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INTERACTIONS BETWEEN NÉRÉ (*PARKIA BIGLOBOSA*) AND UNDER-PLANTED SORGHUM IN A PARKLAND SYSTEM IN BURKINA FASO

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SUMMARY

A farmer's intercropping system of white sorghum (*Sorghum bicolor*) and néré (*Parkia biglobosa*) was studied in Burkina Faso. In quadrats in three differing zones of tree influence, full sun (open field), semi-shade (under the edge of the tree crown) and full shade (under the crown), tree morphology and associated sorghum growth were recorded together with micro-meterological parameters. Mean photosynthetic photon flux density (PFD) was reduced to 51 and 26% of full sun levels, in the semi-shaded and fully shaded quadrats respectively. Soil temperature and moisture were also recorded. In the season studied, the principal effect of the trees on the crop was competition for light. For plants in full shade, total shoot and panicle mass were halved compared with the crop in full sun. However, plants in semi-shade were able to compensate for decreased PFD almost entirely. Measurable compensatory effects were decreased rate of leaf senescence, greater partitioning of resources into leaf production, and larger, thinner leaf laminae. It was concluded that the current farmers' practice of sowing under the crowns of trees produced a worthwhile, if somewhat reduced, crop yield, and that socially, economically and ecologically the sorghum–néré parkland system was worth retaining.

INTRODUCTION

The cultivated savanna parklands of central Burkina Faso, in the Sudanian ecozone, are dominated by *Parkia biglobosa* (Jacq.) Benth. (Mimosoideae), the locust bean, known locally as néré, and *Vitellaria paradoxa* C. F. Gaertn. (Sapotaceae), the shea butter tree, known as karité. Farming systems around Ouagadougou, the capital city of Burkina Faso, commonly include spaced néré and karité trees in crop land. Néré is an economically important food source in West Africa. The seeds of néré are fermented on the farm and the resulting product, *soumbala*, is a condiment sold widely at market. The young pods and pulp are also consumed. The bark and roots have useful medicinal properties (Booth and Wickens, 1988), and the leaves can also be used as fodder (Sabiiti and Cobbina, 1992). A sorghum (*Sorghum bicolor*)–néré–karité intercropping system is practised widely, although the following crops are also successfully grown in association with the two trees: pearl millet (*Pennisetum glaucum*)–sorghum; pearl

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millet–common bean (*Phaseolus vulgaris*); pearl millet–sorghum–common bean; maize (*Zea mays*).

The pressure for agriculture to intensify around Ouagadougou is increasing due, in the main, to the rising population density. Many farmers have reduced or discarded fallow periods and as a result soil fertility is decreasing. Some farmers, who can afford to, buy city domestic waste which they spread over their fields to act as a fertilizer to alleviate this problem. With an average sorghum yield of only 0.89 $\mathrm{t\,ha^{-1}}$ (FAO, 1994), further improvements to the system and to the crops themselves could still be made.

In view of the population pressure rising at about 3% per annum (Alexandratos, 1995), a growing number of people are dependent upon néré–karité parkland systems. In order to improve the system, it is important for farmers and scientists to have detailed quantitative information about the interactions between the trees and sorghum. The potential of néré within agroforestry systems has been recognized frequently (Kessler, 1992; Sabiiti and Cobbina, 1992; Booth and Wickens, 1988). However, quantitative descriptions of the morphological characteristics of néré in relation to shading and the role it plays at the crop interface have not been well documented.

Recent research on farming systems associated with néré and karité trees includes that of Kessler (1992), Kater *et al.* (1992), Bagnoud *et al.* (1995), Boffa (1995) and Schreckenberg (1996). Bagnoud *et al.* (1995) and Schreckenberg (1996) considered primarily the socio-economic implications of karité in agroforestry systems, whilst Boffa (1995) also included eco-physiological interactions between karité and the understorey crops. The work of Kessler (1992) and Kater *et al.* (1992) will be considered in the discussion.

It was anticipated that trees such as néré would influence the light, water and temperature regimes experienced by undercropping sorghum. It was hypothesized that the presence of trees in fields of sorghum would affect crop productivity, but not to the point at which it was not worth the farmer growing the crop in close proximity to the trees, due to the ability of the crop to compensate in resource-limiting conditions. Thus, the output from such a tree–crop system would be greater than if the two components had been grown in separate fields. The available equipment was limited, so recordings were restricted to describing the gross morphology of néré, quantifying the degree and extent of shade, measuring soil moisture content and soil surface temperatures, and determining the relationship between these and the productivity of sorghum situated at varying distances from the trees.

MATERIALS AND METHODS

The study was conducted in 1995 on a smallholder's farm at Nagaré (lat 12°36′N, long 01°45′E), situated 5 km south-west of Ouagadougou. In the 1995 cropping season, annual rainfall was 740 mm in 64 rainy days (Ouagadougou Airport meteorological data, unpublished), the majority falling from May to

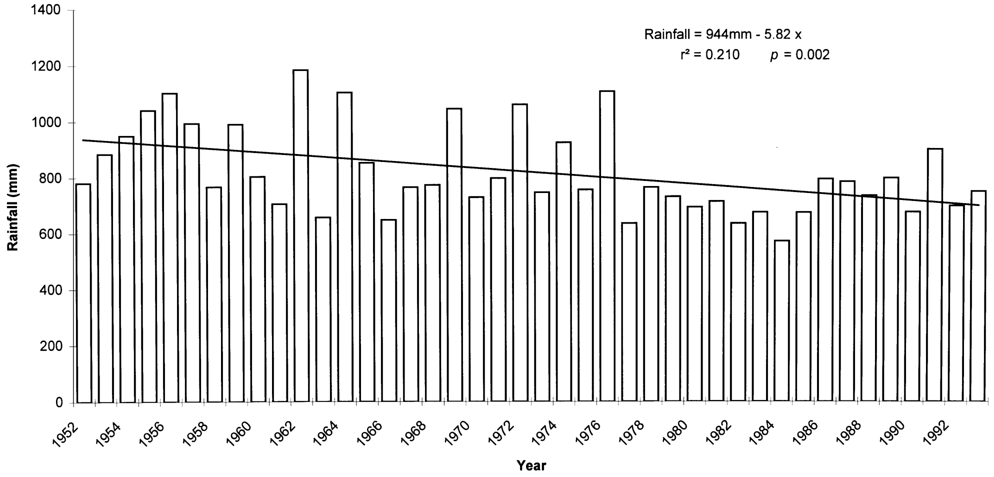

Fig. 1. Annual rainfall at Ouagadougou Airport, 1952–1993.

September. The trends in rainfall over the four decades prior to the experiment are presented in Fig. 1. In the 1995 growing season, 114, 118, 258 and 137 mm of rain fell in June, July, August and September respectively. The mean daily temperature was 28 °C with a maximum of 35 °C in April and May, and a minimum of 22 °C in January and February.

The study site was relatively flat with an altitude of approximately 300 m. The tropical ferruginous soils, Alfisols, lie on a bedrock of Precambrian granite (Bonkoungou and Framond, 1988). The natural vegetation is commonly referred to as a mixed shrub–tree savanna (Sudanian phytogeographical domain) (Kessler, 1992). In areas near habitation, an anthropogenic farmed parkland savanna has evolved.

Eight néré trees were selected for the study. Five trees were approximately 85 years old and three were approximately 50 years old (local farmer's information). The following parameters were recorded for each sample tree: trunk diameter at breast height (dbh), height at which the trunk first branched, distance of lowest branches from the ground, and the extent of the crown in each cardinal direction.

White sorghum of the *guinea* race (Zongo *et al.*, 1993) was grown from seed saved from the farmer's previous harvest. The slightly open panicles of the crop placed it in the Type 3 group, according to the classification system of Harlan and de Wet (1972). The plants were tall, approximately 3.6 m at maturity, and were not phenotypically uniform. This landrace was selected for study because the results would be more applicable to local farmers. Zongo *et al.* (1993) found that sorghums with typical *guinea* characteristics produced the highest yields in Burkina Faso, and the most productive accessions were tall and had long panicles. Hence, whilst *guinea* sorghum is a comparatively low yielding variety on an international scale, it appears to be a relatively popular, high-yielding variety in Burkina Faso, where 63.5% of sorghum accessions belong to the *guinea* race (Zongo *et al.*, 1993).

The farmer planted sorghum in the week beginning 19 June. Fields were ridged using a donkey-drawn plough or manually by hoeing. Seeds were dropped manually into planting holes spaced approximately 30–40 cm apart. The mean established crop density was 4 plants m^{-2} and did not vary according to proximity to trees.

To sample spatial variation in the effect of spaced trees upon environmental parameters, three light zones (full sun, semi-shade and full shade) were sampled per tree, with two fixed quadrats (1.5 m × 1.5 m) per zone. Quadrats in full sun were located well beyond the tree canopy in the open field while those in full shade were located under the tree canopy. Of the two semi-shaded quadrats, one received full sunlight until approximately 1300 hours and was then shaded, whilst the other was shaded until approximately 1300 hours and received full sunlight in the afternoon. The quadrats were located in the crop from which biomass and leaf area were recorded, and were cleared of sorghum plants in order to record environmental variables: soil moisture, photosynthetic photon flux density (PFD) and soil temperature.

Light and temperature data were collected from every quadrat under one of the trees, over a five-day period in July and a four-day period in August. Daily integrals of PFD (400–700 nm) were recorded using solid state silicon sensors wired to millivolt integrators (Delta-T Devices, Burwell, Cambridge, UK). Soil temperatures in each light zone were measured at a depth of 5 cm, using thermistors, and were recorded by a Squirrel data logger (Grant Instruments, Cambridge). When the data logger ceased to function, it was necessary to measure soil temperature using solid-state thermometers. These data were recorded manually. Crown-shade movements were measured at eight points of the compass around the trees every hour between 0800 and 1600 hours, in order to determine the land area affected by shade. The area of land shaded by the tree crown at different times during the day was determined from scale drawings of shadow dimensions. Paper cut-outs of shaded areas were weighed to determine actual land area shaded.

Soil moisture was measured twice during the growing season, at 35 and 97 days after planting (DAP), 20 July and 19 September respectively. Samples were taken in every quadrat at a horizon depth of 0–15 cm (that is 16 quadrats per light zone) and mixed thoroughly in a plastic bag. Gravimetric water content was determined by oven drying a sub-sample of approximately 45 g at 105 °C for 24 h.

Two sorghum plants adjacent to each quadrat zone were randomly sampled (a total of 32 plants per light zone) on two occasions: during vegetative growth, at 77 DAP (31 August) and at maturity at 118 DAP (10 October). The height of each sorghum plant was measured and they were then severed at the base and sealed in individual plastic bags. In the laboratory, each plant was divided into dead leaves ($>50\%$ senesced), green leaves ($<50\%$ senesced) and stems. At 118 DAP the panicle was also treated separately. Samples were placed in paper bags for drying at 80 °C for 48 h, or to constant weight.

At 49 and 118 DAP, leaf length (measured from the leaf tip to the point of attachment to the leaf sheath) and breadth (at the widest point) of all leaves from the plants sampled were recorded. To convert these measurements to area, leaf area from a sample of 20 leaves was determined from length and breadth by tracing on to paper of known weight, cutting out the leaf shape, and weighing. A regression equation was derived and used to calculate leaf area from length and breadth field measurements ($\text{area} = (\text{length} \times \text{breadth}) \times 0.769$). The intercept was not significantly different from the origin and was therefore ignored.

In agroforestry experiments where crops are sampled at different distances from the perennial component, treatment allocation is not fully random. The systematic arrangement adopted made it impossible to determine a valid estimate of error, as neighbouring quadrats could have correlated residuals. Therefore, treatment effects were tested by subjecting the differences in values of variables between plots to pairwise t-tests. Thus, for a particular variable, results from quadrats in full shade were subtracted from those from quadrats in semi-shade and full sun, and semi-shade from full sun. The null hypothesis assumed that differences between treatments were equal to zero. A significant t-test resulted in this hypothesis being rejected.

RESULTS

Dimensions of the eight trees studied are presented in Table 1. Crown radius, tree height, point of first branching and mean distance of lowest branch from the ground were not significantly different between age classes of trees, despite three trees being considerably younger than the others. Trunk diameter at breast height (dbh) of the younger trees was significantly smaller ($p < 0.05$) than the older trees.

Table 1. Characteristics of undercropped néré trees at Nagaré

	Estimated tree age (years)			
Characteristics	50		85	
Number of trees in sample	3		5	
Diameter at breast height (cm)	54.3	(3.33)†	75.2	(5.45)
Point of first branching (m)	2.10	(0.28)	2.38	(0.23)
Distance of lowest branches from ground (m)	3.58	(0.43)	3.46	(0.27)
Tree height (m)	12.9	(1.12)	16.6	(2.28)
Crown radius (m)	6.71	(0.22)	7.18	(0.71)
Crown area (vertically projected) (m^2)	165	(30.7)	179	(26.6)
Ground area shaded by tree 0800–1600 hours (m^2)	288	(35.8)	326	(31.3)

†Standard errors of means in parentheses.

The branches tended to droop around the periphery of the crown, giving rise to the characteristic bell-shaped architecture. The mean height of the lowest branches from the ground was 3.51 m. The trunks of the trees forked relatively low on the trunk, at a mean height of 2.28 m from the ground.

Regression analyses were conducted to determine how the morphology of néré influenced sorghum growth. The results revealed that, in general, less than 1% of the variation in vegetative and reproductive biomass of plants shaded for part of the day (semi-shade) could be explained by tree characteristics. In contrast, variation in shoot mass of fully shaded plants was significantly and negatively affected by tree height ($r^2 = 0.76$), but not by any of the other tree morphological characteristics recorded.

PFD varied diurnally, with a typical peak of 1900 μm m^{-2} s^{-1} at noon on bright days. When not in shade, the semi-shaded quadrats received the same incident PFD as the unshaded quadrats. As the shade cast by the crown moved, the PFD incident upon the semi-shaded quadrats fluctuated between 16 and 33% in the shade of néré, when compared with quadrats in full sunlight. Over the nine days on which recordings were taken, all but one being sunny days, mean PFD incident upon semi-shaded and fully shaded quadrats was 51 and 26% respectively of that incident upon unshaded quadrats. Examples of shade movement between 0800 and 1600 hours around two of the néré trees are presented in Fig. 2. In general, crown shade moved towards the east throughout the day, though the shape of the shade area reflected the shape of the crown.

As might be expected, soil temperature at a depth of 5 cm was highest in the unshaded quadrats receiving full sun. On days when it was recorded, soil temperature did not exceed 38 °C. In full shade, soil temperatures did not exceed 30 °C, and differentials between shaded and sunny quadrats amounted to 5–10 °C in the middle of the day.

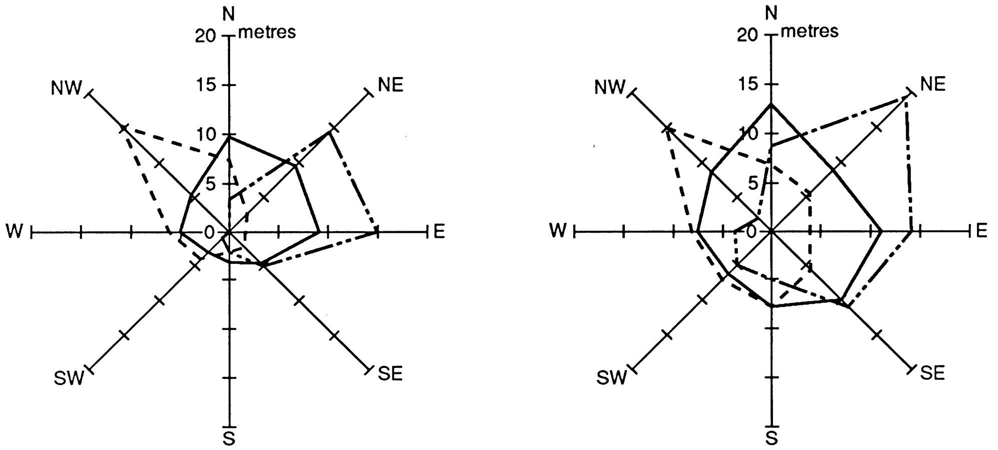

Fig. 2. Examples of daily shade movement around two néré trees, measured hourly between 0800 and 1600 hours, with extent of shade at 0800 (– – – –), 1200 (———) and 1600 (– · –) shown.

Table 2. Mean percentage soil moisture (gravimetric) of the 0- to 15-cm horizon in sun, semi-shade and shade treatment zones at 35 (20 July) and 97 (19 September, 1995) days after planting (DAP)

DAP	Sun		Semi-shade		Shade	
35	15.14	(0.493)†	18.01	(0.727)	15.82	(1.13)
97	9.83	(0.367)	11.41	(0.451)	12.16	(0.335)

†Standard errors of means in parentheses.

Gravimetric soil moisture content analysis indicated that by 35 DAP, there were no differences in soil moisture between full sun and shade quadrats, but the moisture content of soil in semi-shaded quadrats was significantly higher than both. By 97 DAP, soil moisture beneath néré trees was higher than in semi-shade and the open field (Table 2).

Fig. 3a and 3b illustrate sorghum shoot structure at 77 and 118 DAP. In every treatment zone, the sorghum stem elongated with age, though shaded sorghum stems were significantly shorter than plants in the full sun and semi-shade. Green leaf area and number of leaves per plant decreased as the plants grew older.

The results of analysis of sorghum biomass at 77 and 118 DAP are presented in Table 3. At 77 DAP, sorghum grown in full shade possessed the lowest mean shoot mass which was approximately half that of plants in full sunlight. Green leaf and stem mass of shaded plants were significantly lower than those of semi-shaded plants or those in full sun. Leaf senescence, as shown by mass of dead leaves, was greatest in plants in full sun and least in full shade.

Leaf area index (LAI) was significantly greater in semi-shaded plants than in either of the other treatments (Table 3 and Fig. 3a). Leaf area ratio (LAR), the ratio of green leaf area to total shoot mass, was least in plants growing in full sun, and greatest in fully shaded plants. Specific leaf area (SLA), the ratio of leaf area to leaf mass, followed the same trend, although there was no significant difference between the semi- and full-shade treatments.

At maturity, 118 DAP, sorghum panicles had developed fully (Table 3), but the plants still had some green leaves remaining at this stage (Fig. 3b). There were no significant differences in green leaf mass or LAI between treatments. Green leaf mass decreased between 77 and 118 DAP, presumably as a result of senescence, but the rate of leaf abscission was not recorded. Stem mass of shaded plants was significantly lower than that of plants in full sun or semi-shade.

Reproductive (panicle) mass of plants in full sun was double that of fully shaded plants but, although greater, was not significantly different from that of semi-shaded plants. Total shoot mass followed the same trends. Harvest index (HI), the ratio of these two variables, appeared to decrease with increasing shade, and was significantly lower in full shade compared with the other two treatments.

The LAR of plants in full shade was more than double that of plants in full sun, with semi-shaded plants being intermediate. However, unlike the 77 DAP sample, treatment effects upon SLA were not significant.

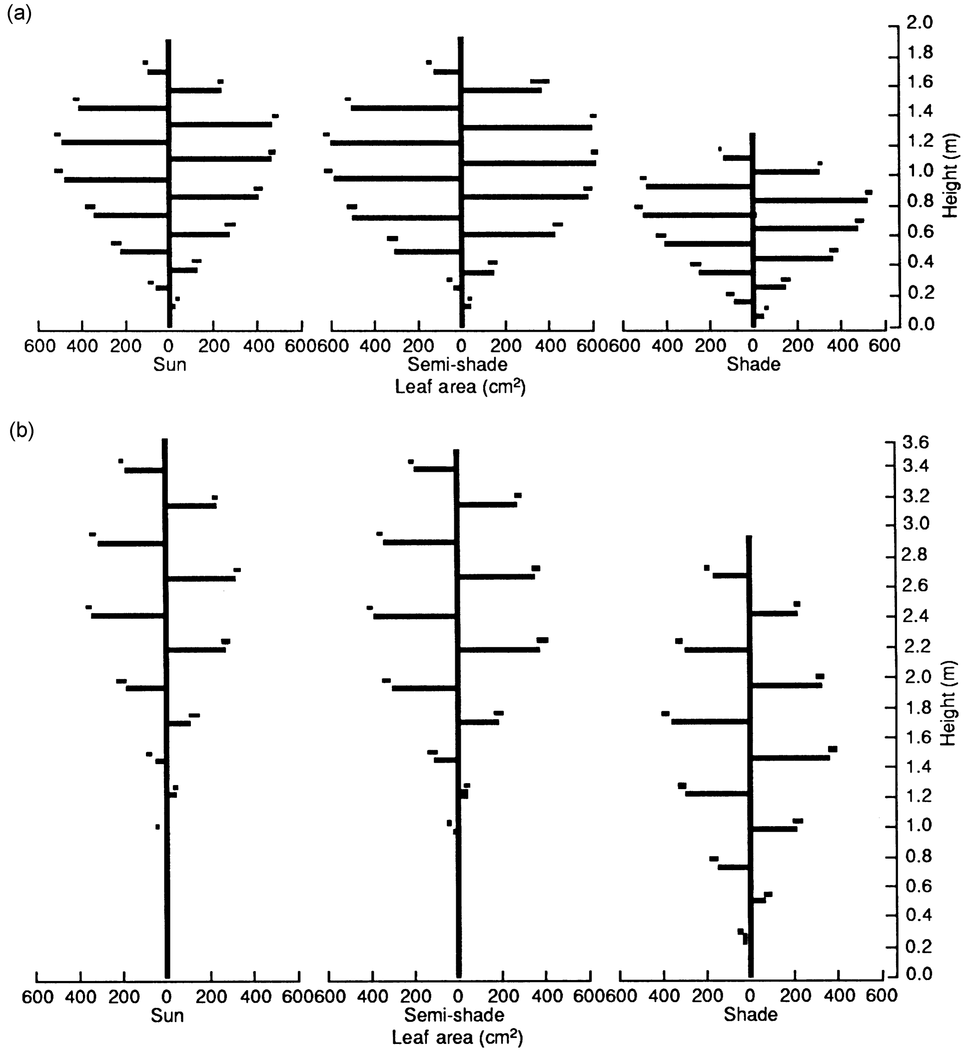

Fig. 3. Height and mean area per leaf of sorghum plants in sun, semi-shade and shade treatments at (a) 77 and (b) 118 days after planting. Sorghum leaf area (—) and standard error of the mean (▬, above main bar).

LAR, SLA and HI are all derived variables, being quotients of other directly recorded variables. Sometimes the means of derived variables reported in Table 3 differed from the ratio of the reported means of variables from which they were derived. This is not an unusual phenomenon, and arises when the ratio of pairs of values of x and y are not always constant as x varies, or when the regression line of y on x does not pass through the origin.

DISCUSSION

In the literature there are several descriptions of the architecture of néré. Height varies with age, but most workers report heights in the range 10–20 m (Hopkins,

Table 3. Sorghum characteristics and mean dry biomass (g m^{-2}) at 77 (31 August) and 118 (10 October, 1995) days after planting (DAP) for sun, semi-shade and shade treatments

	DAP	Sun		Semi-shade		Shade	
Green leaf	77	78.8	(6.23)†	81.1	(4.43)	55.8	(5.98)
	118	40.4	(4.62)	48.5	(4.46)	42.4	(3.66)
Dead leaf	77	14.0	(1.69)	9.10	(1.07)	5.87	(1.12)
	118	8.4	(1.31)	6.37	(1.57)	5.35	(1.24)
Stem	77	164	(21.7)	140	(10.3)	71.7	(10.3)
	118	310	(33.2)	252	(29.0)	163	(16.0)
Panicle (whole)	118	204	(34.5)	168	(22.9)	96.4	(20.3)
Total shoot dry weight	77	256	(28.4)	231	(12.5)	133	(16.0)
	118	563	(65.1)	475	(45.0)	307	(30.4)
Leaf area index (green)	77	1.63	(0.167)	2.08	(0.097)	1.41	(0.142)
	118	0.64	(0.059)	0.83	(0.062)	0.78	(0.072)
Leaf area ratio (cm^2 g^{-1})	77	66.8	(4.97)	91.2	(2.31)	116	(9.29)
	118	12.4	(0.940)	20.4	(2.67)	29.0	(3.15)
Specific leaf area (cm^2 g^{-1})	77	206	(14.0)	260	(9.30)	270	(19.8)
	118	165	(8.98)	183	(13.9)	192	(15.3)
Harvest index	118	0.352	(0.032)	0.346	(0.030)	0.274	(0.041)

†Standard errors of means in parentheses.

1983; FAO, 1988; Carlowitz, 1991; Kater *et al.*, 1992; Kessler, 1992), with a maximum height of 30 m (Booth and Wickens, 1988). Timmer *et al.* (1996) reported that trees in the Cental Plateau of Burkina Faso had a height of 13.9 m, a dbh of 85.9 cm and a height to the first branch of 2.1 m. These dimensions correspond closely to the values of 14.6 m, 67 cm and 2.4 m respectively obtained in this study. Many authors refer to the characteristic umbrella-shaped crown of néré trees (Hopkins, 1983; FAO, 1988; Booth and Wickens, 1988; Carlowitz, 1991), but only a few give information on mean crown diameter. In southern Mali trees with a dbh of 56 cm had a mean crown diameter of 14.3 m (Kater *et al.*, 1992) and in central Benin smaller trees with a dbh of 22.6 cm had a mean crown diameter of 6.24 m (Schreckenberg, 1996). The trees in the current study had a mean crown diameter of 14.0 m and a dbh of 67 cm, dimensions which are closer to those of the larger trees recorded by Kater *et al.* (1992). The only significant effect of estimated tree age on a morphological parameter was on dbh (Table 1).

Despite the significant and possibly deleterious effect of shade cast by néré upon intercrops, the area affected by shade of a single tree throughout the day is not well documented. The crown area for unpruned néré was reported to be 166 m^2 in

Burkina Faso, (Kessler, 1992) and 161 m^2 in southern Mali, based on calculations from radii, assuming the crown to be circular (Kater *et al.*, 1992), but in neither case was the extent of shade movement during the day measured. These values correspond closely with the mean crown area of 159 m^2 in the current work, when calculated from the mean crown radius measured at the four cardinal compass points. This area is lower than that obtained for estimating the extent of shade recorded at 1200 hours, which gave a crown area of 174 m^2. However, these two estimates were not significantly different from each other. From the measurements of the shade movement during the 8 h period from 0800 to 1600 hours, it was revealed that the total area affected by shade per tree during this period was 312 m^2, 185% of the shade area at 1200 hours. Thus, taking the area of crop affected by shade as equivalent to the crown diameter of the tree underestimates the effects of shade cast by the crown considerably.

This study found that a sorghum crop in full shade received, on average, 26% of PFD and it is probable that the photosynthetic system was constantly well below the light saturation point. This confirms Kessler (1992) who stated that PAR was reduced to 20% under néré trees. Sharkaway and Hesketh (1965) and Rabo (1996) found that light intensities equal to or greater than full sunlight were required to saturate the photosynthetic apparatus of sorghum, a C4 species. Therefore, it would be expected that the reduction in available PFD under néré would have reduced the rate of photosynthesis and, consequently, assimilate availability. Variation in shoot mass of fully shaded plants was negatively correlated with tree height, which may have been because radiation had to penetrate a greater number of leaf layers in a tall tree before it reached the understorey crop.

Mean final biomass of fully shaded plants was 54% of those in full sunlight. In contrast, sorghum plants in semi-shade, which received an average of 51% of the PFD of full sunlight, were able to compensate for this reduction almost completely, there being no significant differences in crop biomass in sun and semi-shade quadrats (Table 3). These results suggest that efficiency of biomass production per mole of photons captured by the crop was greater in shade and semi-shade than in full sunlight. Leaf temperatures were not measured directly. However, if it is inferred from the effects of shade on soil temperatures that leaf temperatures in shaded sorghum plants were, on average, lower than those of plants in full sun, then the rates of transpiration in shaded leaves would have been less. This would decrease the likelihood of water stress. Similar work in semi-arid Nigeria on sorghum plants growing in the shade of *Prosopis juliflora* showed that they developed less negative leaf water potentials than plants in full sun (V. Grime, University of Wales, personal communication, 1996).

The ability of semi-shaded sorghum plants to compensate may also have been the result of a greater investment of assimilates into leaf tissue compared with plants growing in full sun. Although treatment differences in green leaf and stem mass were evident, they were not significant (Table 3). However, the quotient of their effects, expressed as LAR, was significantly different. LAI was significantly greater in semi-shaded plants compared with those in full sun, despite the lack of a significant difference in leaf mass referred to above. This was achieved by leaves of semi-shaded plants having a greater area to mass ratio (SLA), producing leaves that were thinner in the abaxial–adaxial axis.

Between the semi-shaded treatments and those in full sun, the only variable which differed significantly was LAR (Table 3). Across all three treatments LAR decreased considerably between 77 and 118 DAP due to the cessation of leaf growth, leaf abscission and the developmental switch to reproductive growth. Partitioning of assimilates to the reproductive organs, as measured by HI, was only slightly less in semi-shaded plants. The combined effects of decreased investment of assimilates into non-laminar tissue and thinner leaves, enabled semi-shaded plants to utilize incident PFD more effectively than unshaded plants. This tendency to increase organ size to capture the resource most limiting productivity is well documented (for example Tilman, 1988).

Similar compensatory growth mechanisms operated in fully shaded plants, but incident PFD was reduced to the point where it was insufficient to produce the same dry matter as the other two treatments. Plants growing in full shade had shorter stems (Fig. 3b) but, despite decreased investment in stem tissue, also partitioned proportionally fewer resources to the panicles (Table 3). The result was a halving of reproductive organ dry weight compared with plants growing in the full sun.

Following research on the effects of soil temperature on seedling establishment Peacock *et al.* (1990) concluded that, even when adequate soil moisture is available, soil temperatures greater than 45 °C can inhibit establishment of sorghum seedlings. During the sampling period, soil temperature did not reach 45 °C in any of the sampling areas, and thus sorghum seedling establishment was unlikely to have been affected. Shade cast by trees would not therefore have had any positive effect on seedling survival, and thus establishment.

Other reports of sorghum–tree interactions in this ecozone vary in their conclusions. Kessler (1992) found that sorghum plants under the tree crown matured less rapidly and at the time of harvest were often unripe (but were nevertheless harvested with the other plants). He concluded that sorghum grain yields under néré in Burkina Faso were reduced by an average of 70% (range 35–90%), in comparison with the yields in the open field. In the current study there was a difference between treatments in ripeness. Kessler believed that reduced light intensity explained why sorghum yields were lower under tree crowns. Boffa (1995) found that at up to 2 m from karité trees sorghum yield was 87% of that at at least 8 m from the tree in the open field, and Tilander *et al.* (1995) found that at 0–3 m from neem (*Azadirachta indica*) sorghum yields were 82% of those at 8–9 m from the trees. However, from experiments conducted with sorghum in southern Mali, Kater *et al.* (1992) concluded that panicle weight per plant in néré shade was not significantly different from panicle weight of plants grown in full light. Effects of néré on sorghum in the current work seemed to fall somewhere in the middle of the foregoing somewhat contradictory findings. Such variations in results may be explained in part by inter-seasonal climatic differences, variable tree sizes and possibly differing positions of sample quadrats in relation to the tree.

The climate of the Sudanian ecozone of West Africa is renowned for its instability and unpredictability, and delayed, inadequate or inconsistent rains are an ever present threat. A linear regression was the best fit for the annual rainfall data presented in Fig. 1, showing that on average rainfall declined by 5.8 mm a^{-1} over the period 1952–1993. There was also a decline in the number of rainy days from 77 to 64. If this rate of decline continues, within the next fifty years sorghum cultivation will become increasingly unproductive. In the current study, soil moisture results were rather inconsistent, possibly because of the small sample sizes. Similarity in soil moisture content at 35 DAP for quadrats in full sun and full shade suggested that some unrecorded phenomenon was responsible for the higher soil moisture recorded in the semi-shaded quadrats, possibly water drip from crown perimeter. Overall soil moisture contents were lower by 97 DAP, and there was some evidence that the upper horizon of the soil was beginning to dry out in unshaded areas, whilst retaining a higher percentage soil moisture under the crown.

Nevertheless, due to the pronounced effects of the proximity of sorghum plants to trees on sorghum morphology and productivity, it was concluded that, in the season studied, the principal factor limiting sorghum growth was competition for light rather than soil moisture. Other factors, for example soil nutrients and biotic factors, which were not measured may also have influenced crop productivity, and further studies need to consider their importance. In particular, to understand the processes operating in this system, such studies could measure water use directly by the crop and compare this with spatial and temporal variation in soil water status, crop transpiration, photosynthesis and nutrient status, across the three zones of tree influence.

Trees in parklands influence the distribution of soil nutrients. Organic matter and mineral nutrients have been found in higher concentrations beneath néré crowns (Tomlinson *et al.*, 1995) and at the crown edge of karité (Boffa, 1995) compared with the open field. Although néré is a legume, Tomlinson *et al.* (1995) could find no evidence of root nodulation in mature trees in the field, and they reported similar results from other workers. In the current experiment, sorghum in quadrats in the semi-shade, where plants were often at the crown edge, may have benefited from increased soil fertility compared with plants in quadrats in the full sunlight. This may have helped to compensate for the decrease in light intensity. Kessler and Breman (1991) concluded that most of the nutrients accumulated around trees were there at the expense of areas without trees, but from this experiment it was not possible to determine whether plants in the open field were limited by nutrient supply.

With tree pruning, it may be possible to exploit the positive characteristics of néré, such as its suspected influence upon soil fertility and moisture, whilst reducing the deleterious effects of shade. However, in a recent study in the

Central Plateau, Burkina Faso, to investigate why farmers pruned néré trees, Timmer *et al.* (1996) found that of 83 trees 59% were pruned to improve tree survival and productivity whilst only 3% were pruned to reduce shade effects on the crop. At present, pruning is not a common practice and in total only 10–30% of néré trees in the Central Plateau were pruned. Work on other tree species (Rabo, 1996) has shown that pruning can increase understorey sorghum yield significantly. Were such management applied to néré, this would have the additional benefit of increasing fruit production (Timmer *et al.*, 1996).

The néré–sorghum intercrop system, which is common in Burkina Faso, occupies a niche for which few other agroforestry systems could be substituted, because of the hostile climatic regime. Despite frequent years when rainfall, and presumably crop yield, were inadequate, most farmers have retained néré in their fields. This indicates the importance they attach to these trees, as they are willing to forsake the yield of a staple for the yield of a tree cash crop. This study found that sorghum yields were reduced locally under each tree, but less so at the crown edge. Therefore it may be advantageous to sow sorghum within the boundary of the crown edge. At present, many farmers cultivate up to the base of the tree, possibly because they are trying to maximize output per field rather than efficiency of labour, and this cultivation may also control weeds which might otherwise proliferate beneath the crown.

Kessler (1992) studied the economics of a sorghum–néré intercrop and concluded that in 1992, at a tree density of 5–10 ha^{-1} there was a net benefit of 5000 f CFA (1995 exchange rate \$1.00 = 480 f CFA) per hectare from the intercrop when compared with a sole sorghum crop. If adequate land is available to produce sufficient grain for dependent families, this sum may be enough in itself to persuade farmers to retain néré and to accept lower grain yields. Bagnoud *et al.* (1995) estimated that the economic benefits of having néré and karité on farmland were also 3–4 times higher than the losses in the crop yields. The benefits gained from néré were also 2–3 times higher than those from karité, which would explain their preservation on farmland, despite their large size in comparison with karité.

Smallholder farmers in Burkina Faso often hold little capital and therefore tend to be averse to taking risks. The danger of total failure of the farming system is lessened if sorghum is intercropped with néré. The roots of trees are able to tap soil moisture held several metres below ground. Thus, in the event of annual crop failure, it may be possible to salvage a crop from néré trees.

The effect of retaining trees raises the overall financial output from an area of land whilst stabilizing the area ecologically, particularly by reducing wind erosion of soil. Thus, it appears that despite local effects upon crop yields, the total productivity of an area is increased by intercropping with néré. In any farming system subjected to greater stresses, a component such as néré, which helps to stabilize the whole system, is to be encouraged.

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