi-arid regions, particularly in areas where there are limited alternative crops. In these regions, pearl millet is commonly intercropped with cowpea under the traditional small farming system. The millet-based system aims to produce pearl millet as a staple food crop, while cowpea has secondary importance. The productivity of this system, however, is severely restricted by the low and erratic rainfall and the infertile sandy soils, which have a low water-holding capacity (Matanyaire, 1998). Under such conditions, strong competition for limited soil water between intercropped pearl millet and cowpea may occur. Although the agronomy of the millet-based system has been extensively investigated (Ntare, 1990; Reddy et al., 1992; Craufurd, 2000), only limited number of studies has dealt with the water use and water competition between pearl millet and legumes. In field experiments, for example, water use and water competition have been indirectly evaluated based on the soil water balance method (Morris and Garrity, 1993). A large part of the water lost to the atmosphere could be accounted as soil evaporation rather than plant transpiration, especially in semi-arid environments, where the atmospheric evaporative

demand is large. Morris and Garrity (1993) concluded that the total water use by sole cropping and intercropping differ slightly without discriminating direct evaporation from the soil surface. Singh et al. (1988) reported higher water use by intercropped pearl millet-cowpea than monocropped pearl millet, but Oluwasemire et al. (2002) described the opposite trend. In pot experiments, much detailed analysis of water use pattern of intercrops were reported in a series of experiments conducted by Petrie and Hall (1992 a, b, and c). They found that cowpea was able to survive under water deficits more effectively than pearl millet. In these experiments, mix-planted pearl millet had lower predawn leaf water potential, lower stomatal conductance and lower leaf area than cowpea.

In north east Nigeria cowpea is often sown later than pearl millet. The exact time of sowing cowpea (2-6 weeks later) depends on the establishment of pearl millet and soil water availability (Grema and Hess, 1994). This planting system is aimed to have the minimal adverse effect on pearl millet production. Cowpea generally shows higher drought tolerance than pearl millet (Petrie and Hall, 1992 a), because cowpea may have higher ability to acquire soil water than pearl millet when the two crops are mix-planted.

Table 1. Deuterium concentration (atom % excess) in xylem sap of single, pair and mix-planted crops at vegetative and early flowering stages.

		Vegetative stage #		Early flowering stage §		
		Well-watered	Drought	Cowpea sown same day (1)	Cowpea sown seven days later (2)	Cowpea sown 14 days later (3)
Cereal [pearl millet (PM)]						
Single planted	PM	0.517	0.567	0.243 b	0.243 b	0.243 a
Pair planted	PM-PM	-	-	0.253 b	0.253 b	0.253 a
Mix planted	PM-CP	0.858 *	0.722 *	0.309 a	0.313 a	0.252 a
Legume [cowpea (CP)]						
Single planted	CP	0.708	0.632	0.434 b	0.412 ab	0.321 a
Pair planted	CP-CP	-	-	0.626 a	0.457 a	0.365 a
Mix planted	PM-CP	0.654 ns	0.617 ns	0.418 b	0.390 b	0.319 a

Determined at 33 days after sowing (Exp. 1).

§ Determined at 51 days after sowing for pearl millet, while at 51⁽¹⁾, 44⁽²⁾ and 37⁽³⁾ days after sowing for cowpea (Exp. 2).
- No data.

At vegetative stage * indicates significant difference within single and mix-planted crops at 5 % level. At early flowering stage different letters within columns for each species indicate significant differences (P<0.05) among the planting patterns (Duncan's multiple range test).

Evaluations of water competition between plants have been traditionally done by direct observations of root distribution, water uptake capacity, and water use efficiency (Nambiar and Sands, 1993; Casper and Jackson, 1997). A more agile way to determine water sources and root activity in competitive environments is to examine the variation in the relative abundance of deuterium in xylem sap water of plants. Tracing water sources is important to understand species interactions in intercropping systems, particularly when mix-planted species have greatly different functional characteristics (Burgess et al., 2000). Hydrogen stable isotopes have already been used to determine the source of water taken up by shrub-grass (Schwinning et al., 2002) and forest (Dawson, 1993) communities, and crop species (Araki and Iijima 2004; Sekiya and Yano, 2004; Zegada-Lizarazu and Iijima 2004). By using hydrogen stable isotopes in the mix-planted pearl millet system, the water relations including water source of each component species of the intercrops can be evaluated, which has not been conducted so far. This information may provide further knowledge on the water relations between pearl millet and mix-planted legumes. The aim of the present study was to evaluate water competition between pearl millet and three grain legumes at different growth stages using deuterated water as one of the criteria for water use, together with biomass production and leaf water relations in the mix-planted crops.

Materials and Methods

A series of experiments was conducted to evaluate the water competition between pearl millet and grain

legumes at vegetative (Exp. 1) and early flowering (Exp. 2) stages. In Exp. 1, three legume species as the intercrop with pearl millet were compared at the vegetative stage. In Exp. 2, pearl millet was mix-planted with cowpea sown at three different dates to compare the water competition among the crop species at the early flowering stage. The plants were grown in a growth chamber in Exp. 1 and in a greenhouse in Exp. 2.

1. Plant materials and environmental conditions

Exp. 1 (Vegetative stage)

Pearl millet cv. Okashana-1 [(*Pennisetum glaucum*), PM] was mix-planted with three grain legume species: cowpea cv. Nakale [(*Vigna unguiculata*), CP], pigeon pea cv. ICPV-87119 [(*Cajanus cajan*), PP], and bambara groundnut cv. Ogongo local [(*Vigna subterranea*), BN]; single plants of each species were grown as controls under two water regimes. All species were sown in pots of 25 cm height and 7.5 cm diameter. Pots were loosely filled with sandy loam soil with a bulk density of 1.33 Mg m⁻³. Three seeds of each species were sown simultaneously at the center of each pot in October 14, 2002. At five days after sowing, pots were thinned to one and two plants per pot in the single and mix-planted pots, respectively. The temperature in the growth chamber was controlled at 30/25°C (day/night), and the day length was set to 14 h. From two weeks after sowing, the soil water content (gravimetric basis) was adjusted every day at around 1600 h to 25 % ($\psi = -7$ kPa) and 8 % ($\psi = -280$ kPa) in the well-watered and drought treatments (water treatment), respectively. Until then, all species

Table 2. Average transpiration rate (\pm se) and ratio of transpiration rate of single and mix-planted crops at vegetative stage (Exp. 1).

		Transpiration (g d ⁻¹)				
		Well-watered (WW)	Ratio [#]	Drought (D)	Ratio [#]	1- (D/WW)
Single planted	Pearl millet (PM)	35.7 \pm 2.8		25.4 \pm 1.9		0.29
	Pigeon pea (PP)	54.5 \pm 5.9		18.7 \pm 1.4		0.66
	Bambara nut (BN)	53.9 \pm 5.4		25.9 \pm 2.2		0.52
	Cowpea (CP)	105.8 \pm 10.7		26.2 \pm 1.6		0.75
Mix planted	PM - PP	66.4 \pm 5.8 b	0.73	30.3 \pm 1.9 a	0.68	0.54
	PM - BN	65.3 \pm 6.7 b	0.72	27.4 \pm 1.2 a	0.54	0.58
	PM - CP	105.0 \pm 8.8 a	0.73	31.2 \pm 1.6 a	0.63	0.70

[#] Ratio of transpiration rate = [mix-planted / (single planted cereal + single planted legume)].

Different letters within columns indicate significant differences ($P < 0.05$) among mix-planted combinations (Duncan's multiple range test).

had been grown under well-watered conditions. Shoot biomass was sampled at 33 days after sowing. Together with soil water adjustments, daily transpiration was determined by weighing the pots.

Exp. 2 (Early flowering stage)

Pearl millet cv. Okashana-1 [(*Pennisetum glaucum*), PM] and cowpea cv. HAF-43 [(*Vigna unguiculata*), CP] were grown in pots of 19.5 cm height and 16.0 cm diameter. Pearl millet and cowpea were sown in single-, pair- and mix-planted patterns. Three seeds of each species were sown at the center of each pot between 15 and 29 July 2004. In the monocrop situations one and two plants in the single- and pair-planted patterns were remained in each pot after thinning (seven days after sowing). In the mix-planted situation two plants (one pearl millet and one cowpea) were remained. Sowing date was variable only for cowpea in the single-, pair- and mix-planted patterns; cowpea was sown at the same day, seven days later and 14 days later than pearl millet to test the growth response of intercropped pearl millet. Average maximum and minimum temperatures in the greenhouse during the growth period were 35 °C and 25 °C, respectively. Three weeks after sowing, plants were subjected to progressive soil dehydration. Soil water content in each pot was determined gravimetrically. When soil water content decreased to 4 % ($\psi = -1200$ kPa) or lower, pots were re-watered to well watered conditions ($\psi = -7$ kPa). These drying and re-watering cycles were continued up to harvesting time. Pearl millet was grown for 51 days while cowpea for 51, 44 and 37 days depending on the sowing date.

One day prior to plant harvesting photosynthetic and transpiration rates were measured with a portable photosynthesis system (LI-6400), using the first fully expanded leaf from the top. Midday leaf water potential was also determined one day before plant

harvesting. Leaf water potential was measured using leaf hygrometer/psychrometers, which were connected to a HR 33T dew point microvolt meter. At the time of plant harvesting, leaf area was measured with a Li-Cor area meter (LI-3100), and shoot dry weight was determined. Plants were harvested at the end of a drying cycle.

2. Deuterium labeling

In both Exp. 1 and 2, the water acquisition strategy of pearl millet mix-planted with cowpea was evaluated by the stable isotope method, which is widely used in natural forest ecosystems. A definite amount of heavy water (2.0 atom % D₂O), which was calculated as the amount transpired previous day, was applied to the soil surface of the pots 15 h before xylem sap collection. In Exp. 1, between 52 and 141 mL of deuterated water were applied depending on the water treatment. In Exp. 2, the amount of transpired water per day was calculated from the average of transpired water during the last 15 days of plant growth (last three re-watering cycles). Between 120 and 179 mL of deuterated water were applied depending on the cropping treatment. Average soil water content before the application of heavy water was between 4 and 16% in Exp. 1 and between 4 and 6% in Exp. 2. In Exp. 1, xylem sap samples of all plants were collected at 33 days after sowing and in Exp. 2, xylem samples of pearl millet were collected at 51 days after sowing and those of cowpea at 51, 44 and 37 days after sowing. The application of heavy water was regarded as the recently irrigated water. Xylem samples were collected by cutting the stems, placing cotton puffs on the top of the stumps, and wrapping them with thin polyethylene film. Three hours after cutting the stems, the cotton puffs containing xylem sap were gathered and placed in plastic bags and stored at -30 °C before analysis of δD of the extracted xylem sap; care was

Table 3. Transpiration rate and midday leaf water potential of single, pair and mix-planted crops at early flowering stage (Exp. 2).

		Transpiration rate (mmol m ⁻² s ⁻¹)			Midday leaf water potential (MPa)		
		Cowpea sown same day	Cowpea sown seven days later	Cowpea sown 14 days later	Cowpea sown same day	Cowpea sown seven days later	Cowpea sown 14 days later
		(1)	(2)	(3)	(1)	(2)	(3)
Cereal [pearl millet (PM)]							
Single planted	PM	2.45 a	2.45 a	2.45 a	-1.79 a	-1.79 a	-1.79 a
Pair planted	PM-PM	1.70 b	1.70 b	1.70 b	-1.76 a	-1.76 a	-1.76 a
Mix planted	PM-CP	1.23 b	1.13 b	2.92 a	-2.25 b	-2.19 b	-1.94 a
Legume [cowpea (CP)]							
Single planted	CP	0.76 a	1.79 ab	3.03 a	-1.32 a	-1.51 a	-1.62 a
Pair planted	CP-CP	0.40 b	0.78 b	2.78 a	-1.49 a	-1.53 a	-1.56 a
Mix planted	PM-CP	0.86 a	2.21 a	2.51 b	-1.49 a	-1.66 a	-1.88 b

Measured at 51 days after sowing for pearl millet, while at 51⁽¹⁾, 44⁽²⁾ and 37⁽³⁾ days after sowing for cowpea (Exp. 2).

Different letters within columns for each species indicate significant differences ($P < 0.05$) among the planting patterns (Duncan's multiple range test).

taken to minimize evaporation and, therefore, isotopic fractionation.

δD values were determined by mass spectrometry (DELTA^{plus}, Finnigan Mat Instruments, Inc.) in water extracted from plant stems. Isotope ratios are presented in standard delta notation (δD) in parts per thousand (‰) relative to Vienna Standard Mean Ocean Water (V-SMOW). The δD values were expressed as $\delta D = [(R_{\text{sample}}/R_{\text{V-SMOW}}) - 1] * 1000$ ‰ where R is the molar ratio of heavy to light isotope (D/H) with D being deuterium and H, hydrogen. These values were converted into the concentration of deuterated water (atom % excess).

3. Statistical analysis

Pots were arranged in a complete randomized block design with four and five replications in Exp. 1 and 2, respectively. In both experiments, one-way analysis of variance (ANOVA) and Duncan's multiple range tests were used for the comparison of all the parameters measured between the single-, pair- and mix-planted patterns among the three crop combinations and within each species.

Results

1. Water acquisition strategies

Table 1 shows the deuterium concentration in xylem sap at vegetative and early flowering stages. At vegetative stage (Exp. 1) pearl millet showed significantly higher deuterium concentration values in mixed planting as compared with single planting. From these values the dependence on the recently irrigated water was calculated as $D_R = (D_2O_{XS} - D_2O_{SW}) / (D_2O_{RIW} - D_2O_{SW})$, where D_2O_{XS} is the deuterium concentration in xylem sap extracted from each species, D_2O_{SW} is the deuterium concentration in stored (before deuterated

irrigation; 0.0152 atom %) soil water, and D_2O_{RIW} is the deuterium concentration in recently irrigated water (2.0 atom %). Forty-two percent of water taken up by mix-planted pearl millet was from recently irrigated water, while single planted pearl millet was mainly reliant on stored (before deuterated irrigation) soil water, that is, 75 % of the water was derived from stored soil water. Under dry conditions, the same pattern was found. In contrast, cowpea did not show significant differences in deuterium concentration in xylem sap water; mixed planting did not alter the water sources in cowpea. At the early flowering stage (Exp. 2), the same trend of deuterium enrichments in xylem sap water in both crops was found when cowpea was sown at the same day and 7 days later than pearl millet. By contrast, the deuterium concentration was not altered for pearl millet when the cowpea was sown 14 days later than pearl millet. These results indicated that the water source of pearl millet was modified by mixed planting with cowpea sown less than a week later, but not by mixed planting with cowpea sown two weeks later. On the other hand, the deuterium concentrations in xylem sap of single and pair planted cowpea were higher than those in the single and pair planted pearl millet at vegetative and early flowering stages of plant development.

2. Transpiration rate and leaf water potential

Table 2 shows the transpiration rate of whole pot at vegetative stage of pearl millet and three legumes. Transpiration rates per pot in the PM-CP combinations were higher than those in the other two combinations. Under well-watered conditions, PM-CP transpired, 105 g d⁻¹ of water on average, while the other two combinations transpired about 65 g d⁻¹. On the other hand, in the dry treatment, the difference among

Table 4. Shoot dry weight of single, pair and mix-planted crops at vegetative and early flowering stages.

		Vegetative stage (g pot ⁻¹) [#]		Early flowering stage (g pot ⁻¹) [§]		
		Well-watered	Drought	Cowpea sown same day (1)	Cowpea sown seven days later (2)	Cowpea sown 14 days later (3)
Cereal [pearl millet (PM)]						
Single planted	PM	3.20 a	2.63 a	27.95 a	27.95 a	27.95 a
Pair planted	PM-PM	-	-	13.84 b	13.84 c	13.84 b
Mix planted	PM-CP	1.20 c	1.05 cd	13.89 b	21.16 b	26.72 a
	PM-PP	2.43 b	2.27 ab	-	-	-
	PM-BN	2.03 b	1.33 c	-	-	-
Legume						
Cowpea (CP)						
Single planted	CP	4.30	2.50	14.03 a	10.33 a	6.19 a
Pair planted	CP-CP	-	-	7.13 b	5.60 b	3.47 b
Mix planted	PM-CP	3.57 ns	2.23 ns	7.22 b	2.67 c	0.42 c
Pigeon pea (PP)						
Single planted	PP	1.30	0.83	-	-	-
Mix planted	PM-PP	0.80 ns	0.57 ns	-	-	-
Bambara nut (BN)						
Single planted	BN	2.10	1.77	-	-	-
Mix planted	PM-BN	1.67 ns	1.53 ns	-	-	-

[#] Measured at 33 days after sowing (Exp. 1).

[§] Measured at 51 days after sowing for pearl millet, while at 51⁽¹⁾, 44⁽²⁾ and 37⁽³⁾ days after sowing for cowpea (Exp. 2).
- No data.

At vegetative stage different letters within pearl millet columns indicate significant differences ($P < 0.05$) among the planting patterns. As for the legumes ns indicates no significant differences between single and mix-planted crops at 5 % level. At early flowering stage different letters within columns for each species indicate significant differences ($P < 0.05$) among the planting patterns (Duncan's multiple range test).

the three combinations was not significant; all mix-planted crops transpired between 27 and 31 g d⁻¹ of water. Water stress strongly reduced the transpiration rate in the PM-CP combination (by 70%), as compared with PM-PP (54%) and PM-BN (58%) combinations. In general, well-watered single-planted legumes transpired much more water than single-planted pearl millet. In the drought treatment, however, single-planted crops showed similar values of water use, except for pigeon pea. Although the transpiration rate per pot in the PM-CP combination was higher, the ratio to single planting was quite similar in all the three crop combinations. The reduction of transpiration rate by mixed planting in all combinations was greater under dry conditions than under well-watered conditions.

Transpiration rates of the single leaf of pearl millet and cowpea plants were measured at the early flowering stage (Exp. 2). As compared with the single planted situation, the transpiration rate of pearl millet was strongly reduced by mixed planting with cowpea sown at the same day and 7 days later, but not when sown 14 days later (Table 3). Cowpea mix-planted with

pearl millet had lower transpiration rates than single- and pair-planted cowpeas only when it was sown 14 days later than pearl millet.

The midday leaf water potential was measured only at the early flowering stage. Regardless of the cropping pattern and sowing date, pearl millet always had a lower midday leaf water potential than cowpea (Table 3). Mix-planted pearl millet developed significantly lower leaf water potential values than single- and pair-planted pearl millet when cowpea was sown at the same day and 7 days later, but not when sown 14 days later. By contrast, cowpea showed a trend opposite that of pearl millet. In summary, both the transpiration rates and midday leaf water potential of pearl millet were reduced by mix-planting when cowpea was sown within a week after pearl millet. The two-weeks delayed sowing of cowpea did not alter pearl millet water relations as described above for water source.

3. Dry matter production, leaf area and photosynthetic rate

Under both well-watered and drought conditions, pearl millet shoot dry weight at vegetative stage

Table 5. Leaf area and photosynthetic rate of single, pair and mix-planted crops at early flowering stage (Exp. 2).

		Leaf area (cm ²)			Photosynthetic rate ($\mu\text{mol m}^{-2}\text{s}^{-1}$)		
		Cowpea sown same day (1)	Cowpea sown seven days later (2)	Cowpea sown 14 days later (3)	Cowpea sown same day (1)	Cowpea sown seven days later (2)	Cowpea sown 14 days later (3)
Cereal [pearl millet (PM)]							
Single planted	PM	832 a	832 a	832 a	16.67 a	16.67 a	16.67 a
Pair planted	PM-PM	433 b	433 b	433 b	10.47 b	10.47 b	10.47 b
Mix planted	PM-CP	521 b	767 a	832 a	8.16 b	7.23 b	14.59 a
Legume [cowpea (CP)]							
Single planted	CP	1728 a	1240 a	948 a	3.26 a	8.42 a	11.53 a
Pair planted	CP-CP	927 b	751 b	519 b	1.68 b	2.94 b	12.01 a
Mix planted	PM-CP	942 b	348 c	154 c	3.00 a	8.98 a	7.27 b

Measured at 51 days after sowing for pearl millet, while at 51⁽¹⁾, 44⁽²⁾ and 37⁽³⁾ days after sowing for cowpea (Exp. 2). Different letters within columns for each species indicate significant differences ($P < 0.05$) among the planting patterns (Duncan's multiple range test).

(Exp. 1) was significantly lowered by mixed planting with cowpea (Table 4). It was also lowered by mixed planting with pigeon pea and bambara nut, but less significantly. By contrast, the shoot dry weight of all legumes did not show significant differences between single and mix-planted situations. At the early flowering stage, pearl millet showed significantly lower biomass production under mixed planting than the single planting when cowpea was sown within a week later than pearl millet. Mix-planting with cowpea sown 14 days later did not show any effects on pearl millet dry matter production. Among the different cropping patterns, pair-planted pearl millet always had the lowest shoot dry weight. Cowpea shoot dry weight was significantly lowered by the pair and mixed planting compared with single planting situation.

Leaf area and photosynthetic rates were determined only at the early flowering stage (Table 5). The leaf area, showed the same trend as shoot dry weight shown in Table 4. The photosynthetic rate of pearl millet also showed the trend similar to leaf area and shoot dry weight. By contrast, the photosynthetic rate of cowpea was not significantly reduced by mixed planting with pearl millet when it was sown within a week after pearl millet.

Discussion

1. Water acquisition strategies

In this study, deuterated water was used to examine the water source of mix-planted pearl millet at vegetative and early flowering stages. Deuterated water was applied as recently irrigated water to find out whether mix-planted pearl millet relies on existing soil water or on recently applied irrigation water. The results indicated that the dependence of pearl millet on recently irrigated water at both vegetative and

early flowering stages, increased by mixed planting with cowpea, but the dependence of cowpea was not increased by mixed planting with pearl millet (Table 1). The results also indicated that the water sources of pearl millet are modified by varying the date of sowing cowpea. These results provide new evidence on the water competition in the pearl millet-cowpea intercropping system; cowpea has higher ability to acquire existing soil water than pearl millet. As a result, pearl millet could not acquire enough resources from the existing soil water. Consequently, the dependence on the recently irrigated water increased significantly by mixed planting. Sowing cowpea at two weeks later than pearl millet, when pearl millet seedlings were well established, did not cause any effects on pearl millet water sources. In such case, competition for soil water from the legume was considerably weak due to its smaller size. In fact pearl millet had reduced significantly the transpiration rate and shoot dry weight of cowpea (Tables 3 & 4). On the other hand when the two crops were planted simultaneously or within a week, pearl millet was forced to rely more on the recently irrigated water. When single or pair planted, cowpea showed a higher D₂O absorption than pearl millet, especially under well-watered and pair planted conditions. This indicated that the utilization of recently irrigated water itself was relatively higher in cowpea when water competition did not occur. Under drought conditions and when cowpea is sown 14 days later than pearl millet, however, the difference between the two species became smaller, which implies that the water use pattern under these conditions may be similar in both species. When the two different species competed to acquire soil water, the water source of pearl millet was shifted to recently supplied water, most probably due to the relative weak ability

to access to the existing soil water as indicated by the lower midday leaf water potential values (Table 3).

The physiology of plant water relations in the mix-planted pearl millet and cowpea has already been discussed by comparing the leaf water potential changes of the plants grown in the pot environment (Petrie and Hall, 1992a). Pearl millet developed a significantly lower predawn leaf water potential than cowpea under the dry condition, indicating the higher ability of cowpea to tolerate drought conditions. Field experiments indicated that cowpea is a drought-resistant legume crop (Hall and Grantz, 1981). In fact, cowpea under field conditions often survives, while intercropped pearl millet dies under severe drought. More detailed field studies on deuterium analysis may provide further knowledge on the water sources of intercropped pearl millet and cowpea.

2. Transpiration rate and plant water status

Under well-watered conditions, single-planted pearl millet showed lower transpiration values than single planted legumes at the vegetative stage (Table 2), which agrees with the results of field experiments by Singh et al. (1988). Under drought stress in the present experiment similar actual water use by single and mix-planted crops was observed, which is in agreement with the results of intercropping field experiments in semi-arid areas (Morris and Garrity, 1993).

When both species were sown at the same day, cowpea had a larger leaf area than pearl millet (Table 5). The same results were reported by Petrie and Hall (1992a). It was suggested that a plant with larger leaf area depletes soil water faster and develop a lower leaf water potential more rapidly (Petrie and Hall 1992 b). In our experiment as well as in those of Petrie and Hall (1992 a, b and c) leaf area of cowpea was higher than that of pearl millet (Table 5), but midday leaf water potential was always lower in pearl millet (Table 3). It is well known that water moves preferentially from the regions with a higher water potential to regions with a lower water potential. Therefore, the higher dependability of mixed planted pearl millet on the recently irrigated water, expressed in the higher deuterium concentration in xylem sap water, could be explained by the lower midday leaf water potential developed before the application of the newly irrigated water. Sowing cowpea 14 days later, however, did not have any effects on leaf water potential and water uptake sources of pearl millet.

3. Competition in terms of dry matter production

Pearl millet biomass production was strongly reduced by mixed planting with cowpea (Table 4), which agrees with the yield results of a field experiment in northeast Nigeria (Grema and Hess, 1994), indicating that cowpea exerted a high

competitive pressure on pearl millet production. Competition of mix-planted pigeon pea and bambara nut with pearl millet was not so serious, because these legumes showed a smaller canopy at the early developmental stages. Rana and Mahendra-Pal (1997) indicated that pigeon pea is a slow-growing crop at early stages, which provides ample opportunity to be dominated by weeds.

Biomass production of mix-planted pearl millet was significantly lowered when cowpea was sown less than a week later (Table 4). In a field experiment Reddy et al. (1992) reported that yields of mono and intercropped pearl millet were similar when cowpea was sown one and two weeks later, while cowpea yield was strongly reduced when it was sown eight weeks later. Other studies revealed that the legume component of an intercrop can be severely impaired by late sowing relative to the cereal (Ntare, 1990; Craufurd, 2000). Under the farmers' conditions, Oluwasemire et al., (2002) found that pearl millet became the dominant crop in the intercrop as the planting density decreased.

In summary, the results of this study provide new direct evidence on the water competition in the pearl millet-cowpea intercropping system; cowpea has higher ability to acquire existing soil water when sown at the same time or one week later than pearl millet. Field trials should be conducted to find out the competitive effects of cowpea under various soil water conditions and planting dates to understand the implications or much better selection of crop components and cultural practices in pearl millet-based systems.

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