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Competition and facilitation-related factors impacts on crop performance in an agro-forestry parkland system in Burkina Faso

Bayala J.[1]*, Bazié H. R.[2] and Sanou J.[2]

[1]World Agroforestry Centre (ICRAF), ICRAF-WCA/ Sahel Node, BP E5118 Bamako, Mali.
[2]Institut de l'Environnement et de Recherches Agricoles, Département Productions Forestières, 03 BP 7047 Ouagadougou 03, Burkina Faso.

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***Parkia biglobosa* and *Vitellaria paradoxa* are known to improve soil fertility and redistribute water under their crowns in parkland systems. A field experiment was conducted to separate above and belowground interactions between these species and associated *Sorghum bicolor* using root trenching and crown pruning during three cropping seasons. Trenching increased soil water availability because *Sorghum* plants displayed higher leaf water potential (-0.73 ± 0.11 MPa) in the trenched plots than control plots (-1.32 ± 0.14 MPa). There were no significant differences in grain (315 ± 80 kg ha^{-1} versus 217 ± 48 kg ha^{-1}) and straw biomass (1639 ± 295 kg ha^{-1} versus 1307 ± 278 kg ha^{-1}) yields between trenched and control plots. Crown pruning increased sorghum grain yield in the trenched plots in 2008 and 2009 under P*. biglobosa* while the opposite happened under *V. paradoxa*. Better performance of *Sorghum* in the trenched plots under unpruned *V. paradoxa* trees than pruned trees could be an indication that light was less limiting under this species as previously thought but also that crown removal induced soil water evaporation and decreased soil water content under this species. An implication of this is that recommendations for including trees in cropland, or for management of existing trees within cropland, must be context and species specific.**

Key words: Crown pruning, plant water potential, tree-crop interactions, root trenching.

INTRODUCTION

Agroforestry parklands are land use systems where mixtures of trees and shrubs that farmers select for certain functions are found scattered and the space between trees is cultivated with staple food crops, such as millet and sorghum. It is the principal cropping system used by subsistence farmers in the Sahel (Bonkoungou et al., 1997; Boffa, 1999). The trees are selected and deliberately left standing when converting natural woodland to farmland. The trees are selected because farmers value their multipurpose uses and functions (Gijsbers et al., 1994; Lamien et al., 1996; Teklehaimanot, 2004). Parkland trees are sources of food, including fruits, fats, oils, leafy vegetables, nuts and condiments that complement staple food crops in the local diet. Some of these foods are particularly important during periods when grains are in short supply, and during years of intense drought. The trees also contribute to the increase and maintenance of soil carbon pools and thus are important in carbon sequestration in semi-arid zones where soil carbon is also a major factor controlling

*Corresponding author. E-mail: j.bayala@cgiar.org. Tel: (223) 20 23 50 00 / 77 71 41 90. Fax: (223) 20 22 86 83.

soil organic matter formation and soil fertility (Bationo and Buerkert, 2001; Lufafa et al., 2008).

Although these preserved trees play key roles in farmlands, they can also exert a competition for growth resources on associated annual crops particularly in the Sahel where soils are poor and the rainfall is low and poorly distributed. Tree-crop-interactions or water-soil-plant interfaces are documented in previous studies (Kessler, 1992; Jonsson et al., 1999). For example, Kater et al. (1992), Kessler (1992) and Bayala et al. (2002) reported that sorghum grain yield was reduced by 50 to 70% under the canopies of *Vitellaria paradoxa* and *Parkia biglobosa*, respectively compared to the open area. Despite reported negative impacts of *V. paradoxa* and *P. biglobosa* on associated crops due to the competition for light, nutrients and water (Bayala et al., 2002, 2008c), there is a possibility of facilitation in the association in such cropping systems through additional water provided through hydraulic redistribution by tree roots (Burgess et al., 1998) and through soil fertility improvement (Bayala et al., 2002). Jonsson et al. (1999) suggested that the negative effect of tree shade may be compensated for by improvement in crop temperature and soil fertility. Based on research findings on resource sharing between trees and crops in the semiarid areas, the greatest opportunity for simultaneous agroforestry practices is to fill niches within the landscape where resources are currently under-utilized by crops (Ong and Leakey, 1999). However, scientific studies of the phenomena of facilitation and competition in agroforestry in the Sahel are scarce because of the complexity of tree-crop interactions. Bayala et al. (2008) conducted a simulation study using water, light and nutrient captures in Agroforestry Systems (WaNuLCAS) model to determine the most limiting factors in *V. paradoxa* and *P. biglobosa* parklands in the same site. The simulation study showed that above-ground competition for light was more important than below-ground competition for water and nutrients under *P. biglobosa* and *V. paradoxa*. Water was the second most limiting factor under *V. paradoxa* while under *P. biglobosa* it was phosphorus. However, results of simulation studies need to be substantiated by experimental field data by manipulating the levels of various factors involved (Bayala et al., 2008).

Based on the prevailing environmental conditions in Burkina Faso, we hypothesized that (1) light is the most limiting factor and canopy pruning will lead to yield increase which is a combined effect of increased light availability and reduced belowground competition linked to associated fine roots reductions (Bayala et al. 2004); (2) below-ground competition for resources is not compensated for by higher soil fertility under trees and the hydraulic water redistribution and therefore root pruning will lead to increase in crop yield; and (3) competition is more important than facilitation in parkland system in semi-arid environment. Therefore, the aim of the present study was to assess competition for growth resources by experimentally separating tree-soil-crop interactions in an agroforestry parkland in Saponé, Burkina Faso. The study was conducted specifically to assess the impact of tree canopy pruning and tree root pruning on *Sorghum bicolo*r yields.

MATERIALS AND METHODS

Site and studied materials

The study was conducted in the parklands around Saponé (12°03' N, 1°43' W, altitude 200 m.a.s.l), a village located 30 km south of Ouagadougou, the capital city of Burkina Faso, West Africa. The soils in these parklands are shallow (on average ca. 60 cm deep), sandy loamy regosols (FAO classification) with very low nutrient contents. The climate is Sudano-Sahelian, with a single rainy season marked by intermittent rains in April and May, followed by more persistent rainfall from June to October. Figure 1 shows rainfall distribution from 2007 to 2009. In a vegetation survey conducted in the study area in 1999, 35 tree species from 27 genera and 17 families were recorded, the most abundant trees being *V. paradoxa* (relative frequency 58% of all counted trees, 9.05 individuals ha^{-1}) followed by *P. biglobosa* (relative frequency 8%, 1.22 individuals ha^{-1}), and the overall tree density was 15.5 trees ha^{-1}.

Vitellaria paradoxa C. F Gaertn (karité) and *Parkia biglobosa* (Jacq.) Benth (néré) were used in the present study because they are the most abundant tree species in the area and the Sahel in general. With the help of field owners from the village, 4 mature and healthy trees, which were at least 40 m apart, each of karité and néré (total 8 trees) were randomly selected in 2007. In 2008, 4 new trees of each species (total 8) were added to the sample trees to allow the application of crown pruning. Sorghum (*Sorghum bicolor* (L.) Moench), a local variety with a growth period of ca. 130 days was used as an associated crop because it is one of the most commonly grown crops in the study area.

Experimental design

In 2007, 4 trees of each species (karité and néré) were selected and in 2008, 8 new trees, 4 of each species (with the follwing mean values for the 8 karité trees: 11.54 ± 0.28 m height, 62.81 ± 4.15 cm diameter at breast height, 11.30 ± 0.44 m crown diameter and for the 8 néré trees: 12.66 ± 0.23 m height, 64.61 ± 4.06 cm diameter at breast height, 17.00 ± 1.15 m crown diameter) were selected with the help of farmers and the following treatments were imposed on the sample trees after an agreement with the farmers: 8 unpruned (controls, trees selected in 2007), and 8 total-pruned (100% of the crown removed, trees selected in 2008). Under each tree four plots of 4 × 4 m were laid out in four compass directions and two plots per tree were randomly assigned as controls. Around the two remaining plots, trenches (depth 2 m, width 60 cm) were dug. Under each tree, trenched and control plots were replicated twice and 8 times for the four trees per species. When pruning was applied the second year, pruning factor was replicated 4 times per species and trenching 16 times. The closest border of each of the four 4 × 4 m square plots established at the four compass directions was at 1 m from the tree trunk. Soil was removed from the trenches for the first time in June 2007; after which the trenches were refilled with the same soil that had been removed. The trenching treatment was repeated in 2008 and 2009 by renewing the trenches at the beginning of each cropping season in June.

A local variety of sorghum (*Sorghum bicolor*) was sown in the

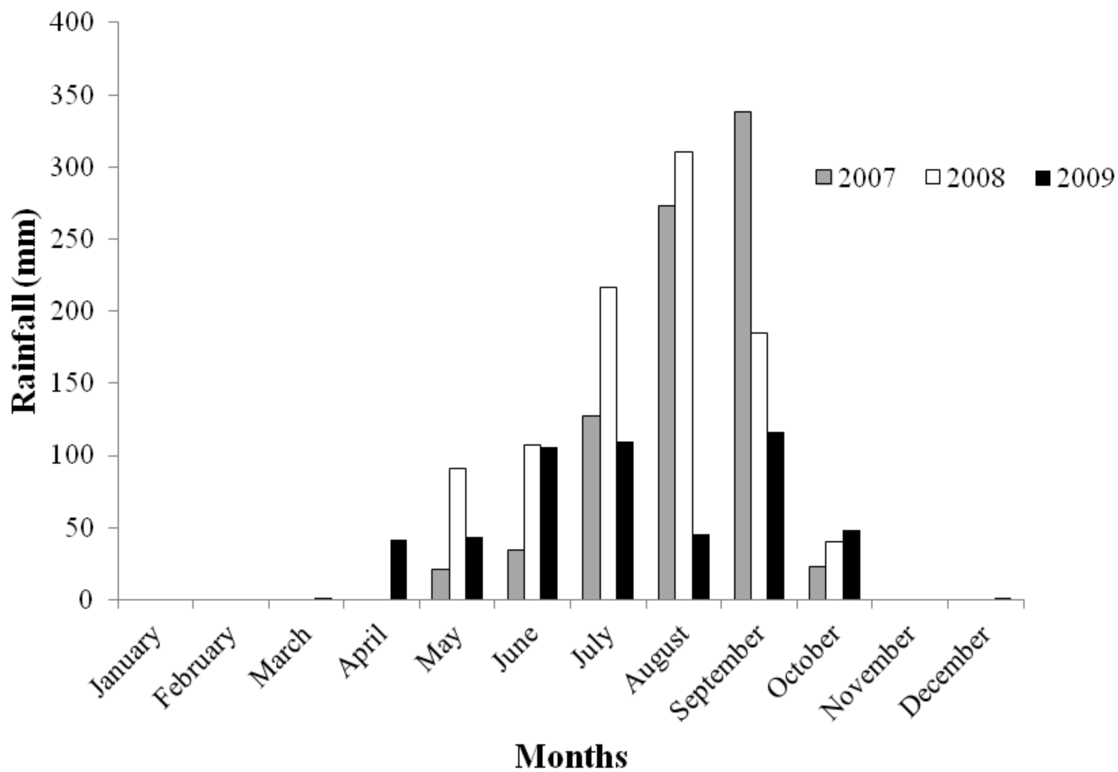

Figure 1. Rainfall of 2007(A), 2008 (B) and 2009 (C) in Saponé village in Burkina Faso, West Africa.

second half of July in 2007, 2008 and 2009 at spacing of 0.8 m between and 0.4 m along rows in each plot of 4 × 4 m. One sowing hole was selected randomly, labeled and leaf water potential (ψ_l) monitored in 2007 only using thermocouple psychrometers (TP) (Wescor, model L-51SF, Logan, Utah, USA). The measurements of ψ_l were made at one minute intervals with a 30 s cooling time for Peltier effect and the 60 min mean values were stored in a data logger (PSYPRO, Wescor, Logan, UT) for one day before moving the equipment to another tree of another species; and this was done only once during the 2007 cropping season. The psychrometers were corrected for temperature effect using calibration curves supplied with each psychrometer to determine the correction factors for each sensor. Data from sensors that displayed an offset value greater than 3 µV were discarded to limit effects of temperature gradients on ψ_s. All sorghum plants in each plot under each tree were assessed at harvest (130 days after planting) in November. Crop parameters measured were; (1) grain yield and (2) total dry matter of the straw per unit area. Then, harvest index (HI) was calculated as the ratio of the dry grain weight (kg ha^{-1}) divided by the above-ground total dry matter weight (kg ha^{-1}).

Statistical analysis

Data were checked for normality and the difference between treatments was analyzed with ANOVA using Genstat 5 release 8.11 (Rothmasted Experimental Station) using tree species, pruning, and trenching as factors. Because the data per season could be considered as repeated data and the analysis revealed differences for years, they were analysed separately for each sampling date or per year. Significant differences at $P < 0.05$ were further tested using standard error of differences of means test.

RESULTS

The results showed that grain yield, straw dry matter and harvest index were significantly affected by growing season. There were significant interactions between growing season and pruning (for grain yield and straw dry matter), growing season and root trenching (for grain yield). The values of the harvest index were significantly different between the growing seasons with the following values; 0.14 ± 0.01, 0.34 ± 0.01, and 0.30 ± 0.01 for the 2007, 2008 and 2009 growing seasons (Figure 2). There was no significant interaction between tree species and root trenching in the 2007 growing season for all variables (Table 1). Similarly, crop performance did not reveal any significant difference between either species or root trenching for grain, straw biomass yield and harvest index (Table 2 and Figure 2). Nevertheless, root trenching led to grain yield increases of 20 and 175 kg ha^{-1} compared to control plots whereas straw biomass yield increases were 171 and 492 kg ha^{-1} for karité and néré, respectively (Table 2). No interaction and no significant effects of factors were observed for the harvest index in 2007. There was no significant interaction between tree species and root trenching for leaf water potential whereas only root trenching significantly affected this variable ($P<0.001$). The average leaf water potential was significantly higher (-0.70 ± 0.11 MPa) in the root trenched plots than in the control

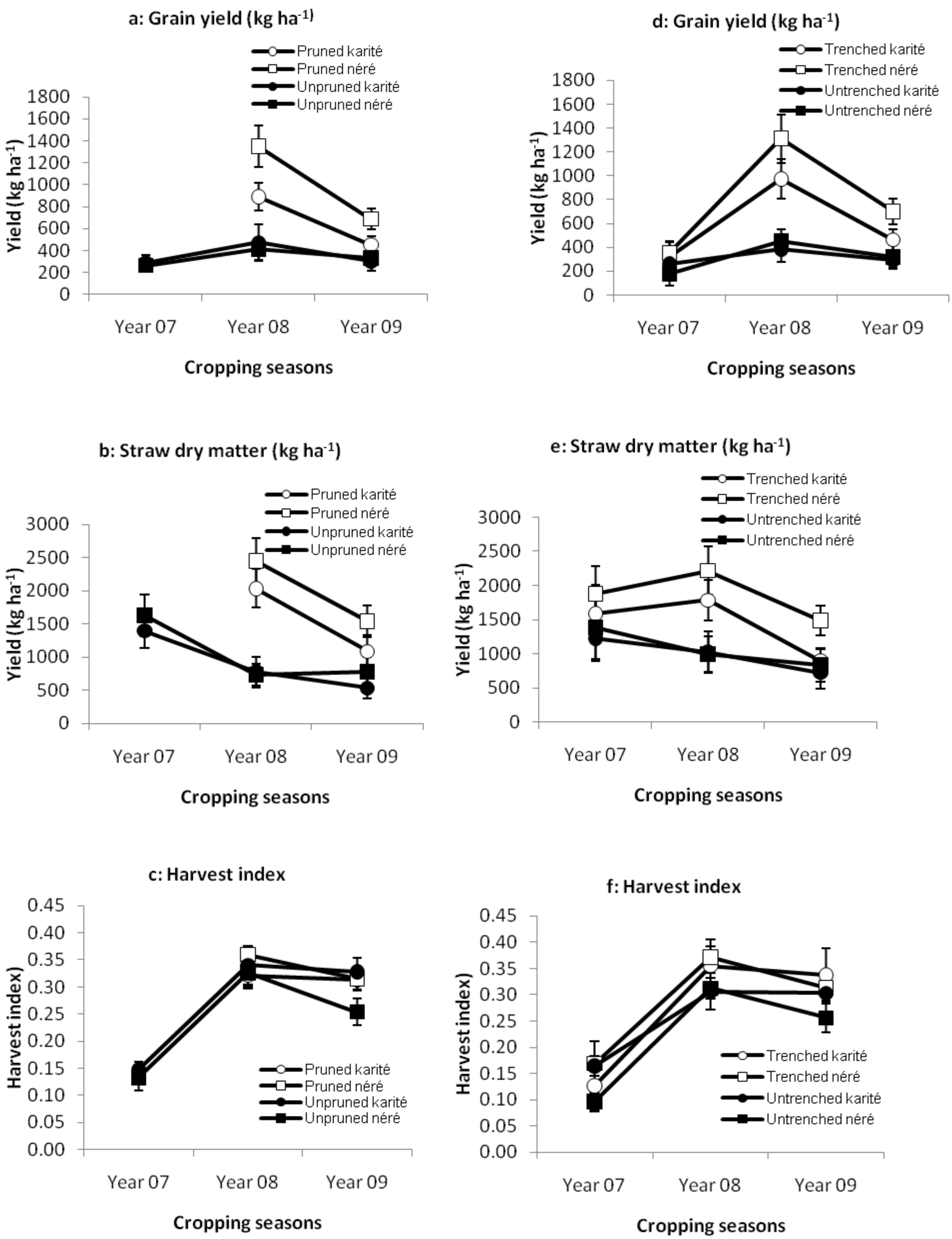

Figure 2. Variation in grain yield, dry matter yield and harvest index of *Sorghum bicolor* as affected by tree species (*Parkia biglobosa* and *Vitellaria paradoxa*), pruning, and trenching in a parkland system in Burkina Faso for the cropping seasons 2007, 2008 and 2009.

Table 1. Analysis of variance of grain yield, dry matter yield and harvest index of *Sorghum bicolor* as affected by tree species (*Parkia biglobosa* and *Vitellaria paradoxa*), pruning, and trenching in a parkland system in Burkina Faso for the cropping seasons 2007, 2008 and 2009.

a: Cropping season 2007

		Leaf water potential			Grain yield			Straw dry matter yield			Harvest index		
Effects	**DF**	**MS**	**F value**	**Pr>F**	**MS**	**F value**	**Pr>F**	**MS**	**F value**	**Pr>F**	**MS**	**F value**	**Pr>F**
Species	1	1.452	0.37	0.541	160	0.00	0.962	820801	0.60	0.446	0.001464	0.25	0.621
Trenching	1	89.765	23.16	<0.001	76052	1.09	0.305	881958	0.64	0.430	0.002774	0.47	0.497
Species*trenching	1	0.098	0.03	0.874	48921	0.70	0.409	205200	0.15	0.702	0.022922	3.92	0.058
Residual	*1040/27	3.875			69621			1373875			0.005854		

b: Cropping season 2008

		Grain yield			Straw dry matter yield			Harvest index		
Effects	**DF**	**MS**	**F value**	**Pr>F**	**MS**	**F value**	**Pr>F**	**MS**	**F value**	**Pr>F**
Species	1	480729	2.45	0.123	303360	0.36	0.550	0.00126	0.11	0.737
Pruning	1	7903346	40.30	<0.001	37563492	44.69	<0.001	0.00183	0.16	0.686
Trenching	1	9007861	45.93	<0.001	17699112	21.06	<0.001	0.05123	4.62	0.036
Species*pruning	1	1299404	6.63	0.013	1187759	1.41	0.240	0.01358	1.22	0.273
Species*trenching	1	424340	2.16	0.147	1364151	1.62	0.208	0.00088	0.08	0.780
Pruning*Trenching	1	118058	0.60	0.441	8072	0.01	0.922	0.00642	0.58	0.450
Species*pruning*trenching	1	1016069	5.18	0.027	2356705	2.80	0.100	0.00094	0.09	0.772
Residual	54	196104			840452			0.01109		

c: Cropping season 2009

		Grain yield			Straw dry matter yield			Harvest index		
Effects	**DF**	**MS**	**F value**	**Pr>F**	**MS**	**F value**	**Pr>F**	**MS**	**F value**	**Pr>F**
Species	1	278004	2.31	0.134	1962188	2.84	0.098	0.021047	2.78	0.101
Pruning	1	1003774	8.33	0.006	6837408	9.90	0.003	0.008531	1.13	0.293
Trenching	1	1219138	10.12	0.002	2658428	3.85	0.055	0.034101	4.50	0.038
Species*pruning	1	167469	1.39	0.243	169512	0.25	0.622	0.022285	2.94	0.092
Species*trenching	1	174472	1.45	0.234	918902	1.33	0.254	0.001904	0.25	0.618
Pruning*Trenching	1	447589	3.71	0.059	1423174	2.06	0.157	0.019497	2.57	0.114
Species*pruning*trenching	1	13875	0.12	0.736	229351	0.33	0.567	0.012247	1.62	0.209
Residual	56	120502			690930			0.007581		

*=For psychrometer measurements.

(-1.29 ± 0.12 MPa) under karité and -0.76 ± 0.11 MPa for root trenched plots and -1.34 ± 0.14 MPa for the control under néré.

In 2008, the results revealed a significant three-way interaction between pruning, species and root trenching (P<0.05). A significant two-way interaction

Table 2. Yields of *Sorghum bicolor* (mean kg ha^{-1}) affected by root exclusion using root trenching under karité (*Vitallaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland system in Burkina Faso for the cropping season 2007.

Variable	Grain yield		Straw dry matter	
	Roots excluded	Unpruned roots	Roots excluded	Unpruned roots
Karité	278	258^a	1398^a	1227^a
Néré	351^a	176^a	1879^a	1387^a
s.e.d.		132		586
Prob.		P=0.409		P=0.702

Table 3. Grain yield of *Sorghum bicolor* (mean kg ha^{-1}) affected by root exclusion and crown pruning under karité (*Vitallaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland system in Burkina Faso for the cropping season 2008.

Variable	Karité		Néré	
	Roots excluded	Unpruned roots	Roots excluded	Unpruned roots
Pruned crown	1101^b	679^c	1974^a	723^c
Unpruned crown	849^c	95^d	648^c	73^d
s.e.d.		221		
Prob.		P=0.027		

was observed between species and root trenching (P<0.05) and a single very highly significant effect of pruning and root trenching (All P<0.001) for grain yield (Table 1). Root trenching led to grain yield increases of 442 and 754 kg ha^{-1} for pruned and unpruned karité compared to control plots whereas the figures were 1252 and 575 kg ha^{-1} for pruned and unpruned néré, respectively (Table 3 and Figure 2). A single very highly significant effect of pruning and root trenching was observed on straw biomass yield (P<0.001). Thus, the pruned treatment yielded significantly higher straw biomass yield (2240 ± 224 kg ha^{-1}) compared to unpruned treatment (708 ± 142 kg ha^{-1}). Similarly, a significantly higher straw biomass yield was observed on root pruned plots (2000 ± 228 kg ha^{-1}) versus unpruned roots plots (948 ± 197 kg ha^{-1}). Root trenching induced straw dry biomass yield increases of 398 and 1121 kg ha^{-1} for pruned and unpruned karité compared to control plots whereas the figures were 1750 and 937 kg ha^{-1} for pruned and unpruned néré, respectively (Table 3 and Figure 2). No significant interaction was observed for harvest index between the studied factors (species, pruning and trenching) but root trenching induced a significant difference between trenched plots (0.36 ± 0.02) and their root untrenched counterparts (0.31 ± 0.02) in 2008.

In 2009, there was no significant interaction between the three factors. The gain yield under pruned trees (569 ± 63 kg ha^{-1}) was significantly higher (P<0.01) than under unpruned trees (319 ± 72 kg ha^{-1}). Similarly, the grain yield in root pruned plots (582 ± 73 kg ha^{-1}) was significantly higher (P<0.01) than in the root unpruned plots (306 ± 60 kg ha^{-1}). Root trenching led to grain yield increases of -26 and 368 kg ha^{-1} for pruned and unpruned karité compared to control plots whereas the figures were 242 and 518 kg ha^{-1} for pruned and unpruned néré, respectively (Figure 2). Straw dry biomass was significantly affected by pruning only (P<0.01) with 1312 ± 170 kg ha^{-1} under pruned trees and 659 ± 133 kg ha^{-1} under unpruned trees. No significant interaction was observed for harvest index but root trenching induced a significant difference between trenched plots (0.33 ± 0.01) and control (0.27 ± 0.02) in 2009.

DISCUSSION

Root trenching led to yield increase in grain and straw dry biomass of *S. bicolor* with the exception of straw dry biomass under karité in 2009 (Tables 1 and Figure 2). Root trenching was expected to reduce soil water content through water redistribution as demonstrated in a previous study with the same species and in the same site (Burgess et al., 1998a). In contrast, trenching to exclude tree roots did not appear to reduce soil water as the plants of the associated crop in root trenched plots displayed higher leaf water potential compared to the control in 2007. This is probably due to increased soil water content in plots where tree roots were excluded using root trenching indicating that trees take up more water from the topsoil than redistributed via hydraulic lift (at least at the time of the season measurements were taken) as reported by Ludwig et al. (2004). This is also in agreement with Bayala et al. (2008) who found a higher fine root density of both tree species and crops in the upper soil layers. If trees and crops have their roots concentrated in the topsoil layers, the two components will interact and very often compete for water and nutrients in the topsoil. Thus, grain and straw biomass yields were higher in trenched plots probably because of the reduction in competition for water and nutrients. This shows that belowground interactions between trees and crops are dominated by competition and not facilitation as also observed by Ludwig et al. (2004) for grasses associated with *Acacia tortilis* in trenched plots.

When tree crowns were pruned during the last two cropping seasons (2008 and 2009), trenching induced higher yield increase under pruned trees than unpruned trees of néré while the opposite happened under karité (Table 3 and Figure 2). These results probably indicate that root competition is much more important under karité compared to competition for light while for néré; both above and belowground competitions seem to be important. This could be due to the upright habit of the branches of karité species which allows more light to reach underneath trees while shade under néré was reported to be severe (Kater et al., 1992; Bayala et al., 2002). The findings under karité are not in agreement with the results of Bayala et al. (2008c) who reported that light is the most limiting factor followed by water under karité and P under néré. But the fact that crown pruning improved crop performance under both species is in agreement with the findings reported by Kater et al. (1992) and Bayala et al. (2002). Better crop performance of *S. bicolor* in the trenched plots under unpruned karité trees than their pruned counterparts may be an indication that light was less limiting as previously thought but also that crown removal leads to more soil water evaporation and decrease soil water content under this species. In turn, higher soil organic matter under néré (Jonsson et al., 1999; Bayala et al., 2006) may have helped in improving the soil water holding capacity under this species thereby allowing the crops to perform better in islands of higher soil fertility found in the influence zone of néré trees (Bayala et al., 2002).

The average HI recorded for sorghum in this study was within the range (0.12 to 0.57) reported by Prihar and Stewart (1991); Hammer and Broad (2003) and Tariq et al. (2007). Pruning did not affect HI despite improvement in plant growth whereas root trenching did in the 2008 and 2009 growing seasons. This could be due to the fact HI was independent of plant size (Prihar and Stewart, 1991). The differences between growing seasons may be due to differences in total rainfall as well as to its distribution as they can both significantly affect assimilation during grain filling and remobilization of preanthesis assimilate (Hammer and Broad, 2003).

The magnitude of yield increase due to trenching varied between growing seasons (Figure 2) and may be due to the amount of the rainfall as well as to its temporal distribution (Figure 1). This is in agreement with the findings of Bayala et al. (2002), Ludwig et al. (2004) and Sanou (2010). Larger pruning effect in 2008 compared to 2009 may also be due to the beginning of crown recovery in the last year leading to increase competition and therefore to reduced crop performance (Figure 2). Previous studies have shown that these two tree species recovered well from pruning (Bayala et al., 2002, 2008).

Conclusion

Higher soil fertility under trees and the occurrence of hydraulic redistribution in agroforestry parkland ecosystem suggested that trees facilitate the under storey associated crops by increasing nutrients and water availability; however, the results of the pruning and trenching experiment show that trees also compete with crops for below-ground resources. It thus appears that trees facilitate and compete with associated crops simultaneously as also reported by Ludwig et al. (2004) for associated grasses under trees. Not only do trees have both positive and negative effects on associated crops water availability, they also facilitate crop growth through increased nutrient cycling and trees reduce crop growth during the wet season as a result of shade (Bayala et al., 2002; Sanou, 2010). Whether the net effect of these complex interactions is positive or negative depends on a range of factors and could vary between growing seasons as shown by our results. However, based on the data of three different cropping seasons of our study, we concluded that beneficial effects of soil fertility improvement and hydraulic redistribution for associated crops in parklands in semi-arid areas are probably limited and that belowground competition for water and the above-ground competition for light are usually the most important process with *P. biglobosa* and *V. paradoxa*.

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